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Re-use of Building Products in the Netherlands

The development of a metabolism based assessment approach

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Re-use of Building Products in the Netherlands

The development of a metabolism based assessment approach

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by

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I can't thank
Bastiaan, Maties and Ardaan
enough for their patience.

I dedicate this book to them
and to the women in science.

Contents

List of Tables

List of Figures

Glossary

Sustainability
It is a concept aiming on "*the possibility that humans and other life will flourish on the Earth forever*". (Ehrenfeld, J. 2008. "Sustainability by Design: A Subversive Strategy for Transforming our Consumer Culture." New Haven: Yale University Press., pg. 49)

Assessment
It is a process of gathering information (quantitative and qualitative) about an entity or a situation with the purpose to identify the cause of a phenomenon or "diagnosis" or inefficiencies in a system. In relation to the term "metabolism" applied in Industrial Ecology as a metaphor for biological processes in living organisms.

Metabolism
Chemical and physical changes and exchanges taking place in and between organisms (cells, tissues, industries, cities, regions and ecosystems) driven by regulatory processes. (Based on Schwann, T. H. Microscopical Researches into the Accordance in the Structure and Growth of Animals and Plants.Рипол Классик, 1847. Tansley, Arthur G. "The use and abuse of vegetational concepts and terms." Ecology 16.3 (1935): 284-307.)

Industrial metabolism
"*...is the whole integrated collection of physical processes that convert raw materials and energy, plus labor, into finished products and wastes in a (more or less) steady-state condition. The production (supply) side, by itself, is not self-regulating. The stabilizing controls of the system are provided by its human component.*" (Ayres, Robert U., and Udo Ernst Simonis, U. E. (1994) "Industrial metabolism: Restructuring for sustainable development." pg. 23).

Urban metabolism
"*...the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste.*" (Kennedy, Christopher, John Cuddihy, and Joshua Engel Yan. "The changing metabolism of cities." Journal of industrial ecology 11.2 (2007): 43-59, pg.44)

Lock-ins
"*Central to the idea of lock-in is that technologies and technological systems follow specific paths that are difficult and costly to escape. Consequently, they tend to persist for extended periods, even in the face of competition from potentially superior*

substitutes. Thus, lock-in is said to account for the continued use of a range of supposedly inferior technologies, ranging from the QWERTY1 keyboard to the internal combustion engine." (Perkins, R., 2003. Technological "lock-in". Internet Encyclopedia of Ecological Economics, pg. 1).

Building stock
Existing buildings in use in a determined geographic area.

System
"*A system is defined by a group of elements, the interaction between these elements, and the boundaries between these and other elements in space and time. It is a group of physical components connected or related in such a manner as to form and/or act as an entire unit*." (Brunner, P. H. and Rechberger, H. "Practical Handbook of Material Flow Analysis." CRC Press 2004 336pp, pg.43.)

MFA
"*Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time*." (Brunner, P. H. and Rechberger, H. "Practical Handbook of Material Flow Analysis". CRC Press 2004 336pp, pg.3.)

Carrying capacity
"*An environment's carrying capacity is its maximum persistently supportable load*." (Catton, W. (1986). In Rees, W. E. (1996). Revisiting carrying capacity: area-based indicators of sustainability. *Population and environment*, 17(3), 195-215).

Technical life
"*The technical life, meaning the time at which advances in technology have made the product unacceptably obsolete*". (Ashby, M. F. "Materials and the Environment. Eco Informed Material Choice". Elsevier 2nd Edition 2013, pg. 80.)

Obsolescence
"*Obsolescence is a concept that has dramatically influenced the making of new buildings and the destruction of existing building stock in the name of aesthetics, planning efficiency, real estate value and the ideals of modernity*". (Fernández, J. "Material Architecture". Architectural Press 2006, pg. 37)

1 Based on the paper: David, P.A., 1985. Clio and the Economics of QWERTY. The American economic review, 75(2), pp.332-337.

Service life-the
"*The service life of an asset is the total period during which it remains in use, or ready to be used, in a productive process. During its service life an asset may have more than one owner*". (OECD, http://stats.oecd.org/glossary/detail.asp?ID=2430).

Remanufacture
"*Remanufacturing is defined as a process by which an end of life product is returned to an as-new condition with an equivalent warranty*". (B. Walsh PSS for Product Life Extension through Remanufacturing _ The Centre for Remanufacturing and Reuse, UK.)

GDP
"*GDP corresponds to the cash value of all goods and services produced by the economic units in a country within a given period, less the value of the goods used in the production process. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are provided at constant 1995 prices. Valuation at constant prices means valuing the flows and stocks in an accounting period at the prices of the reference period. Unit: US dollars*". (World Bank, World Tables, 2002, pg. 199)

Building products
Building products correspond to any building part and not the entire building that can be removed from site after renovation or demolition to be commercialized for reuse.

Survivability
Survivability is the likelihood buildings will survive full demolition.

Holistic
The understanding of a system's behavior is contingent to the understanding of the interconnected parts within it. "*Semantic holism denies the claim that all meaningful statements about large-scale social phenomena ... can be translated without residue into statements about the actions, attitudes, relations, and circumstances of individuals*". (Neha Parwani, Encyclopedia Brittranica, 2010).

Factor
It is an element that can be a circumstance or a data or an information that affects the result or the characterization of a phenomena.

Mechanism
An operation, a system, a natural or established process by which something takes place or is brought about (processes in a supply chain).

Abbreviations

MRQ	Main Research Question
RQ	Research Question
RO	Research Objective
C&DW	Construction and Demolition Waste
CBS	Centraal Bureau voor de Statistiek
SYSWOV	Systeem Woningvoorraad
LAP	Landelijk Afvalbeheer Plan
SD	System Dynamics
CE	Circular Economy
IE	Industrial Ecology
EU WFD	European Waste Framework Directive
UNEP	United Nations Environment Programme
RMC	Raw Material Consumption
EC	European Community
GDP	Growth Domestic Product
VANG	Van Afval Naar Grondstof
VROM	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu
OECD	Organisation for Economic Co-operation and Development
NCDO	Nationale Commissie voor internationale samenwerking en Duurzame Ontwikkeling
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek
WEEE	Waste Electrical and Electronic Equipment
LCA	Life Cycle Analysis
MFA	Material Flow Analysis
DMC	Domestic Material Consumption
PSTUS	Physical Supply and Use Tables
NAMEA	National Accounting Matrix Including Environmental Accounts
PIOTS	Physical Input Output Tables
SFA	Substance Flow Analysis
LMA	Landelijk Meldpunt Afvalstoffen
LSS	Large-Scale Sustainable

Summary

Over the years, the consumption of materials for construction exceeded more than half of the total materials consumed in the Netherlands, and construction waste exceeded the volume of solid waste produced by households. Since the introduction of the "*Ladder van Lansink*" (in the 1970's) and the further development of the European Waste Framework Directives followed by the Circular Economy concept, waste prevention has been considered a priority measure. Whereas the goals to improve waste management towards waste-to-resource and waste elimination evolved from guidelines to political action (throughout the EU), reuse of products remained a less implicit strategy. The reuse of building products is an ancient practice; nonetheless, limited information is available regarding the aspects involved in the existing process. Reuse of building products has seen limited regulatory changes and remained a vague procedure within the resource efficiency discourse in the Netherlands.

Building products remain in use for long time spans, which affects the planning and integration of strategies to recover them for reuse. When they are released from buildings (after renovation or demolition) and recovered, these products may not be compatible with new updated technical building requirements, or may not be competitive with upgraded, certified and cheaper new products.

The weight, size, and practical challenges to deconstruct buildings are also factors affecting the harvest of such products. Besides these technical and economic aspects, used goods are susceptible to subjective evaluation regarding their "style" and used appearance. Contrary to different forms of waste treatment that transform used products into commodities; used products have intrinsic cultural, historical and aesthetic values influencing their economic value.

To foster the integration of industrial activities to promote more efficient use of resources from the anthropogenic environment, it requires a better understanding of the constraints and opportunities among relations within a non-linear economy.

This research departs from the desire to understand the practice of reuse of building products from a systemic standpoint, to illuminate its current condition and help to foresee future perspectives.

System

The holistic approach in this research implies the investigation and representation of a network of multiple factors influencing the process of reusing in analogy to the nature of sustainability as a systemic concept that infers a holistic construction of different conceptual subsets.

To perceive the continuity of the strategy of reuse, this research positions the object of study from an evolutionary perspective where relations condition the action of reuse. These relations are dynamic and contextually bounded defining the commercial feasibility of products to be reused rather than wasted.

Understanding these relations enables to construct an analytical discourse that takes into consideration a multidisciplinary approach from which different strategies can be designed while contemplating their connectivity.

From a pragmatic research tradition, the central research question explored is:

What are the perspectives for reuse of building products from the housing stock, given contextual factors that influence the process chain and reserves?

The Industrial Ecology concept provides a system's perspective and the foundation of this study's methodological framework to answer the main research question. It postulates that the internal relations of the industrial process, as well as relations that go beyond the industrial boundary, are sources of perturbations in the natural system, which is driven by human activities and motivate changes in material and substance flows by demand for services provided by products.

Through this systemic perspective, to effectuate reuse of building products in the Netherlands, this research proposes to examine this practice as an industrial ecosystem. It describes the activities; actors and how different factors influence the process of building products' reuse.

This research is the result of a collaboration between the Faculty of Industrial Design Engineering and Architecture and the Built environment of TU Delft to construct a multi-scale scope ranging product thinking and regional resource management. The investigation departs from the following assumptions:

- Reuse of products brings environmental benefits.

This study does not evaluate which conditions and what are the environmental benefits of reuse. Nonetheless, the study acknowledges that not one-measure fits all, nor that reuse is the best measure in all contexts. The study departs from the premise established by existing guidelines in waste management and the CE (Circular Economy) concept that waste prevention including reuse should be prioritized.

– Assessing singular aspects of reuse can lead to limited or partial interpretations, risking future ineffective action plans or their complete absence.

The practice of reuse is inferred in this study as a cluster of activities that co-exists with other clusters of activities (recycling industry, technological evolution of construction systems and product innovation, waste management, lifestyle, environmental education, policy, primary resources among others), and that changes occurred in each of these parts can also affect the performance of reuse. Single focus analyses are needed but complementary to the holistic approach to increment knowledge and verification of findings.

The Industrial Ecology concept is used to emphasize the relevance to develop a systemic vision of reuse. The approach developed in this research exposes the connectivity between different factors and activities within the process and illuminates how these activities are performed. As result, different paths could be designed to improve the performance of the system.

– Description of the existent practices can help sharpen the understanding of the waste prevention of building products among scholars, practitioners, and policymakers.

This research departs from the observation of the existing practice of reuse in the Netherlands to develop a tangible form of analysis and representation of the phenomena in the real world. The research contributes to the waste prevention and management debate, the possible conceptual vagueness, lack of detailing and transparency of what reuse consists, and how waste prevention is equivocally related to curbing economic growth. It also adds knowledge to the concerns of building a systemic approach for a CE exposed by previous scholars.

Research structure

A design-based research framework is applied to articulate how the study was performed. The analysis was divided into two main parts:

A **The organizational, socio-economic and technological aspects of building products reuse.**

This segment examines internal relations of the industrial system of reuse, comprised by a description of the organization of activities and actors involved that characterize the supply chain and the practice of commercial reuse of building products in the Netherlands. The relations that go beyond the industrial boundary are clustered by the social, cultural economic, and technological factors influencing how building products are harvested from the building stock for consumption.

Conventionally, natural systems are assessed regarding the impact caused by industrial activities or the availability of resources to supply these same activities. As the anthropogenic environment evolves, it is relevant to comprehend how fit the industrial system is in this dynamic context, leading to the second part of the study:

B **The evolution of the housing stock as dynamic reserves (supply of reusable products).**

The industry of reuse, by analogy, relies on the evolution of the building stock to supply the consumption of reusable building products. To exam this relation, the study investigates what products are commercially reusable (present). These products are a reference to the examination of the housing stock evolution (reserves), which affects the supply of reusable products in speed, composition, and amount of products released from the stock.

Finally, the research methodology delimits the industrial ecology of reuse as the sum of different relations influencing the flows of products harvested for commercial transactions of used building products. The representation of this network of relations reveals vulnerabilities and potentials in the industrial system to support future effectuation and evaluations for practice and policy. The conceptual model proposed is a map, a tool to assist the formulations of plans and tests in the learning curve to systematically implement waste prevention measures in the Netherlands.

Findings

The following limitations guided the mixed methodology proposed in this study: Scarce information about the practice of building product reuse in the Netherlands including social demand for used products; the availability of hard numeric information in waste prevention and periodic consumption of building products for housing construction; the metabolism of the building stock in the Netherlands including information about the survivability and obsolescence of houses as well as periodic physical description of housing the stock at the product level and building sizes.

In the first part, the research process was based on literature review, surveys and semi-structured interviews with practitioners in product reuse, experts in construction waste management, governmental agencies and designers. The central object in this stage is the representation of the industrial system of reuse connected to several relations that influence its performance. The key findings in this segment were:

Organizational

The practice of reuse currently functions as an appendix of the demolition industry, bringing benefits as well as disadvantages. Among the benefits is a lean and integrated management of activities able to absorb time, administrative and economic hurdles. Some of the disadvantages are the limited formalization and specialization of activities as product development (treatment of used products), quality control and marketing, as well as lack of formal representation affecting public recognition and political support.

Economic

In the economic context, direct costs involved in the process of reusing including transportation, storage, and workforce to deconstruct (associated with technology), as well as costs associated with processes to recondition used products for retail are critical parts of the economic equation. External factors influencing the economic benefits of reuse are for instance related to developments in waste management, tipping fees, fines of mixed materials and, prices of virgin materials and new products. The economic performance of reuse is also affected by investments and other forms of stimuli focused on developments in waste treatment or by policy regulating waste disposal and resource recovery.

Social

The social component is not only critical but has also been the least understood within the reuse process. Potential users and “waste” owners fundamentally lack knowledge on how to reuse, information about used products, where to find them and what are the benefits of reusing. Lack of certifications, warranties, standardization of products are also factors affecting the demand for used products. Additionally, the demand for used products concerns the interaction with potential consumers as the shopping experience, the image of the used product determining the "value" of the product and of reusing. Value is liable to change according to how the consumer perception arises about used products, about the action and experience to reuse and the economic benefits.

Technological
Technology is not yet developed in the building product reuse industry through three perspectives:

- Building deconstruction evolved to harvest materials for recycle rather than harvesting products for reuse;

- Construction technologies of new buildings indicated to evolve towards concrete intense systems less feasible to be deconstructed for reuse; and

- The absence of quality control of used products to be applied in new constructions can pose risks to the performance of new buildings.

In this context, integrating cascading reuse indicated to be a beneficial strategy complementary to reuse. Although the challenges to develop methods to efficiently process (remanufacture, resize, recondition) used components into new products while securing quality standards, safety requirements and economic viability exist; cascading reuse can help to overcome barriers related to public perception and consumption of used products.

Lastly, the dynamic character of how the socioeconomic and technological relations identified above occur in the real world has to be taken into account to comprehend the status of building product reuse and to foresee future adaptation. Although improvements can be made in each one of these relations, it is relevant to understand how they can affect the system combined. For instance, increase building disassembly does not guarantee increase demand for used products in the future.

Reserves
Whereas the first part of the study revealed that a combination of factors defines what is commercially reusable in the Netherlands, the second part research analyses the capacity of product reuse in an existent context as a reference to estimate or plan strategies for future continuity. The juxtaposition between the operability of the industry of reuse and the evolution of the building stock represents the organization of a "typical" supply chain of reuse in the Netherlands.

Although in the real world different factors combined influence changes in the housing stock, in this research, the method to analyze trends in the housing stock behavior explored the evolution of different characteristics in the stock through binary "increase" or "decrease" trends based on historical data. The key findings in this research stage were:

– Regarding housing survivability, the housing stock in the Netherlands evolved to be characterized by single-family private houses, apparently larger, built under non-traditional methods and better sound constructed compared to the recent post-war period. These characteristics indicated to influence (increase) housing survivability. Especially in the West, where most activities in the national housing stock are concentrated, the increase of private single-family houses influences overall housing survivability in the Netherlands (particularly when the pre-1946 group gradually decreases).

– Regarding amounts of materials released accumulating in the housing stock, consumption of building materials per capita as well as continued housing stock increase were observed. As the population of single households expands, it is uncertain that house sizes will continue to rise as well. Nonetheless, despite the growth of material stock, the amount of material output can be offset by the increase housing survivability.

– Regarding types of materials, the study of frequent house typologies, as well as the analysis of material consumption trends, indicates stronger dissipation of stony based products, and in particular concrete and plastic based, in comparison to wood ceramics and metals. The decrease of traditionally built houses can influence decrease supply of used wood in the future, inflicting the industry of reuse to adapt to these changes.

The analysis of trends in the housing stock and material consumption revealed how the supply of materials could affect reusing. The understanding of such trends at product scale resulted to be challenging through top- bottom approach and traditional material flow accounting. The study of the evolution of physical characterization of the housing stock from a bottom-up approach produced more consistent insight of housing stock trends at product level. Improving the classification system of the built housing stock according to physical characteristics including housing typologies, building age, description of building products (some of these characteristics are already being assessed to monitor energy efficiency) can facilitate monitoring of future material management. Strategies designed to improve waste prevention through reuse could be limited if they do not consider knowledge improvement of material reserves.

The stock is getting larger but there should be delays in material output for reuse through withdraws due to the increase housing survivability. The accumulation of stony based products indicates future challenges to overcome as the technical and economic viability to reuse them and demand for this type of products; especially when considering the competition with technological advances aiming to improve recyclability of concrete.

Tool

Finally, this holistic approach generates an overview of how dynamics in the housing stock and socioeconomic, and technological factors, associated direct and adjacent to the reuse process influence what is harvested for reuse in practice. The representation of these dynamic relations composes a conceptual model, which is the representation of the metabolism of building product reuse in the Netherlands. This "map" offers a way to improve the visualization and the understanding of how the trajectories of flows of products are reused as well as the motivations, conditions, and limitations behind them.

It is a tool that facilitates future assessments on how to improve the recovery of products for reuse (illustrated by the case of wooden products); how to support decision making by practitioners and policymakers; how to detect the connectedness among different aspects of building product reuse. Ultimately it offers different paths to (re) generate additional evaluation or action with the aim to adapt the practice of reuse to changing conditions.

The proposed conceptual model evolved from a composition of concepts adapted from the Industrial Ecology theoretical background to represent the system of the typical commercial practice of reuse of building products in the Netherlands, supplied by-products derived from the housing stock, and are centralized on the role of the practitioner. Accordingly, the data collection and most findings from the qualitative analysis departed from clustering information structured by the preconceived theoretical framework.

Overall, the insight out of this research indicates that more work needs to be done in the direction to optimize existing relations associated with materials derived from building demolition activities in the Netherlands, to improve efficiencies through these relations foreseeing future integration with the evolution of waste management and circular resource management, and as well as diversify stakeholders unfolding in new collaboration, business models and new supply chains.

Samenvatting

De afgelopen jaren bedroeg het verbruik van bouwmaterialen meer dan de helft van de totale hoeveelheid verbruikte materialen in Nederland, en het volume van bouwafval was meer dan dat van vast huishoudelijk afval. Sinds de introductie van de "Ladder van Lansink" in de jaren zeventig en de verdere ontwikkeling van de Europese kaderrichtlijnen afvalstoffen, en later het concept van circulaire economie, heeft afvalpreventie als maatregel een hoge prioriteit. Men tracht afvalbeheer te verbeteren door afval te benutten als grondstof en door afval te elimineren, waarbij er in de hele EU een verschuiving plaatsvindt van richtlijnen naar politieke actie, maar hergebruik van producten is hierbij tot nu toe geen vanzelfsprekende strategie. Bouwproducten worden al vele jaren hergebruikt, maar er is maar beperkte informatie beschikbaar over de aspecten die bij dit proces betrokken zijn. Voor hergebruik van bouwproducten zijn er beperkte wijzigingen in regelgeving geweest, en dit bleef een onduidelijke procedure binnen het discours over efficiënt gebruik van grondstoffen in Nederland.

Bouwproducten blijven gedurende lange perioden in gebruik, wat van invloed is op de planning en de integratie van strategieën om ze te herwinnen voor hergebruik. Wanneer ze vrijkomen uit gebouwen (na renovatie of sloop) en worden herwonnen, zijn deze producten soms niet compatibel met gewijzigde technische bouwvereisten, of kunnen ze de concurrentie met verbeterde, gecertificeerde en goedkopere nieuwe producten niet aan.

Ook gewicht, grootte en praktische uitdagingen bij de deconstructie van gebouwen spelen een rol bij het winnen van dergelijke producten. Naast deze technische en economische aspecten zijn gebruikte goederen ook gevoelig voor subjectieve beoordelingen met betrekking tot hun 'stijl' en het feit dat eraan te zien is dat ze gebruikt zijn. In tegenstelling tot andere vormen van afvalverwerking waarbij gebruikte producten worden omgezet in grondstoffen, hebben gebruikte producten een intrinsieke culturele, historische en esthetische waarde die de economische waarde beïnvloedt.

Als we willen stimuleren dat er industriële activiteiten plaatsvinden om een efficiënter gebruik van hulpbronnen uit de antropogene omgeving te bevorderen, hebben we meer inzicht nodig in de beperkingen en mogelijkheden bij relaties binnen een niet-lineaire economie.

Dit onderzoek gaat uit van de wens om de praktijk van hergebruik van bouwproducten vanuit een systemisch standpunt te begrijpen, licht te werpen op de huidige toestand en toekomstperspectieven te schetsen.

Systeem

De holistische benadering in dit onderzoek houdt een onderzoek en representatie in van een netwerk van meerdere factoren die het proces van hergebruik beïnvloeden, naar analogie met het karakter van duurzaamheid als systeemconcept dat een holistische constructie van verschillende conceptuele subsets impliceert.

Om de continuïteit van hergebruikstrategie te beschouwen, plaatst dit onderzoek het onderzoeksobject in een evolutionair perspectief, waarin relaties de randvoorwaarden vormen voor het functioneren van hergebruik. Deze relaties zijn dynamisch en contextueel begrensd, en definiëren de commerciële haalbaarheid van hergebruik vergeleken met weggooien van producten.

Wanneer we deze relaties begrijpen, kunnen we een analytisch discours construeren op basis van een multidisciplinaire benadering van waaruit verschillende strategieën kunnen worden ontworpen, rekening houdend met het verband tussen de relaties.

Vanuit een pragmatische onderzoekstraditie is de centrale onderzoeksvraag:

Hoe kan hergebruik van bouwproducten uit het gebouwenbestand in Nederland worden beoordeeld ter ondersteuning van toekomstige implementatie vanuit het perspectief van een afvalpreventiestrategie?

Het concept ‘industriële ecologie’ biedt een systeemperspectief en vormt de basis van het methodologische kader van dit onderzoek om de hoofdonderzoeksvraag te beantwoorden. Dit concept stelt dat de interne relaties van het industriële proces, en ook relaties die zich buiten de grenzen van de industrie bevinden, bronnen zijn van verstoringen in het natuurlijke systeem, dat gebaseerd is op menselijke activiteiten die de motivatie vormen voor veranderingen in materiaal- en stoffenstromen als gevolg van vraag naar diensten die via producten worden geleverd.

Via dit systemisch perspectief om hergebruik van bouwproducten in Nederland te verwezenlijken stellen we in dit onderzoek voor om deze praktijk te onderzoeken als een industrieel ecosysteem. We beschrijven de activiteiten, de actoren en de manier waarop verschillende factoren van invloed zijn op hergebruik van bouwproducten.

Dit onderzoek is het resultaat van samenwerking tussen de faculteiten Industrieel Ontwerpen en Bouwkunde van de TU Delft voor de ontwikkeling van een meerschalig productdenken met een grote geldigheid en regionaal grondstoffenbeheer. In het onderzoek worden de volgende aannamen gedaan:

- Hergebruik van producten levert milieuvoordelen op.
  In dit onderzoek wordt niet beoordeeld wat onder welke omstandigheden de milieuvoordelen van hergebruik zijn. Desalniettemin erkennen we dat er niet één maatregel is die overal geschikt voor is, en dat hergebruik niet in alle contexten de beste maatregel is. Het onderzoek gaat uit van het uitgangspunt dat is vastgelegd in de bestaande richtlijnen voor afvalbeheer en van het concept van de ‘circulaire economie’ (CE), dat stelt dat afvalpreventie inclusief hergebruik prioriteit moet krijgen.

- Het beoordelen van afzonderlijke aspecten van hergebruik kan leiden tot beperkte of gedeeltelijke interpretaties, waardoor toekomstige actieplannen mogelijk ineffectief worden of helemaal niet tot stand komen.
  De praktijk van hergebruik wordt in dit onderzoek gezien als een cluster van activiteiten die bestaat naast andere clusters van activiteiten (zoals recycling, technologische ontwikkeling van bouwsystemen en productinnovatie, afvalbeheer, levensstijl, milieueducatie, beleid, primaire hulpbronnen), waarbij veranderingen in deze onderdelen ook van invloed kunnen zijn op het succes van hergebruik. Analyses met een meer specialistische focus zijn ook nodig, maar dienen als aanvulling voor de holistische benadering om kennis te vergroten en bevindingen te verifiëren.

  Het concept van industriële ecologie wordt gebruikt om de relevantie te benadrukken van het ontwikkelen van een systemische visie op hergebruik. De benadering die in dit onderzoek wordt ontwikkeld, legt de verbindingen bloot tussen verschillende factoren en activiteiten binnen het proces, en laat zien hoe deze activiteiten worden uitgevoerd. En op grond hiervan kunnen er verschillende wegen worden bewandeld om het systeem succesvoller te maken.

- Een beschrijving van de bestaande werkwijzen kan ertoe bijdragen dat wetenschappers, praktijkmensen en beleidsmakers meer inzicht krijgen in de preventie van bouwproductenafval.
  Dit onderzoek gaat uit van de observatie van de bestaande praktijk van hergebruik in Nederland om een tastbare vorm van analyse en representatie van de verschijnselen in de echte wereld te ontwikkelen. Het onderzoek draagt bij aan het debat over afvalpreventie en -beheer, het kan zorgen voor helderder concepten, meer details en transparantie omtrent hergebruik, en het laat zien dat afvalpreventie onlosmakelijk verbonden is aan beperking van economische groei. Het zorgt ook voor meer kennis om

de problemen op te lossen rondom het opzetten van een systemische benadering voor een CE, zoals die door eerdere wetenschappers waren aangestipt.

Onderzoeksstructuur

Er wordt een op ontwerp gebaseerd onderzoekskader toegepast om uit te leggen hoe het onderzoek is uitgevoerd. De analyse is verdeeld in twee hoofdonderdelen:

A De organisatorische, sociaal-economische en technologische aspecten van hergebruik.

In dit deel worden de interne relaties van het industriële systeem van hergebruik onderzocht, in de vorm van een beschrijving van de serie activiteiten en actoren die kenmerkend zijn voor de toeleveringsketen en de praktijk van commercieel hergebruik van bouwproducten in Nederland. De relaties die buiten de grens van de industrie liggen, worden geclusterd naar de maatschappelijke, culturele en technologische factoren die van invloed zijn op de manier waarop bouwproducten worden verworven uit het gebouwenbestand om te worden gebruikt.

Traditioneel worden natuurlijke systemen beoordeeld met betrekking tot de impact die wordt veroorzaakt door industriële activiteiten of de beschikbaarheid van grondstoffen om deze activiteiten te kunnen uitvoeren. Aangezien de antropogene omgeving zich ontwikkelt, is het relevant om te begrijpen hoe bruikbaar het industriële systeem is in deze dynamische context, hetgeen leidt tot het tweede deel van het onderzoek:

B De ontwikkeling van het huizenbestand als dynamische reserve (aanbod van herbruikbare producten).

De industrie van hergebruik is afhankelijk van de ontwikkeling van het gebouwenbestand voor levering van herbruikbare bouwproducten voor gebruik.
Om deze relatie te onderzoeken, bekijken we eerst welke producten commercieel herbruikbaar (aanwezig) zijn. Deze producten dienen als referentie bij het onderzoek naar de ontwikkeling van het gebouwenbestand (reserves), die van invloed is op het aanbod van herbruikbare producten voor wat betreft snelheid, samenstelling en hoeveelheid waarin de producten uit het bestand worden vrijgegeven.

Ten slotte bakenen we in de onderzoeksmethodologie de industriële ecologie van hergebruik af als de som van verschillende relaties die van invloed zijn op stromen van producten die verworven worden voor commerciële transacties van gebruikte bouwproducten. De representatie van dit netwerk van relaties onthult kwetsbaarheden en mogelijkheden in het industriële systeem om in de toekomst verwezenlijking en evaluatie voor praktijk en beleid te ondersteunen. Het voorgestelde conceptmodel is een schema, een hulpmiddel om bij te dragen aan de formulering van plannen en tests in de leercurve om in Nederland systematisch afvalpreventiemaatregelen te implementeren.

Bevindingen

De in dit onderzoek voorgestelde gemengde methoden werden door de volgende zaken beperkt: schaarse informatie over de praktijk van hergebruik van bouwproducten in Nederland, inclusief de maatschappelijke vraag naar gebruikte producten; de beschikbaarheid van harde cijfers voor afvalpreventie en periodiek gebruik van bouwproducten voor woningbouw; het metabolisme van het gebouwenbestand in Nederland, inclusief informatie over de levensduur en veroudering van huizen en periodieke fysieke beschrijving van het huizenbestand op productniveau en naar gebouwgrootte.

In het eerste deel was het onderzoeksproces gebaseerd op literatuuronderzoek, enquêtes en semigestructureerde interviews met professionals in producthergebruik, deskundigen op het gebied van bouwafvalbeheer, overheidsinstanties en ontwerpers. Het centrale doel in deze fase was de representatie van het industrieel systeem van hergebruik, in verband met verschillende relaties die het succes van dit systeem beïnvloeden. De belangrijkste bevindingen in dit deel waren:

Organisatorisch

De praktijk van hergebruik fungeert op dit moment als aanvulling op de sloopindustrie, wat zowel voordelen als nadelen heeft. Een van de voordelen is een efficiënt en geïntegreerd beheer van activiteiten waardoor tijd kan worden bespaard en administratieve en economische hindernissen kunnen worden genomen. Nadelen zijn de beperkte formalisering en specialisatie van activiteiten als productontwikkeling (verwerking van gebruikte producten), kwaliteitscontrole en marketing, en een gebrek aan formele representatie die tot publieke erkenning en politieke steun zou kunnen leiden.

Economisch

Economisch cruciaal zijn de directe kosten voor hergebruik, inclusief transport, opslag en arbeidskrachten voor de demontage (wat betreft het technologische aspect), en kosten verbonden aan processen voor het opnieuw in goede staat brengen van gebruikte producten zodat ze geschikt zijn voor de detailhandel. Externe factoren die van invloed zijn op de economische voordelen van hergebruik, houden bijvoorbeeld verband met ontwikkelingen in afvalbeheer, stortkosten, compensaties vanwege de onzuiverheid van materialen en prijzen van nieuwe materialen en producten. Het economisch succes van hergebruik wordt ook beïnvloed door investeringen en andere soorten prikkels gericht op ontwikkelingen in de afvalverwerking, en door het beleid omtrent afvalverwerking en terugwinning van grondstoffen.

Maatschappelijk
De maatschappelijke component is niet alleen van cruciaal belang, maar is ook het minst begrepen binnen het hergebruikproces. Potentiële gebruikers en 'eigenaren van afval' hebben onvoldoende kennis over hoe ze producten kunnen hergebruiken, en hebben onvoldoende informatie over gebruikte producten, waar ze te vinden zijn en wat de voordelen zijn van hergebruik. Het ontbreken van certificeringen, garanties en normen voor de producten heeft ook invloed op de vraag naar gebruikte producten. Daarnaast hangt de vraag naar gebruikte producten ook af van de interactie met potentiële consumenten, zoals de winkelervaring en het imago van het gebruikte product dat de 'waarde' van het product en van hergebruik bepaalt. De waarde kan veranderen afhankelijk van welke perceptie er bij consumenten ontstaat over gebruikte producten, over hoe hergebruiken functioneert en ervaren wordt, en over de economische voordelen.

Technologisch
De technologische component van het hergebruikproces is in drie opzichten nog niet rijp voor hergebruik van bouwproducten:

- Demontage van gebouwen is tot nu toe meer gericht op het verwerven van materiaal voor recycling dan voor hergebruik.
- Bouwtechnologieën bij nieuwe gebouwen vertonen een trend richting systemen met veel beton, die minder makkelijk kunnen worden gedemonteerd voor hergebruik.
- De afwezigheid van kwaliteitscontrole voor gebruikte producten die in nieuwe gebouwen worden toegepast, kan een risico vormen voor de kwaliteit van nieuwe gebouwen.

Het integreren van cascaderend hergebruik in deze context beloofde een gunstige strategie te zijn als aanvulling op hergebruik. Hoewel het niet gemakkelijk is om methoden te ontwikkelen voor het efficiënt verwerken (reviseren, verdelen in kleinere eenheden, bewerken) van gebruikte onderdelen tot nieuwe producten, met behoud van kwaliteitsnormen, veiligheidsvereisten en economische haalbaarheid, kan cascaderend hergebruik ook helpen om barrières te overwinnen die verband houden met de publieke perceptie en het gebruik van gebruikte producten.

Ten slotte moet rekening worden gehouden met het dynamische karakter van de manier waarop de hierboven genoemde sociaal-economische en technologische relaties in de echte wereld vorm krijgen, om de status van het hergebruik van bouwproducten te begrijpen en toekomstige aanpassingen te plannen. Hoewel in elk van deze relaties verbeteringen kunnen worden aangebracht, is het relevant om te begrijpen hoe deze samen het systeem kunnen beïnvloeden. Het in grotere mate demonteren van gebouwen biedt bijvoorbeeld geen garantie voor een hogere vraag naar gebruikte producten in de toekomst.

Reserves

Terwijl het eerste deel van het onderzoek uitwees dat in Nederland een combinatie van factoren bepaalt wat commercieel herbruikbaar is, wordt in het tweede deel de capaciteit van producthergebruik in een bestaande context geanalyseerd als referentiepunt om strategieën voor toekomstige continuïteit te schatten of te plannen. De combinatie van de werkbaarheid van de industrie van hergebruik en de ontwikkeling van het gebouwenbestand bepaalt hoe een 'typische' toeleveringsketen van hergebruik in Nederland werkt.

In de echte wereld hebben verschillende factoren samen invloed op veranderingen in het huizenbestand, maar in dit onderzoek analyseren we met name trends in het gedrag van het huizenbestand door te kijken naar de historische ontwikkeling van verschillende kenmerken in het bestand via trends met de binaire waarden 'toename' en 'afname'. De belangrijkste bevindingen in dit deel van het onderzoek waren:

- Wat betreft de levensduur van huizen is er een ontwikkeling in het huizenbestand in Nederland naar eengezinswoningen, die groter lijken, gebouwd zijn met niet-traditionele methoden en beter geluiddicht zijn dan huizen uit de recente naoorlogse tijd. Deze kenmerken lijken de levensduur van huizen te beïnvloeden (vergroten). Met name in het westen, waar de meeste activiteiten in het nationale huizenbestand zijn geconcentreerd, beïnvloedt de toename van particuliere eengezinswoningen de algehele levensduur van huizen in Nederland (vooral omdat vóór 1946 gebouwde huizen geleidelijk in aantal afnemen).
- Met betrekking tot de hoeveelheid vrijgekomen materialen die gebruikt wordt in het huizenbestand, werd er een continue toename in verbruik van bouwmaterialen per hoofd van de bevolking en van huizenbestand waargenomen. Aangezien er steeds meer eenpersoonshuishoudens komen, is het onzeker of de omvang van huizen ook zal blijven toenemen. Desalniettemin wordt, ondanks de toename van de materiaalvoorraad, de hoeveelheid materiaaloutput mogelijk gecompenseerd door de levensduur van de huizen.
- Wat soorten materialen betreft, duidt onderzoek naar veelgebruikte huizen, evenals een analyse van trends in materiaalgebruik, op een toenemend gebruik van producten op basis van steen, en vooral op basis van beton en kunststof, en wordt er minder hout, keramiek en metaal gebruikt. De afname van het aantal traditioneel gebouwde huizen kan leiden tot een lager aanbod van gebruikt hout in de toekomst, zodat de industrie zich hieraan zal moeten aanpassen.

Uit de analyse van trends in het huizenbestand en het materiaalverbruik is gebleken hoe het aanbod van materialen van invloed kan zijn op hergebruik. Inzicht in deze trends op productschaal door middel van een top-downbenadering en het op traditionele wijze in kaart brengen van materiaalstromen bleek een uitdaging. Onderzoek naar de ontwikkeling van fysieke kenmerken van het huizenbestand vanuit een bottom-upbenadering leverde een meer consistent inzicht in trends van het huizenbestand op productniveau op. Het verbeteren van het classificatiesysteem van het huizenbestand aan de hand van fysieke kenmerken, zoals woningtypologie, leeftijd van het gebouw, beschrijving van bouwproducten (sommige van deze kenmerken worden al beoordeeld ten behoeve van de energie-efficiëntie) kan monitoring van materiaalbeheer in de toekomst vergemakkelijken. Strategieën die zijn ontworpen om afvalpreventie door hergebruik te verbeteren, hebben mogelijk een beperkt effect als er geen element van kennisverbetering van grondstoffenreserves in is opgenomen.

De voorraad wordt groter maar er komt langzamer materiaal voor hergebruik beschikbaar doordat de huizen langer blijven staan. De toename van meer producten op basis van steen betekent een uitdaging voor hergebruik in de toekomst, omdat om technische en economische redenen hergebruik van producten op basis van steen minder gunstig is, en er minder vraag naar zal komen; zeker met het oog op de concurrentie met technologische vooruitgang gericht op het verbeteren van de recyclemogelijkheden van beton.

Hulpmiddel

Ten slotte biedt deze holistische benadering een overzicht van de invloed van dynamiek in het huizenbestand en sociaal-economische en technologische factoren die direct met het hergebruikproces samenhangen, op wat in de praktijk wordt verworven voor hergebruik. Bij de bevindingen van de kwalitatieve analyse gingen we uit van informatie die was geclusterd in categorieën die in aangepaste vorm zijn overgenomen uit de benadering van de industriële ecologie, en de rol van de praktijkmensen staat hierin centraal.

De verrichting van deze dynamische relaties vormt een conceptueel model, dat de vertegenwoordiging is van het hergebruik metabolisme van bouwproducten in Nederland. Deze "kaart" biedt een manier om de visualisatie en het begrip te verbeteren van hoe trajecten van productstromen worden hergebruikt, evenals de motivaties, voorwaarden en beperkingen erachter.

Het is een hulpmiddel dat de toekomstige beoordeling vergemakkelijkt om het herstel van producten voor hergebruik te verbeteren (geïllustreerd door 'houten producten'); hoe de besluitvorming door praktijkmensen en beleidsmakers te ondersteunen;

hoe de verbinding van verschillende aspecten van bouwproducten hergebruik te detecteren. Uiteindelijk moet het verschillende mogelijkheden bieden om aanvullende evaluatie of actie te (her-)genereren, met het doel om de praktijk van hergebruik in veranderende omstandigheden aan te kunnen passen.

Het voorgestelde conceptuele model komt uit een samenstelling van concepten aangepast vanuit de theoretische achtergrond van de industriële ecologie. Het model moet een typisch systeem weergeven van de commerciële praktijk van hergebruik van bouwproducten in Nederland, door producten vanuit de woningvoorraad, en geconcentreerd op praktijk belang. Vervolgens de gegevensverzameling en meeste bevindingen van de kwalitatieve analyse ontstond vanuit clusteringinformatie gestructureerd door het vooropgezette theoretische raamwerk.

Over de hele linie geeft het inzicht uit dit onderzoek aan dat er meer werk moet worden gedaan in de richting van het optimaliseren van bestaande relaties in verband met materialen afkomstig van sloopactiviteiten in Nederland. De efficiëntie moet via deze relaties worden verbeterd met het oog op toekomstige integratie met de ontwikkeling van afvalbeheer en circulair grondstoffenbeheer, en om meer soorten stakeholders te bereiken in nieuwe samenwerkingsvormen, bedrijfsmodellen en nieuwe toeleveringsketens.

1 Introduction

In the past hundred years, "*human population increased fourfold while material and energy consumption increased tenfold*" (Weisz and Steinberger, 2010, pg. 185). Projections indicate that urban areas will house 60 per cent of the world population by 2030 (United Nations, 2016).

The rate of extraction, harvest, and depletion of resource stocks caused by population growth was associated with the natural reproductive capacity and the effects on environmental quality as originally described in "*The Limits to Growth*" (Meadows et al., 1972). The report examined a collapse of modern civilization due to the environmental damage caused by over-production and over-consumption of resources.

Consumption patterns can be associated with economic and technological changes (Ayres and Kneese, 1969) including cultural and social changes in lifestyle reflecting on the way products are used and discarded (Brezet et al., 2001; Ashby and Johnson, 2002). It can be manifested in different forms, from consumer goods, building design to modern configurations of city growth and their increase land intensity (Kennedy et al., 2014; De Groot et al., 2015; Kalmykova et al., 2016; Bai et al., 2015).

The rise in resource consumption affected by population growth or consumption patterns is directly related to the accumulation of materials in the built environment later affecting waste formation, carrying additional pressure to natural ecosystems in the form of habitat depletion, pollution, scarcity, deterioration, and decline of human health that extend beyond national borders (Brundtland et al. 1987; Van der Meulen et al., 2005; Kennedy et al., 2007; OECD, 2008[a]; Hertwich, 2010). Finally, studying the evolution of resource consumption and waste generation from anthropogenic processes illuminates paths to curb, prevent and improve the capacity for sustainable living on this planet.

§ 1.1 Consumption of construction materials _ direct and indirect impact on ecosystems.

In this study, materials applied in the construction, more specifically the residential segment are the primary material stream in focus. Natural resources that are extracted and processed for construction and operation of buildings and infrastructure account for the most significant consumption of material and energy resources of all economic sectors, particularly in industrialized and newly industrialized countries (Adriaanse et al., 1997; Matthews et al., 2000; Boardman, 2004; Graedel and Howard-Grenville, 2005; Ortiz et al., 2009; Wiedmann et al., 2015). The demand for construction materials represents approximately half of Raw Material Consumption (RMC) in Europe (Econometrics and BioIntelligence, 2014[2]).

UNEP stated that "...*for domestic extraction of materials, the construction industry is disproportionally important, as it uses a significant portion of minerals and, in some countries, biomass extracted from nature*" (Hertwich, 2010, pg. 58), making the assessment and management of the mass of resources used in buildings one of the most substantial challenges (Herczeg et al., 2014, p. 19). The global trend in consumption of construction materials during the 20th century grew a factor of 34, more than GDP (Growth Domestic Product) and other compared resources (Krausmannet et al., 2008).

Consumption of construction materials generates several environmental impacts[3] from extraction, transportation, processing to the end of life (Augiseau and Barles, 2017). Some of these impacts are caused by terrestrial quarries as dust and habitat disruption from the creation of ores and mines, deforestation for wood production (Graedel and Howard-Grenville, 2005), noise, air pollution from blasting and engines, vibration that can cause rock fissures and later influencing pollution to groundwater and aesthetic disturbances (Symonds et al., 2000), loss of biodiversity (Kibert, 2016).

For non-renewable resources including non-metal minerals, although considered abundant in the earth crust (Van der Meulen et al., 2005), local quarries in the Netherlands are either exhausted or occupied by urban settlements. Harvesting materials from locations further away from consumption can induce an increase in

2 "*Construction has the highest RMC when considering all types of materials together. Construction also causes almost as much extraction of non-metallic minerals, in terms of tonnes of RME per capita (3.1 tonnes per capita), as the production of all products requires in terms of extraction of biomass (3.2 tonnes per capita) or extraction of fossil energy materials (3.2 tonnes per capita). Construction also ranks highest as product group causing most extraction of metal ores. Even for biomass and fossil energy materials, construction is among the five product groups with the highest raw material consumption*" (Eurostat, 2015)..

3 "*Even though this consumption does not always manifest itself in a direct and visible problem, issues like climate change, biodiversity loss, and desertification and soil erosion are all linked to extensive material use. More than 30-50 % (different sources give different numbers) of total material use in Europe goes to housing and mainly consists of iron, aluminum, copper, clay, sand, gravel, limestone, wood and building stone. Minerals have the highest share of all materials in buildings. Around 65% of total aggregates (sand, gravel and crushed rock) and approximately 20% of total metals are used by the construction sector*." Herczeg et al., 2014, page 19..

infrastructure, transportation and emissions indirectly related to material extraction (Kennedy et al. 2007; Hammond and Jones, 2008; Costanza et al., 2014[4]).

Moreover, ecologic rucksack (Schmidt–Bleek, 1993) or hidden flows (Adriaanse et al. 1997[5]) present more significant ecological consequences than the actual materials extracted for industrial production (Kibert, 2001, pg. 381). Another phenomenon is the emissions generated from energy use in industrial processes to produce steel (25%), cement (19%), plastic (4%), paper (4%) and aluminum (3%), accounting for 20% of all global emissions (Allwood and Cullen, 2012). The construction industry is the most significant consumer of these five types of materials. From total emissions generated it is estimated that globally, 64% is accounted to burning fuel for energy generation, industry activities, while 36% is caused by changes in land use including agriculture, deforestation and natural decay (Allwood and Cullen, 2012, pg. 13)(see Annex 1.1).

Other impacts can be caused from waste generation presenting several challenges including energy consumption, water pollution and emissions generated during the transportation and treatment of waste and potential contamination from hazardous substances dissipated through waste management (Pacheco-Torgal, et al., 2014). Some examples are Hexabromocyclododecane (HBCDD) (Nie et al., 2015), asbestos, PAHs (Polycyclic aromatic hydrocarbons), PCBs (Polychlorinated biphenyl), mineral oil, sulphate, VOCs (Volatile organic compounds), lead, TCDDs (Tetrachlorodibenzo-p-dioxins), TCDFs (Tetrachlorodibenzofurans) (Pacheco-Torgal et al., 2012; Roussat et al., 2008; Klang et al., 2003), and Radon (Mejer, 2006).

A better understanding of waste flows helps to anticipate planning capacity for future adequate resource management treatment and helps to expand capabilities to formulate how to prevent risks mentioned above whereas increasing resource efficiency towards economic opportunities[6] Section 1.2 summarizes some of the transformations leading to the concept of waste prevention.

4 “*In central Europe the present extraction rate is projected to become problematic in the near future. The long-term allocation of land to mineral material extraction, especially within or close to protected landscape zones, has led to conflicts. The needs of mineral materials over the next 30 years can only be estimated through models of the evolution of the building and infrastructure stock, taking into account different scenarios of recycling*” (Fleckenstein, 1998 in Kohler and Hassler, 2002, pg.228)..

5 These flows refer to materials moved or extracted from nature in order to remove the actual desired amount of material that would be further industrialized for consumption; such as soil removed from the ground to extract metals or materials lost or dissipated along the material chain as rubber from tires during ground transportation.

6 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0021:FIN:EN:PDF

§ 1.2 Construction material waste in the Netherlands_ fostering improvement

The Dutch construction and demolition waste (C&DW) has an annual average volume of approximately 24 megatons, being one of the most significant waste streams in the Netherlands (CBS, 2014[7]; Bio by Deloitte, 2015), with environmental risks applicable both inside and outside national borders (Dobbelsteen and Alberts, 2001; Delahaye and Baldé, 2016).

Traditionally C&DW has been landfilled. Due to the high volume of materials to be disposed of, space availability and proper management, these landfills became gradually more complex to manage (Symonds et al., 2000). With increase processing of building rubble, leachate from demolition waste became less a priority when compared to pre-treatment or pre-selection of C&D materials (Tränkler et al., 1996).

Stony based materials are the most significant percentage (40%) of C&DW (Krutwagen and Broekhuizen, 2010; Lofti et al., 2017). Despite the increased use of secondary resources derived from C&D activities (Delahaye and Baldé, 2016, pg. 11), a significant part of the stony fraction is mainly applied for embankment foundation and sub- base for road construction (1.4%) (Hofstra et al., 2006). In table 1.1, Janssen (2005) summarized most common treatment processes applied for construction material waste treatment in the Netherlands, indicating general trends in processing waste into lower-grade products.

TABLE 1.1 The most important end products regarding the recycling of C&D waste (Janssen, G. M. T., 2005, pg. 2)

SECONDARY PRODUCT	RELEVANT TECHNIQUES	APPLICATION
Recycled mixed aggregates	Crushing & sieving	Sub-base in road construction
Recycled concrete aggregates	Crushing & sieving & washing	Sub-base & concrete products
Recycled asphalt aggregates	Crushing & sieving & melting	Asplhalt layers in roads
Wood chips	Wind sifting. Shredding & incineration	Fibreboard & energy
Iron or steel	Magnetic separation & melting	Steel & iron products
Non-ferrous metals	Eddy current separation & melting	Non-ferrous products
Synthetic materials aggregates	Incineration	Energy generation

7 http://www.clo.nl/indicatoren/nl0147-bouw--en-sloopafval

In an overview of standard recycling technologies for construction materials, Tam and Tam (2006[a]) (see table in Annex 1.2) and Schut et al. (2016) concluded that available recycling technologies for the ten most typical C&D wasted material types result in several different products in lower-grade applications.

According to the Ellen Macarthur Foundation (2013, pg. 25), "*the process of converting materials into new materials of lesser quality, economic value, and/or reduced functionality*" is referred to as "*downcycling*". For instance, using mixed mineral waste flows as foundations mitigates the use of primary natural resources for this application, but also transforms the existing material stock into a "lower" performance degree when compared to the original material estate (Sassi, 2008).

Recycling can be seen as a form of waste treatment that avoids materials to be landfilled and decreases the need for primary resources, while conserving natural landscapes by applying secondary materials (Hendrix and Pietersen, 2000). However, it can't yet be processed without impacts such as noise, transportation, energy use and current losses in energy and material (Symonds et al., 2000; Vogtlander et al., 2001). Few exceptions, such as metals[8], already can be recovered and processed, because of their relatively high economic value (Graedel and Howard-Grenville, 2005; Lasvaux et al., 2010; Bio Intelligence, 2011). Finally, "*there is general global consensus that the climate benefits of waste avoidance and recycling far outweigh the benefits from any waste treatment technology, even where energy is recovered during the process*" (United Nations Environment Programme, 2010, pg.1)

The efforts to simultaneously curb the direct impacts of waste generation and consumption of primary resources are not recent. The first European legislation introduced in 1975 focused on changing dumping of waste in landfills foreseeing the use of waste as a resource (Jackson and Watkins, 2012). In 1976 formal mechanisms have been implemented to control and monitor hazardous waste streams including the quality of secondary materials, combined by the Building Materials Decree in 1999 (Eikelboom et al., 2001). Since the 1980's, several studies were made on how to manage the limited landfill capacity for C&DW (Hendriks, 1998), resulting in a dumping ban in 1997 in the Netherlands (Hendriks, 1998).

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8 According to Pietersen (2000) when describing specific research results in the Netherlands he concluded that: "*The properties of concrete with recycled aggregates may differ from concrete from natural aggregates*"... "*large inventories carried out by the Dutch CUR organization suggest that recycled mixed aggregates is very well applicable for concrete*". (Pietersen, 2000, pg.3).

The so-called "Ladder van Lansink" was introduced in the Netherlands in 1976 during a parliamentary debate. It became an internationally known reference for the subsequent Dutch Environmental Act (Lansink, 2014[9]), and identifies five steps:

1. *Prevention*
2. *Reuse*
3. *Recycle*
4. *Incineration with energy recovery*
5. *Landfill.*

Professor Charles Hendriks and researchers from TUDelft also adapted the Ladder van Lansink into the "Delft Ladder' (Hendriks and Janssen, 2001). The Delft ladder has been introduced to support decision-making at the end of life phase of buildings and building products, and it is regarded as a more flexible Life Cycle Analysis (Eco-cost value ratio and Degradation Factor) offering more steps (10 instead of 5) between waste prevention and landfill. Professor Kibert from the University of Florida later adapted the Delft Ladder by introducing the step "composting" between step 7 and 8 (Te Dorsthorst et al., 2000; van Timmeren et al., 2004). Likewise, waste prevention and reuse have been prioritized over other waste treatments (Vogtlander et al., 2001), resulting in the following the "new Delft ladder":

1. *Prevention (extending service; life of building structure)*
2. *Construction reuse*
3. *Product reuse*
4. *Material reuse*
5. *Useful application*
6. *Immobilisation with useful application*
7. *Immobilisation without useful application*
8. *Combust with energy recovery*
9. *Combustion*
10. *Landfill*

The measures that were initiated in the 1970's helped giving rise to today's Directive 2008/98/EC. The five-step waste hierarchy was introduced in the EU Directive 75/442/EEC, later adapted by Zunft and Fröhlig into the European Directive 2008/98/EC (Figure 1.1).

9 http://www.adlansink.nl/?page_id=153

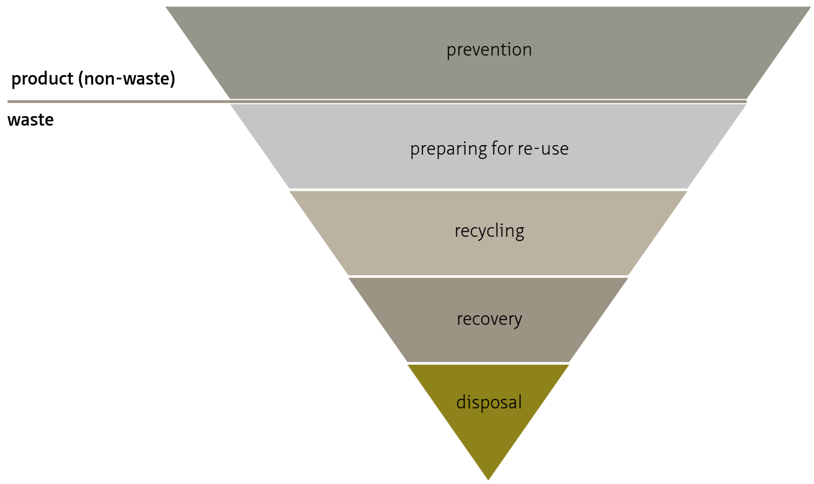

FIGURE 1.1 Waste management hierarchy according to Directive 2008/98/EC (http://ec.europa.eu/environment/waste/framework/)

In 2008, the European Waste Framework Directive specified that by 2013 all waste prevention programs should be established in all member states (Directive 2008/98/EC). The hierarchy indicates that priority should be given to waste prevention. According to the Directive 2008/98/EC waste prevention is defined in Article 3(12) as follows:

"*Measures taken before a substance, material or product has become waste that reduces:*
- *The quantity of waste, including through the re-use of products or the extension of the life span of products;*
- *The adverse impacts of the generated waste on the environment and human health; or*
- *The content of harmful substances in materials and products*".

In the Netherlands, the *Landelijk Afvalbeheer* Plan 2009- 2021 uses similar terms and definitions from the European Framework. It states that waste prevention ultimately leads to "...a reduction in the use of raw materials and energy consequently there are less pollution and deterioration of the (living) environment due to the extraction of the raw materials. Also, a contribution to the climate, including increased focused on the reduction of CO_2 emissions into the atmosphere. It also contributes prevention to more efficient production, which can result in lower production and better working conditions" (LAP 2, 2010, pg. 121[10]).

10 http://www.lap2.nl/sn_documents/downloads/01%20Beleidskader/versie%202010-02%20(1e%20wijzig-ing)/beleidskader-13-preventie_2010-02-16.pdf.

The past decade, in Europe, the Circular Economy (CE) concept has been promoted as "*essential to deliver the resource efficiency agenda established under the Europe 2020 Strategy for smart, sustainable and inclusive growth*" (European Commission, 2014). It determines to boost reuse and recycling to a minimum of 70% of municipal waste in 2020, and it directs investments at the top of the waste hierarchy[11].

The Dutch government showed commitment to the realization of a CE, and in 2014 it launched the program "From Waste To Raw Material" (van Afval Naar Grondstof _VANG) as a transition phase from a linear to a circular economy. VANG tries to connect various activities in the waste prevention programs. As a transitional phase to promote the end of waste concept, it settles to review existing policies perceived as obstructive to a circular economy and promote space for innovation towards the end of waste concept (*Ministerie van Infrastructuur en Milieu*, 2014). A report focusing on the construction sector (Schut, 2016) emphasizes the benefits of building product reuse. However, it fails to detail product reusing mechanisms and how to integrate reuse within the "*circular material chain*." Within this transition, in the Netherlands, targets for waste prevention were designated as follows (*Ministerie van Volkshuivesting Ruimtelijke Ordening en Milieu* VROM, 2010ª, pg. 9):

- "*Stimulate waste prevention, in order to dissociate gross national product from total waste production. Total waste production must not exceed 68 megatons in 2015 and 73 megatons in 2021.*
- *Use waste as secondary raw materials (the "cradle to cradle" concept) for seven waste flows12 so as to reduce pressure on the environment with a 20% reduction in waste for each flow.*
- *Limit the quantity of waste incinerated or buried, moving from 1.7 megatons in 2007 to 0 megatons in 2012.*"

Despite the developments described above to improve waste management towards integrating it with resource management, and that ..." *waste prevention is found at the top of the 'waste management hierarchy', it generally receives the least allocation of resources and effort*" (United Nations Environment Programme, 2010, pg.1).

11 http://eur-lex.europa.eu/legalcontent/EN/TXT/HTML/?uri=CELEX:52014DC0398&from=EN

12 Paper and cardboard, textiles, construction and demolition waste, organic and food waste, aluminum, PVC and bulky waste.

Many strategies lead to waste prevention, which applies different material management focus, and these distinctions have to be considered for adequate implementation (Directive 2008/98/EC; the Dutch *Landelijk Afvalbeheer plan* _LAP 2009-2021; Circular Economy[13].

The list below illustrates some examples of different waste prevention strategies related to construction materials. They primarily focus on promoting less use of materials, or systems that allow easier recoverability of materials to be further reused, or yet the use of materials that can have longer lifespan, postponing the release of materials integrating waste flows. These measures promote waste prevention in different stages of a product cycle and can be complementary.

Reuse

Re-use is "*any operation by which products or components that are not waste are used again for the same purpose for which they were conceived*" (Directive 2008/98/EC, pg. 9), and that the process should not require recycling or remanufacturing (Graedel and Allenby, 2010, pg. 608[14]). Other definitions of reuse accept some degree of reconditioning (OECD, 2004, pg.12[15]).

Waste minimization

Transnational programs of minimal waste production during construction have indicated positive results; they mostly include prefabricated building products and less wasteful building sites, promoting new management schemes (Jaillon et al., 2008; Dainty and Brooke, 2004; Tam et al., 2006[b]).

Design for Disassembly (DFD)

"*Design for disassembly is a useful strategy that can be applied to varying extents to increase the future rates of material and component reuse*." The strategy focuses on "*...reduce resource depletion and species and habitat loss, it can reduce energy use and pollution production, and it can also have significant effects on social and human health issues*" (Crowther, 1999, pg. 1 and 3).

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13 Several other concepts have been developed also promoting sustainable use of resources. The Circular Economy is currently a central part of sustainable discussions in China as well as in Europe and more explicit promoted by governmental organizations as the European Commission and the Dutch Ministry of Infrastructure and Environment. Some of these concepts were depicted in Annex 1.3.

14 "*reemploying materials and products in the same use without the necessity for recycling or remanufacture*"

15 "*Product re-use involves the multiple use of a product in its original form, for its original purpose or for an alternative, with or without reconditioning*."

Design for deconstruction (also named DFD)
Similar to Design for disassembly, Design for deconstruction analyses design of building products foreseeing disassembling after building use, which emphasizes the need for dry connections in building detailing.

Both disassembly and deconstruction promote proactive strategies in the design phase to enable extraction of products from buildings with the higher quality condition than when mixed with other materials and products to facilitate further reuse or recycle.

Dematerialization
It is a strategy used by industries and directly connected to resource- light economies. The idea to reduce materials in buildings also includes reducing material use per unit of service (Fernández, 2006). It is a more inclusive approach considering material intensity in the entire product lifecycle.

Building with durable materials
The use of long life products implies less need to replace them with new ones, which implies less waste production (Berge, 2009; Ayres, 1989). Durable materials may have initial increased costs. Another aspect to consider is how to improve, rather than deteriorate, the environmental impact performance of products that have long life service during the use phase (Ashby and Johnson, 2002). According to Klunder (2005, pg. 60) if durability is a priority when considering minimization of environmental impacts, there are sensitive choices to be made while considering durable materials with large environmental impact but that could, for instance, be more recycled effectively, such as steel or wood from endangered trees in tropical countries.

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The waste prevention strategy in focus in this study is centralized for **reuse** as a concept to prolong the quality and value of existing products[16] before recycling (Directive 2008/98/EC; Circular Economy[17]). Moreover, in both literature and practice, the term "reuse" has been applied to define several different activities that for clarification are grouped below in three aspects:

- **Processes: technical activities applied for reuse**
  Reuse with or without additional processing like refurbishment, recondition, reprocessing, remanufacture. Parker and Butler (2007) distinguish forms of reuse according to how products are treated with the goal to be reused as follows:

  - "*Straight reuse, possibly by someone else, possibly in a different way.*
  - *Refurbishment: cleaning, lubricating or other improvement.*
  - *Repair: rectifying a fault.*
  - *Redeployment & cannibalisation: using working parts elsewhere.*
  - *Remanufacturing: the only option that requires a full treatment process – like new manufacture – to guarantee the performance of the finished object*" (Arcadis et al., 2011, pg. 22).

According to the Directive 2008/98/EC, these activities are distinct as "preparing-for-reuse" (rather than reuse), which is the rehabilitation of wasted products or components (Directive 2008/98/EC), while reuse excludes processing and is applied on non-waste products, therefore, considered as prevention.

"*Technically, "prevention" is not a waste management operation because it concerns substances or objects before they become waste. Consequently, obligations under waste management legislation (permits and registration, inspections, requirements for transfrontier shipments) do not apply*" (European Commission, 2012, pg. 28).

For the European Topic Centre on Sustainable Consumption and Production[18], products or components can be reused with or without reprocessing or reconditioning.

16 http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52014DC0398&from=EN

17 https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram

18 http://scp.eionet.europa.eu/themes/waste

In the Circular Economy Law (2008, pg. 1[19/20]), reuse designates activities applied to waste. From this perspective, there is little clarity on how to specify the processes to improve the condition of products that can vary substantially from polishing, fixing, restoring, and are to specific for the scope of this study. Also, the distinction between waste and non-waste is critical for policy structure to formulate regulations on disposal and treatment, including monitoring material circularity versus waste production.

– **Function: Reuse for original or new function**
The European Topic Centre on Sustainable Consumption and Production[21] consents that products or components can be reused for "*different purpose after its initial use*." In the Directive 2008/98/EC products should be reused in their original function; in this case, if a door extracted from a building is used as a tabletop, it is not considered as reuse even if no reconditioning is applied.

The idea to reuse a product in its original function potentially limits the quantities of materials to be prevented from becoming waste, even if they achieve the goals of waste prevention defined from the same Directive 2008/98/EC. In this study, the function of the product reused will not be pre-determined, but defined by practitioners in the field.

– **Scale: Reuse of a whole product or a component of a product**
The term reuse is commonly addressed at three or sometimes four different scales: product, component/ element, material, and substance. The Delft ladder (Hendriks and Janssen, 2001) hierarchy suggests that there are different levels of intervention associated with size of items to be reused. Generally, the larger the product to be reused the more significant the environmental benefit, as it demands fewer processes (and related environmental load) involved. As an example, reusing entire buildings avoids processes involving demolition.

When considering a building to be a whole product, like an automobile or a refrigerator, component reuse is equivalent to building parts or elements, like doors and windows. A door, however, can also be regarded as a finished product made of components like hinges, handles, and frames. Therefore, reuse can be applied at the product scale levels.

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19 http://www.amcham-shanghai.org/NR/rdonlyres/4447E575-58FD-4D8E-BB0F-65B920770DF7/7987/CircularEconomyLawEnglish.pdf

20 Reuse… "*refers to using wastes as products directly, using wastes after repair, renewal or reproduction or using part or all wastes as components of other products*".

21 http://scp.eionet.europa.eu/themes/waste

Bakas et al. (2011, pg. 57) also identified that initiatives advocating waste prevention of construction waste in Europe were mainly "*waste recycling activities according to the EU waste definition*." The term "reuse" has been found to refer to different activities (European Topic Centre on Sustainable Consumption and Production[22]; OECD, 2004, pg. 12; Graedel and Allenby, 2010; The Circular Economy Law, 2008[23]), challenging the assessment and implementation of the strategy as defined by the Directive (2008/98/EC, pg. 9).

The current study excludes analysis of whole building reuse, to focus on reuse of products (components and parts) removed from existent buildings. Furthermore, the definitions of reuse as mentioned above will be contextualized in practice in the Netherlands.

§ 1.3 Contextualizing Reuse in the Netherlands_ from concept to application

Despite acknowledging reuse as an appropriate measure to curb negative impacts generated by waste, the future of such strategy is uncertain. Reuse continues to exist without the political impetus for action on necessary changes to policy and economic framework (Arditi and Georgeson, 2010, pg. 10).

As previously mentioned, the Dutch government has not specified how the reuse of building products should be implemented. When concerns regarding waste production and treatment culminated with the landfill ban in 1996, dialogue about reuse of building products promoted projects in partnership with Universities (TUDelft[24]) and organizations such as the NCDO (*Nationale Commissie voor internationale samenwerking en Duurzame Ontwikkeling*), and TNO (*Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek*[25]). In this period, there were around

22 http://scp.eionet.europa.eu/themes/waste

23 http://www.amcham-shanghai.org/NR/rdonlyres/4447E575-58FD-4D8E-BB0F-65B920770DF7/7987/CircularEconomyLawEnglish.pdf

24 Interview Kowalczyk (former TUDelft researcher).

25 According to interview with Rob Gort these institutions had co promoted the studies about reused buildings products.

250 to 300 facilities in the country commercializing reusable construction elements[26]. Within the waste prevention debate, reuse received a smaller share of consideration (Eisenriegler, n.a.[27]). Reuse of building products has not been regulated nor guided by any particular targets under the waste prevention goals (Institute For European Environmental Policy et al., 2010).

There is no systemic account of reused construction products in the Netherlands, making it difficult to evaluate the performance of such activity. While periodic assessments of waste recycling, incineration, and landfill, as well as scenarios with the purpose to monitor the capacity to treat waste, are available (Vroegop, 1997; Hofstra et al., 2006; Delahaye, 2004; VROM, 2010[a]; *Agentschap Nl*, 2011; *Rijkswaterstraat*, 2014); assessment of mass of materials prevented from being wasted through reuse is virtually inexistent.

The right side of the dashed line in Figure 1.2 shows where the account of construction material flows are monitored towards the end life use, but no consistent information exist regarding the "*Diverted waste flows*."

26 Interview with Erik van Erne (*Stichting Milieunet/ Kringloopnet*).

27 "*Despite a history of more than 30 years of European waste legislation, Europe is still, regrettably, a long way from stabilizing waste production and reducing its environmental impact, due to a lack of efforts on prevention and reuse*." (Eisenriegler, S., n.a. Prevention, reuse, recycling: Closing the loop. General background situation and legislation. Pg. 1. Retrieved from: https://www.iswa.org/uploads/tx_iswaknowledgebase/617707_Paper.pdf).

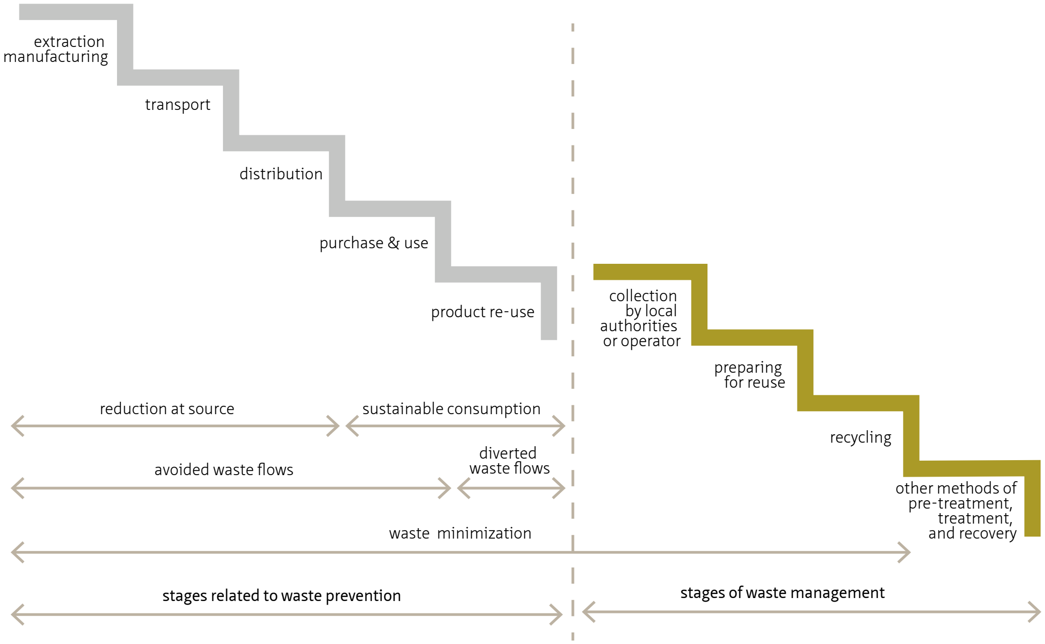

FIGURE 1.2 Illustration of definition of waste prevention (adapted from Waste management strategies. Based on European Commission 2012, quoting ADEME, the French Environment Agency, pg. 10).

It is also difficult to quantify the commercialization of reused building products, lacking a platform that represents, regulates or integrates stakeholders in any political sphere at national or European level[28/29] (contrary to efforts made in the field of electronics _WEEE[30] _ as represented by Reuse[31]. Policy support has been absent in more direct ways, as tax incentives[32] (Bakas, et al., 2011) or acting straightforwardly on key players in the chain as demolition companies or building owners[33] (Losje, 2013). Also, mechanisms to evaluate and communicate quality control of reusable building products are insubstantial in contrast to material recycling (Hendriks and Raad 1997[34]) and no transformative developments have taken place as indicated in Section 1.2.

In the past, seven private companies from the reclaim building sector attempted to form a platform to represent commercial reuse of building products in the Netherlands. The platform, however, was later dissolved[35] with another attempt to connect around 200 companies in this sector between 2003 and 2004 with no success[36]. In the early 1990's, a non-governmental association (*Stichting Milleunet*)tried to coordinated such efforts but ceased activities in 2010 due to lack of government funding[37].

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28 According to interview with Thornton Kay, there is not representative lobby for reuse of building products in Brussels.

29 Interview with Erik van Erne (Stichting Milieunet/ Kringloopnet).

30 Email with Stephane Arditi, Senior Policy Officer Products & Waste (EEB).

31 http://www.rreuse.org

32 "*So far in the EU, all taxes on virgin materials aim at increasing the use of recycled material, as it is usually described in the accompanying procurement. The tax on virgin material, together with good standards and certification measures for recycled products creates an economic advantage for recycled products and therefore a market demand for their absorption. This type of measure might only indirectly create waste prevention, since the recycled products are not taxed. If the raw material tax was combined with a (lower) tax on recycled raw materials, the consumption of these materials would decrease leading to more efficient materials management and waste prevention*." **Assessment of initiatives to prevent waste from building and construction sectors Sustainable consumption and production, Environment**. Bakas et al., 2011, page 49.

33 The environmental guidelines directed to both demolition companies (as Demolition Assessment Safe and Environmentally-BRL SVMS-007 or *Vereniging van sloopaannemers Beoordelingsrichtlijn Veilig en Milieukundig Slopen* BRL-SVMS-007) and to their clients (*Duurzaam Inkoop or Sustainable Procurement*) are focused on waste rather than prevention meaning less demolition.

34 Building Materials Decree established boundaries to evaluate acceptable emission levels for inorganic compounds in building materials into soil and surface water.

35 Interview with van Ijken_ *Oude bouwmaterialen*.

36 Interview with Rob Gort, founder of the *Bouwcarroussel*.

37 Interview with Erik van Erne.

The decay of such initiatives has also been linked to change of priorities from the national policy scenery, which affected the apparent decrease of incentives for research and practice of reuse[38]. In 2010, the Dutch government initiated studies in construction waste prevention in projects restricting reuse in three actions (VROM, 2010[b], pg. 14):

- "*creating a market for surplus building material*
- *developing new methods to delay the incineration of wood for as long as possible*
- *collaborating with other material chains, such as PVC and aluminum*"

Reuse of building products has not yet been systematically integrated in any material supply chain or other waste treatment programs (Moors, 1991), being more appreciated in small-scale projects (Blaauw, 2000; Kay and Essex, 2009; Institute For European Environmental Policy et al., 2010; van Eijke[39]; mainly "*represented by voluntarily initiated measures*" (Bakas et al., 2011, pg. 57).

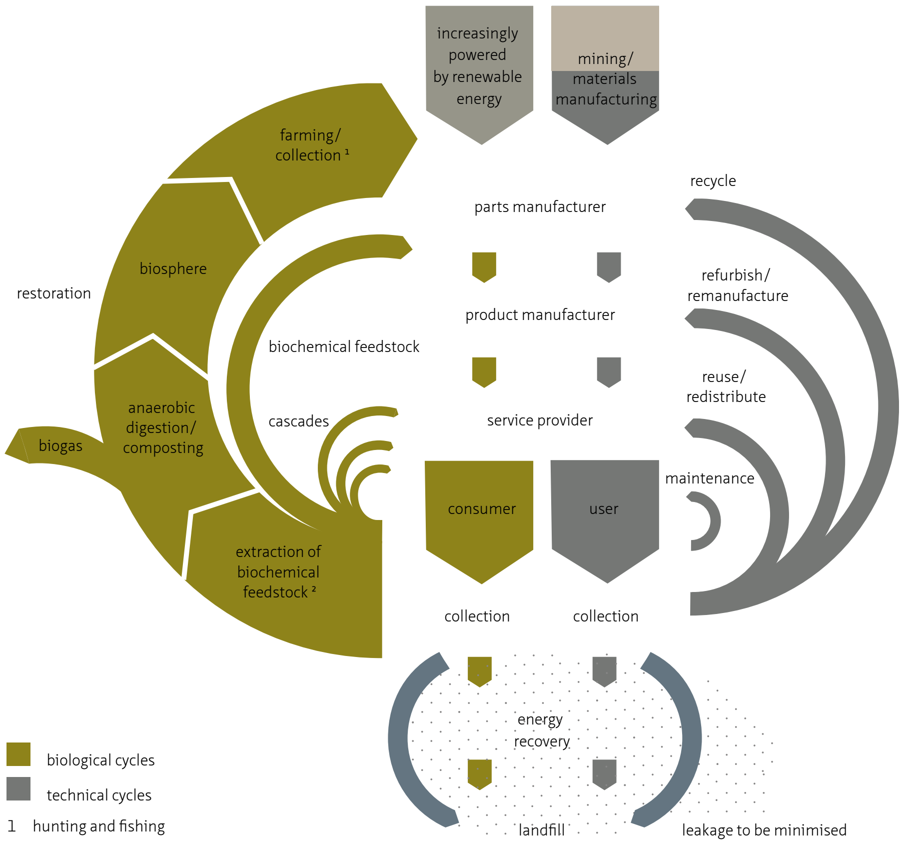
Despite the fact that historically building products made available for re-use was common practice (Moors, 1991, pg. 39), reuse of products in the Netherlands is also associated with the "*kringloopwinkels*", being second hand stores spread around the country mainly reselling furniture, books and other consumer goods, often connected to social and charity work (Losje, 2013). Although detailed description and application of measures regarding reuse are not specified, more recent, the intention to stimulate the activities focused on repair, recondition and commercialization (or donation) of used building products was more focused on wood products (Losje, 2013, pg. 29).

Finally, this section identified some of the conditions that characterize the practice of building product reuse in the Netherlands: the lack of clarity regarding the activities that define the process of building product reuse; weak engagement among key players in the chain; absence of formal accounting systems for used building products that could evaluate the performance of reuse and set future targets. These conditions are apparently disconnected to the developments initiated by the European Waste Framework Directive later culminating with the efforts to promote a Circular Economy (Figure 1.3). According to Schut (2016, pg.7) despite advances, "*there is not still a Circular Economy in the construction sector*."

38 Interview with Eric van Erne and Rob Gort.

39 Interview with van Ijken _ *Oude bouwmaterialen*.

In the Netherlands, there hasn't been an assessment that illuminates the contrast between increasing goals to prevent waste through reuse and the lack of information regarding how reuse of building products operates as a practice, and what influences its apparent decrease in the last decades.



1 hunting and fishing

2 can take both pos-harvest and post-consumer waste as an input

FIGURE 1.3 Reuse integrates in the circular economy scheme (adapted from Ellen Macarthur Foundation. *Towards the Circular Economy* vol. 2, 2013, pg. 24)

§ 1.4 Research problem and main research question_ the need for broader assessment

Past studies from the Netherlands and abroad, have evaluated different aspects of building product reuse. Environmental assessments indicated some of the benefits in reusing products with the goal to curb negative environmental impact caused by waste and use of natural resources (Thormark, 2002; Geyer and Jackson, 2004; Roth, 2005; Nordby et al., 2009ª; O'Brien et al., 2006; Bohne et al., 2008; Dewulf et al., 2009; van Broekhuizen and van Ewijk, 2010; Krutwagen and van Broekhuizen, 2010). Most of these studies were based on Life Cycle Analysis (LCA) to measure and compare environmental impacts of reusing building products and components in place of new ones[40] or as an alternative to different waste treatments. One common aspect in these studies is the indication of higher environmental benefits generated by reusing building products, but also that such benefits can only be reached under specific conditions. When possible, LCA should highlight priorities in individual cases (Arcadis et al., 2011). Although complex and extensive, especially in regard to buildings (Klunder, 2005; Roth, 2005; Blom, 2005; Vieira and Horvath, 2008; Ortiz et al.; 2009; Lasvaux et al., 2010), these analyses are relevant to set referential recommendations for planning and practical applications as proposed by the Waste Framework Directives and other guidelines mentioned in Section 1.2.

Different methodologies and variables were associated to evaluate the reuse of materials according to the focus of each study. Earlier studies focused on the technical feasibility of harvesting products for reuse were based on case study costs benefit analysis combined or not with life cycle analysis (Kibert, 2000; te Dorsthorst and Kowalczyk, 2001; Lazarus, 2002; Chini and Bruening, 2005; Roper, 2006; Asam, 2007; Shami, 2008; Gorgolewski, 2008a). Such studies described steps within the reusing process more often based on specific material and component types (wood or steel structure). The knowledge generated by the collection of individual cases of building deconstruction and reuse of produtcs has also been found in literature from an operational point of view, producing guidelines and best practices for designers, contractors, and clients (Lazarus, 2005; Bioregional, 2007, 2008ª; Addis, 2012; Ogbu, 2010). The collection of these experiments (mainly outside the Netherlands), revealed aspects within the processes of reusing building products that help to justify some of the conditions described in Section 1.3. Some of these aspects were related to time

40 The decision to include international studies in the list is justified by the small amount of studies on LCA based analysis in EOL construction materials in the Netherlands including reuse of building components.

constraints, safety, adequate equipment for building deconstruction and recondition of such products, lack of standardization, logistics, regulations and consumer perception.

Other studies emphasized the economic feasibility of building deconstruction and reuse, including a more systemic description of a production chain with direct and indirect relations economically influencing such practice. When studying the economic aspects of steel reuse, Patel (2010, pg.1) suggested that the methodologies applied in previous studies: System Dynamics (Yuan et al., 2011), Supply Loop Framework (Geyer and Jackson, 2004) and Input- output Analysis (Kanagawa et al., 2008), failed to assess other incentives in place that affect the economic output.

Economic viability is also conditioned by the nature of the material and component type to be reused. Comparatively, some types of products and materials are more or less prone to be reused regarding technical and logistic processes involved (Lazarus, 2005; Addis, 2012; Asam, 2007; Shami, 2008). Other economic analysis identified the relevance and specific role of tax incentives in the commercialization of used building products through non-for-profit organizations compared to for-profit ones (Bioregional, 2008[b]; McLear, and Nobe, 2011).

Besides environmental, technical, economical and policy related aspects included in previous assessments of building product reuse, social behavior is another fundamental force in the reuse process. As materials are extracted with the intent to provide services to humans, social behavior is an essential element in resource management (Lifset and Graedel, 2002, Fischer-Kowalski and Haberl, 2007), which justifies the relevance to understanding the demand for used building products as part of the supply chain. So far, social aspects related to consumption of used products are the least explored topic in the field.

Geyer and Jackson (2004) used different scenarios for the economic analysis relating high or low demand for reused products relative to costs of other waste treatments or new steel products. Chen et al. (2006) narrowed the scope of demand for used products through the perspective of accessibility to information. The circular supply chain of steel products proposed by Fujita et al. (2008) was concentrated on the development of information technology database to build an inexistent connectivity between parts of an efficient supply-demand chain. Hobbs and Hurley (2001) also proposed a Material Recovery Notes as a tool to share material audit prior demolition with interested stakeholders. Van den Briel and Bolhuis (2012) discussed the lack of marketing that affects the perception of the final consumer and consequently demand. Moreover, Hobbs and Hurley (2001) emphasized the importance of demolition companies in the process to harvest reusable products and match them with a commercial demand in the light of technical and legal procedures.

For Patel (2010), the demand for reused products is combined with suggested incentives and legal mechanisms after demonstrating the economic advantages of steel reuse. While Gorgolewski and Morettin (2009) and Poelman (2009) investigated ways for architects to systematically engage used products in the design process, which is absent in conventional educational systems, Bakas et al. (2011, pg. 57) suggested "*the need for education and information among all actors, from the early planning stage*" to implement construction waste prevention measures in Europe.

These studies suggest that challenges related to the demand for reused building products are as relevant as the challenges found in the supply of such products. Therefore, whereas assessing potentials and barriers, feasibility or impact of reusing, existent literature showed that different economic, social and technological factors and policy influence the practice and performance of reusing in one or more stages of the process. In the Netherlands, the description and understanding of these aspects are limited, which could influence the future of C&D waste prevention.

Most of the technical or economic feasibility studies, as well as environmental assessments focused on the reuse of building products conducted in the Netherlands, were based on experiments assessing specific types of buildings or particular types of building products (te Dorsthorst and Kowalczyk, 2001; Gort et al., 2007; Mulder, 2008; Krutwagen and van Broekhuizen, 2010). A common aspect in these studies is the concern to create (better) alternatives to conventional waste treatments for a common type of waste (*e.g.*, bricks).

Little attention has been given to understand how the building stock evolves as a reserve of potential reusable products at larger scale levels. Conventionally, industrial activities have been focusing on measuring reserves and assessing the availability of natural resources to process them into products. Supply chain stakeholders are aware of the vulnerability caused by fluctuations of material supply (Alonso et al., 2007) that will, or not, adapt in response to these changes. Similar is the uncertainty about future availability and fluctuations of material supply for waste management (De Wilde et al., 1996; de Bree, 2005; Guide, et al., 2000; Müller, 2006; Pagell et al., 2007).

Studies that aimed to formulate scenarios of future construction waste flows, to plan capacity by matching flows with a demand to treat them, have more commonly assessed changes in the built stock forecasting type, quantities of materials and the speed they are added to or released from the stock (Kohler and Hassler, 2002; Hsiao et al., 2002; Hashimoto, et al., 2004; Hofstra et al., 2006; Müller, 2006; Fernández, 2007; Bergsdal et al., 2007[b]; Sartori et al., 2008; Hashimoto et al., 2009; Takinawa and Hashimoto, 2009; Hiete et al., 2010; Hu, 2010; Wu et al., 2014; Takinawa et al., 2015).

In other words, the performance of the industrial chain is sensitive to developments of the material reserves or stocks. Stocks of secondary materials as in the case of buildings are dynamic, and fluctuations can occur in size by new buildings being added or demolished, or by type of materials and techniques applied in new constructions. In other words, supply of materials (in this case products) influence adaptations in the chain.

According to Alonso et al. (2007), materials do not only translate into product performance but also determine appropriate production technologies, product characteristics, architecture; influencing the correspondent economic system. Daugherty et al. (2016, pg. 4) described the supply chain, as "*a living, breathing thing, and one needs to think about it as dynamic and impermanent*." In this context, to understand how current and future waste prevention through reuse can be improved or systematically implemented is contingent on understanding changes in the supply of material reserves in this case, the built stock.

In the case of building product reuse, according to literature discussed in this section, more clear assessments on economic and practical mechanisms (Özkan, 2002; Bakas et al., 2011; Hemström et al., 2012), as well as information regarding public perception, awareness, education (Bakas et al. 2011; Gorgolewski and Morettin, 2009; Poelman 2009); policy incentives (Patel, 2010); and technical processes involving safety and quality of products (Pu et al., 2006; Asam, C.; 2007; Kuikka, S. 2012) are required to implement construction waste prevention measures.

The knowledge of building product reuse expanded and the sum of these previous studies indicate that the technical, economic and social aspects influence the potentials and barriers that occur in different stages of the reusing process. Ultimately, these aspects affect the overall performance[41] of the practice of product reuse combined rather than isolated.

The context described above and in Section 1.3 indicates the need to provide more evidence on how the reuse of building products can be evaluated to support its implementation systematically in the Netherlands. According to Yuan et al., (2011), constructing a systemic description is essential to understand the activities that take place in construction waste management, and by analogy, it could be extended to waste prevention. Likewise, whereas the knowledge of building product reuse developed, the methodologies applied haven't yet produced a holistic visualization of

41 Performance in this study is defined as amount of reused materials that substitute the consumption of primary resources.

such interactions. According to Dehoust et al. (2010, pg. 66), "*waste reduction cannot be solved as an isolated problem. In many areas, it requires a change of framework conditions in order to set the necessary incentives for waste prevention*."

Two reasons sustain the aim to construct a holistic approach in this research. One that relates to a system's perspective affecting the supply of products to be reused, and the other one that relates to the processes that effectuate reuse of building products in the Netherlands.

Buildings, as seen in Section 1.1 mobilize vast amounts of resources both as input through the consumption of materials for manufacturing and use, as well as waste produced during manufacturing and post use of the same. According to Fernández (2006, pg. 302), the continual transit or throughput of materials conforms the "*ecology of construction*" _ "*the study of the metabolism of buildings species within the regulating networks of social, economic, political and physical boundaries (city, region) that influence the flow of materials and energy*."

The concept of urban metabolism has been applied in studies aiming to understand interactions between natural and human systems, but also to formulate scenarios of future consumption of construction materials and waste production or to estimate present material stocks (Kohler and Hassler, 2002; Müller, 2006; Hu et al., 2010; Huang et al., 2013). Many of these studies have incorporated the description and analysis of flows of materials and energy related to socioeconomic changes in specific geographic areas.

From this perspective, if the flows of construction materials are defined by the sum of different forces in time, the study of one of these forces acting on material flows would produce a partial understanding of the flows' behavior. For instance, Fernández (2006, pg. 42) discusses the complexity to understand the obsolescence of buildings that can be induced by technical, economic, social, cultural or locational reasons. Economic change, life style, technological evolution on the other hand, are some of the factors influencing new building construction reflected on forms, sizes and material choices. By analogy, understanding how flows of materials occur as input (consumption) or output (release) is associated to the influencing forces to manage or control these flows, which in this case, regards preventing materials (and products) to integrate waste streams through reuse.

This perspective, however, does not disregard knowledge previously generated by single focus studies, on the contrary, it incorporates specific information that helps to examine how different aspects combined act on flows of materials and finally on the decision to prevent or not waste.

The second reason to construct a holistic visualization of the strategy of reuse is intrinsic to the pragmatism aspect carried by the research design and the tools offered by the theoretical framework. Different stakeholders are involved in the practice of reuse and "*prevention-oriented policy can not be successful without the involvement of various stakeholder groups*" (Dehoust et al., 2010, pg. 66). Biesta and Burbules (2003, pg. 2) further explain:

"*If one assumes, for example, that knowledge can provide us with information about reality as it "really is" and if one further assumes that there is only one reality, then one might conclude that there is eventually only one right way to act. If, on the other hand, one believes that the world of human action is created through action and interaction, and that knowledge is intimately connected with what people do, then new knowledge opens up new and unforeseen possibilities, rather than telling us the one and only possible way to act.*"

With the integration of various actors' perspective, it is expected that different barriers and constraints in the reuse process are revealed, helping to build a more elaborate description of the conditions defining the system and possibly different solutions to reach waste prevention through reuse.

MRQ. What are the perspectives for reuse of building products from the housing stock, given contextual factors that influence the process chain and reserves?

§ 1.5 Problem definition and research objectives

Section 1.4 presented different approaches found in literature assessing aspects of building product reuse. Also, whereas waste prevention is proposed as a priority, the lack of clear targets and mechanisms for reuse of building products in the Netherlands indicate that there is little understanding about such practice as an industrial activity. In this context, the objectives of this research are:

RO1: To identify main characteristics of the supply chain of building products in the Netherlands, including critical social, technological and economic factors that characterize and define it.

Some of these aspects have been already investigated in previous studies but not contextualized in the Netherlands. Additionally, this study analyses the physical composition of the building stock and how it evolves as a direct factor influencing the practice of reuse in the Netherlands.

RO2: To identify how changes in the building stock can affect the practice of reusing products.

Similar assessments have been previously made to evaluate how to improve material flows management for construction waste, more specifically assessments focused on the future capacity of recycling (or downcycling), to analyze how industrial organizations should adapt to possible changes regarding material stocks and demands (closed loop supply).

Subsequently, by associating the findings regarding the mechanism of reuse (RO1) with the assessment of the material reserves (RO2), this study attempts **(RO3): to develop a dynamic representation (conceptual model) of how building product reuse could evolve through time to support future implementation.** The context discussed in Sections 1.3 and 1.4 describes the lack of information about the practice of reuse reflected in the absence of clear policies and means to improve the actual practice and justifies the Research objective 3. By describing the system of building product reuse in the Netherlands, it is expected the visualization of different paths to improve waste prevention through reuse now and in the future.

§ 1.6 Thesis outline and detailed research questions

This section outlines the research structure including detailed research questions that address the Main Research Question as well as the Research Objectives discussed in Section 1.5. The primary object in this research is the waste prevention of building products through the reuse strategy. To answer the main research question, it is sensible to investigate and describe what activities define the process of reuse in place in the Netherlands focused on RQ1. RQ2 focuses on investigating how multiple factors related to these activities influence the flows of products commercially reused. Research question 1 and 2 aim to reach research objective 1. An introduction to the existent context of building product reuse in the Netherlands is proposed through an investigation of the supply chain and the forces influencing it, presented by research questions 1 and 2:

RQ1. What activities take place in the supply chain of reusing building products that characterize the practice in the Netherlands?

RQ2. How do different (technical, social and economic) factors influence the process of building products reuse (in the Netherlands)?

The second part of the research addresses the relationship between the existent supply chain and changes in the building stock, aiming to reach the research objectives 2 and 3, where the study of the material stock is an extension of the study of the supply chain. As previously mentioned, capacity planning and analysis of stock dynamics have been included in previous assessments to forecast or evaluate the performance of industrial systems concerning the availability of resources and demand for correspondent goods. The scope of capacity in this research focuses towards evaluating the ability of the reuse strategy to deviate materials from waste flows in relation to the existent reuse supply chain, given the conditions that characterize it found in RQ2.

To assess such capacity, it is necessary first to identify what can be deviated from waste streams through reuse, in other words, which products are reusable according to the existent market. Although not all types of products are currently reused, reusability is conjectured in this study as a varying condition. As technologies to recycle, the design of products, material properties, economic models vary in time and determine the recyclability of some products compared to others. Based on the findings in RQ1 and RQ2, different aspects determine what is reused (technical, social or economic factors), which will be described by research question 3:

RQ 3. Which products (and respective material types) are more prone to be reused in the current context in the Netherlands?

Finally, research question 4 focuses on analyzing changes in the building stock in the Netherlands as a source of potential products to be reused:

RQ4. How do trends in the housing stock affect reuse of building products (in the Netherlands)?

Assessments of dynamic building stocks related to recycling processes are often focused on materials with most mass or bulk materials as non- metallic minerals (Augiseau and Barles 2017), few exceptions included a description of building products (Fujita et al., 2008). Another characteristic in these previous studies is that the applications for secondary resources are pre-established as construction of embankments, roads (Hofstra et al., 2006; Hiete et al., 2010), new buildings and steel for automobiles production (Hu, 2010), with limited or no information about the industrial systems that process these secondary resources. In other words, previous studies focused on assessments of construction material flows and stocks often do not include detailed analysis of the industrial systems that treat or prevent these material streams.

Within the holistic approach, among the multiple forces influencing the reuse process, one of them is the time effect, positioning the description of the strategy of reuse under an evolutionary examination. Consequently, changes in the built stock (supply) of products are included as one of the influential forces in time. Under this framework, a conceptual model will be constructed from the findings derived from each research question with the goal to visualize critical relations to formalize policy recommendations and elaborate necessary adaptations from practitioners.

The following scheme (Figure 1.4) represents how the aim to construct a holistic view of the commercial reuse of building products in the Netherlands unfolds into the RQ1 and RQ2, which includes the multiple technical, social and economic factors influencing the reuse process. It is expected that the description of how the commercial system is shaped leads to understanding the present condition of such practice and to hint paths for future intervention. The forces influencing the operation of reuse also affects what is harvested for commercialization, and it is the focus of RQ3. In combination with the evolutionary examination, findings of RQ3 are the reference to analyze how the evolution of the housing stock as reserves to supply the present and future industry of reuse. Consequently, changes in the built stock (supply) of products are also an influential force in time focused on RQ4. The dynamic conditions that influence how and what is commercially reused (subsidies, consumer demand, competition among other factors), combined with the availability of reusable products in the building stock becomes the main line of the proposed holistic approach to answer the MRQ.

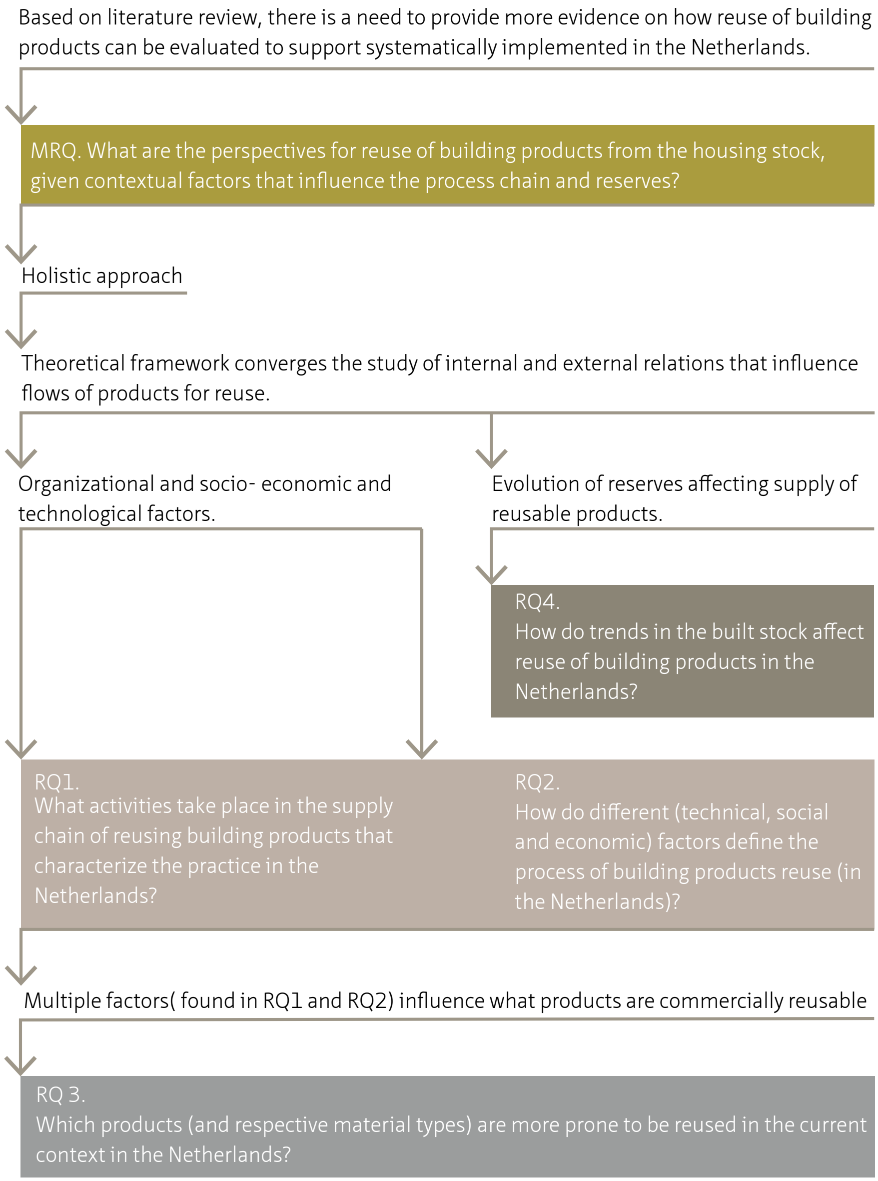


FIGURE 1.4 Systemic approach to construct the Main Research Question.

§ 1.7 Research relevance

To drive implementation of waste prevention strategies in member states, the European Commission suggested that knowledge should be created based on several aspects including "*the historic and expected future development of material and waste flows… potentials to efficiency improvements and ecologic/technological/economic/ social barriers which inhibit improvements on instruments to overcome these barriers and their effectiveness…*" Also, such knowledge should be developed together with stakeholders representing "*a broad range of opinions, concerns and interests and on the other hand, are willing to identify common ground and to contribute to waste prevention*" (Bio Intelligence et al., 2012, pg. 24).

Currently, there is a lack of information regarding how the technical, social and broader economic settings influence the commercial process of reuse in the Netherlands. Simultaneously, the Dutch government set a 50% reduction rate of use of primary resources by 2030, reflecting not only its physical geographic limitations but also within a global concern of increasing resource consumption (The Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, 2016). Such context raises questions regarding specific economic sectors as building construction, showing "*that a substantial amount of building materials are already being purchased at higher rates abroad*" (Mulder, 2008, pg. 2). Consequently, it is desirable to improve alternatives to increasing waste volumes, and consumption of primary resources.

According to Bohne et al. (2008), "*there is a need to discuss future waste management strategies, both in terms of growing waste volumes, stricter regulations ambitions, as well as a trend for higher competition and a need for professional and optimized operations within the C&D waste industry*." Although there is an unclear division between reuse as part of waste management and as part of resource management, there hasn't been an assessment of reuse that included the aspects discussed by Bohne. Therefore the current study approaches reuse both as substitution of primary resources but also being an integral mechanism that cannot be isolated from existent activities and stakeholders involved in building deconstruction and waste management.

National subsidies applied for waste treatment, for instance, biomass incineration with energy recovery is one example of relevant policy measure hampering more environmentally efficient treatments of biomass as cascade use of wood (Odegard et al., 2012; van der Veen, 2016). Through this context, more clarifying information is required regarding future investments where reuse is or could become a competitive alternative to waste treatment.

This study aims to construct a systemic view of reuse of building products for practice and policy to act upon. It is necessary to review objective information in the learning curve between concept and complexities within the implementation of waste prevention measures in the Netherlands, adding to today's existing specific focus analysis that often characterizes literature in reuse of products. According to Graedel and Allenby (2010, pg. 35), a waste-free concept is "*a good starting point, but…deciding when to be circular and when not to be is an analytical issue, not a conceptual one*."

Moreover, according to Kemp and Lente (2011), waste management transitions that occurred in the Netherlands did not radically alter product features regarding design for disassembly and re-use. "*The final waste goal was therefore not achieved because of opposition from product manufacturers and because consumers did not seek products with second-life components*." It is therefore relevant to consider if (or until) building technology does not improve towards deconstruction for reuse, what are the implications for waste prevention strategies in contrast to waste treatment.

A challenge for countries that achieved high levels of recycled waste, like in the Netherlands, is to improve the progress towards waste prevention. Whereas different studies investigate improvements in the design of new constructive systems and products to improve end of life, the housing stock alone in the Netherlands is represented by approximately 700.000.000 m² (de Wildt, 2012[42]) and it continues to grow with limited information regarding the material characterization of the building stock and service lifetime of buildings. Durable products such as buildings and infrastructure have a long lifespan, influencing the speed materials are released if ever released from the stock as in the case of some subsurface structures (Takinawa et al., 2008). For Müller (2006, pg. 142), "*stocks are becoming the most important resource providers, …are important drivers for resource and energy consumption as well as waste and emission generation, and …their magnitudes and dynamics are the parts of the material cycles that, is usually least understood*."

Brunner and Rechberger (2002, pg.1) described the practical importance of stocks examination:

42 Interview with Rob de Wildt (RIGO, Amsterdam), 2012.

- *"as an important reservoir of valuable resources,*
- *as accumulation of materials that awaits assessment in regard to its significance as a resource and as a threat to the environment;*
- *as a long-term source of severe pollutant flows to the environment*
- *as a challenge for future planners and engineers to design new urban systems.*
- *In the future, the location and amount of materials in city stocks should be known. Materials should be incorporated into the stock in a way which allows easy reuse and environmental control;*
- *as an economic challenge to maintain high growth rates, building up even larger stocks, and setting aside sufficient resources to maintain this stock properly over long periods of time.*
- *as a challenge to simulation modelers, who must deal with the complexities of the many processes contributing to urban metabolism, including the influence of long-term global, regional and local environmental, socioeconomic and cultural changes…"*

It is therefore relevant to understand the existing material stock as a reservoir of valuable resources and to avoid that such volume of materials integrates future waste flows. Until December 2015 there was not a "dedicated" national resource efficiency strategy or action plan in the Netherlands (Kazmierczyk et al., 2016, pg. 7), which could benefit with increase knowledge on waste prevention through reuse as a resource efficient strategy.

Finally, investigating the dynamic relation between material reserves (the building stock) and the mechanisms to prevent waste is relevant for both policy and practice, to foresee future capacity of waste prevention through reuse. It is within this context that a qualitative conceptual model is proposed as guidance, outlining critical relations within systematic view of waste prevention through reuse in the Netherlands. Finally, to answer the MRQ, the structure of this study is rooted in the examination of an existing industrial structure influenced by a network of factors that mobilizes materials to be reused and its possible continuity. Figure 1.5 represents the research structure and how each chapter is organized to respond the MRQ.

Sustainable resource management _ Resource consumption & Waste management
General context of Reuse as waste prevention
Literature review of Reuse of building products as a waste prevention strategy
Problems & Objectives
Research questions
Research structure
Research relevance

Chapter 1
Introduction

Theory background
Research classification
Reliability and validity

Chapter 2
Methodology

Description of the system's bounadries
and delimitation of the conceptual model

Chapter 3
Metabolic Analyzes Approach

Description of existing building product reuse operation in the Netherlands
Description of regulating network influencing reuse operation
Social factors
Economic factors and business models
Technological factors

Research Questions 1 & 2

Chapter 4
The Case of Reuse

Understading reusability of building products as consequence
of the social economic and technological factors

Research Questions 3

Chapter 5
Evaluating Reusability of Building Products

Housing stock dynamics and influence
Additional information of material flows

Research Question 4

Chapter 6
Building Products's Reserves in the Housing Stock in the Netherlands

Testing research approach and presentation of the conceptual model
Discussion & Conclusion

Main Research Question

Chapter 7
Evaluation and Conclusion

FIGURE 1.5 Research structure.

2 Methodology

§ 2.1 Theoretical background

This research aims to improve the understanding of building product reuse through a network of different relations that influence how building products are reused rather than wasted. This network is a representation of an industrial system that in this case describes multiple aspects that influence reuse of building products as a practice including how it relates to its environment or the material reserves.

This section discusses the theoretical background and concepts that enable to combine the critical relations in the system comprehensively, associating existing and new information to contextualize the practice of reuse building products and components in the Netherlands.

This research's Industrial Ecology (IE) based theoretical framework provides a system's perspective where both the industrial process is essential, as are the relations that go beyond the industrial boundary. Such relations concern internal and surrounding connections (Commoner, 1997), often focused on sources of perturbations in the natural system, which is driven by human activities that motivate changes in material and substance flows by demand for services provided by products (Lifset and Graedel, 2002, pg. 6).

IE offers a systemic approach to improve relations by looking into industrial systems in analogy to natural systems (Windsperger, 2009, pg. 294). The term "industrial" describes the theory component focusing on "*product design and manufacturing processes*," and "ecology" as it emulates ecosystem models of non-human nature (Liefset and Graedel, 2002). Such biological analogy extends to metabolic metaphor where input and output of materials and substances are exchanged between "living" organisms and the surrounding environment (Wolman, 1965; Ayres, 1994; Fischer-Kowalski, and Hüttler, 1999).

A balance in material consumption from natural resources and waste production have been important pillars in IE studies, which have included the concepts of carrying capacity (Hardin, 1991; Kirchner et al., 1985; Daly, 1986; Catton, 1986; Rees, 1996) and ecological resilience (Gunderson, 2000; Holling, 1973; Berkes and Folke, 1998; Folke et al., 2010) to assess how resource management from industrial systems affect natural ecosystems.

Modeling materials management such as resources and waste from biological non-human ecosystems can be applied in industrial organizations and extended to cities, regions, and countries. The difference between natural non-human and anthropogenic ecosystems is whereas in nature optimization of resources is a spontaneous process where waste becomes input to other systems in nutrient chains; in industrial organizations, optimization is more often motivated by policy or economic control (Windsperger, 2009).

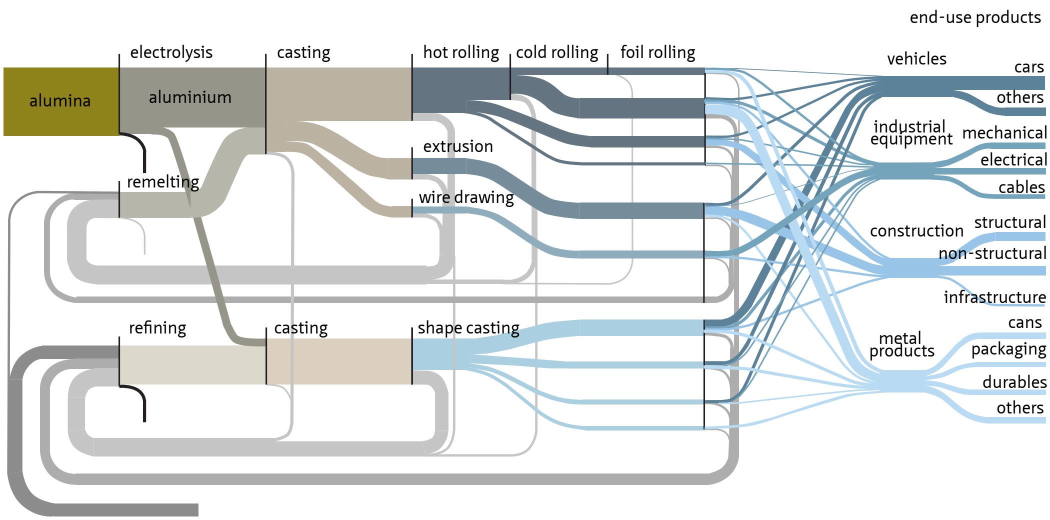


FIGURE 2.1 Sankey diagram of global aluminum flows in 2007 (adapted from Allwood et al., 2012, pg. 55)

The accounting phase provides the opportunity to assess the magnitude and speed of concentrations of materials and substances that are extracted from nature, and responsible for emissions, pollution, and waste. Interpretations generated from data analysis from metabolic models allow visualization of the processes of matter exchange between built and natural environment and their transformations or between industrial systems and resources transformation.

Material Flow Analysis (MFA) has been used to determine the mass balance of materials and their accumulation in the built environment as material stocks (Brunner 1999, 2004; Hashimoto et al. 2007). For Hashimoto et al. (2009), measuring mass flows of materials transferred from the environment to the stock also represents a reserve for wastes and secondary resources. Brunner and Rechberger (2002) reinforced the potential to illuminate material flows as a process to build waste management capacity. Figure 2.1 indicates final sinks of aluminum according to industrial application, which facilitates recovery planning for future treatment.

Material Flow Analysis (MFA) can be limited to the quantitative evaluation of the flows, but it is more often "*coupled with the analysis of energy, economy, urban planning, and the like*" (Brunner and Rechberger, 2004, pg. 3). For Baccini, Brunner, and Bader (in Brunner and Rechberger, 2004), one of the goals of MFA is to improve resource utilization and to control metabolic processes. More broadly, "*the term flow is used to identify and describe the exchanges of materials between and within activities, systems or subsystems. Flows are measured with reference to the accounting period*" (OECD, 2008, pg. 14[b]).

The quantification of material flows in IE studies, is usually assessed in combination with the actors that influence flows in a system, to generate a complete interpretation and to provide more consistent ways to control these flows. In other words, metabolic models developed in IE studies evaluate causes and consequences of inputs and outputs of energy, materials and substances, foreseeing future carrying capacity of natural reserves or management of waste "*that can be sustained indefinitely without impairing productivity of ecosystems*" (Windsperger, 2009, pg. 294). Understanding the operations of exchanges of substances and energy to maintain existing functions in a system as metabolic processes is a metaphor of transformations carried in living organisms by ingesting, storing and exhaling substances to permit growth and reproduction (Ayres, 1994, pg. 23). Urban metabolism emphasizes the description of such processes in cities or regions (Annex 2.1) while industrial metabolism emphasizes processes in industrial systems (Annex 2.2).

Lifset and Graedel (2002, pg.13) describe the focus of IE concept as a "*transformative change through the development and/or implementation of radically innovative technology, changes in consumption patterns, or new organizational arrangements*"; and how these changes connect to shifts in material flow or economic patterns and or "*new political–economic structures*".

The technologies involved in the transformations of natural resources into products (or secondary resources that replace primary ones), the ability to design products that facilitate end- of -life management and general evaluation of all possible impacts through its cradle- to grave cycle are factors that shape material flows. The concept of design of products can also extend to buildings (Müller, 2006; Fernández, 2007), cities and regions (Kennedy et al., 2011; Oswald and Baccini, 2003; Ferrão and Fernández, 2013).

Technical and physical characteristics of products and buildings shape material flows. However, social behavior translated into consumer patterns is another significant force shaping material flows. Understanding social behavior is an integral force in resource management as materials extracted from natural environment intent to provide services to humans (Lifset and Graedel, 2002, Müller, 2006; Fischer-Kowalski, and Haberl, 2007). Ayres and Kneese (1968) demonstrate that products carry materials and energy to provide service to humans and respond to consumer habits, as part of an economic system, and that these products will be accumulated in stocks and subsequently released as waste. Therefore the reduction of waste or residues is directly related to reductions of material input into the industrial system. For Fischer-Kowalski (2002, pg. 26), Ayres and Kneese's "*contribution became the starting point of a research tradition capable of portraying the material and energetic metabolism of advanced industrial economies*."

IE studies seek to understand relations of different factors in a multidisciplinary approach to anticipate ways to control material flows to reach a sustainable balance or sustainable resource management or sustainable resource management (Girardet, 1990; Allenby, 1999; Graedel and Allenby, 2010; Newman, 1999; Korhonen, 2004; Brunner and Rechberger, 2004; Huang et al., 2006; Fischer-Kowalski and Haberl, 2007). Douglas and Lawson (1998), suggest that the account of reused and recycled material flows should be an indicator to help evaluate sustainability in cities and countries.

"*Using the concept of socio-industrial metabolism thus allows for more comprehensive analysis ...Embracing such system-wide perspective thus provides a more profound insight into the material basis of economies and sets the groundwork for a more cause-oriented, more thoroughly based decision making process by the various actors*" (Bringezu and Bleischitcz, 2009, pg. 17).

The importance of a holistic approach when selecting factors that affect material flows is justified as a way to guarantee a level of independency (Ehrenfeld and Gertler, 1997) or flexibility while achieving and conserving "balance" among different dynamic systems.

There is, however, a poor level of standardization among metabolic models, indicators and how to support practical urban design decisions (Schremer et al., 2011; Song, et al., 2017), as there is not a single methodology to apply the concept of metabolic processes of the anthroposphere (Brunner and Recherberger, 2004). This condition allows flexibility on how to explore different aspects of concepts, tools, and approaches within the IE theory.

Finally, the IE framework connects concepts, tools, and approaches that emphasize the importance of closing material cycles or resource efficiency that is the primary goal of waste prevention through reuse. The next section exams how these concepts and tools are integrated into this study to answer the MRQ.

§ 2.2 Theory application and research classification

Literature review discussed in Section 1.4 indicated that several aspects influence the harvesting, processing, and consumption of used building products. To combine and visualize these aspects, two elements of the IE framework discussed above are relevant to the current study: the study of multidisciplinary relations that affect the metabolic process of the industrial system including technologies and social behavior, and the study of material stocks as a source of secondary resources.

Although the definition of “industry” is broad (Nightingale, 1978), systematic implementation of reuse as a measure requires a recognizable repetitive process, and for this reason, this study focuses on constructing an overview of the practice of building product reuse as an industrial system defined by activities in the supply and consumption process related to socioeconomic and technological aspects.

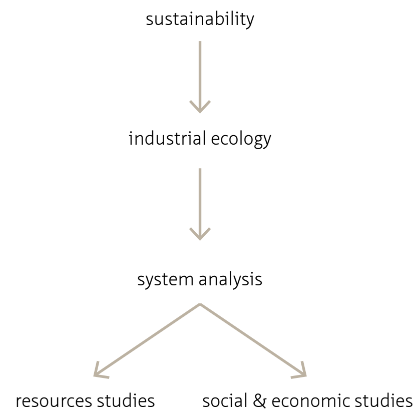


FIGURE 2.2 Industrial conceptualized in terms of its system-oriented and application-oriented elements (adapted from Lifset and Graedel in Ayres, Robert U., and Leslie Ayres, eds., 2002, pg. 11).

Lifset and Graedel (2002, pg. 11) proposed a scheme explaining "*the conceptual and theoretical aspects of industrial ecology*" (Figure 2.2) to indicate how IE studies include the analysis of human activities that generate control and affect material throughput (social, economic and technological aspects), and their impact on the accounting of materials and substances (resources). For Lifset and Graedel (2002, pg. 11)"…*the systems orientation is manifested in several different forms:*

- *use of* a *life cycle perspective,*
- *use of materials and energy flow analysis,*
- *use of systems modeling, and*
- *sympathy for multidisciplinary and interdisciplinary research and analysis*".

The following paragraphs discuss how to explore these forms with the goal to answer the MRQ. For Lifset and Graedel (2002, pg. 10), a system's perspective "*emphasizes unexpected outcomes*," but it also reveals vulnerabilities in the industrial system relevant to illuminate the context of the reuse industry discussed in Section 1.3. Based on this holistic approach, the technologies applied, the economic models, the context of consumer demand, and the supply of products to be reused are directly related to the performance of the industrial system, in this case, the industry of reuse. Section 1.4 described how some of these relations had been already identified in the existent reference literature, as well as the need for an analysis that could converge these findings in the Netherlands. From this perspective, this study investigates a system's view of building product reuse in the Netherlands manifested in a "*multidisciplinary and interdisciplinary research and analysis*."

The conceptual and theoretical aspects of industrial ecology represented in Figure 2.2, two elements are directly connected to the system analysis: resources studies and social and economic studies. (Diagram "A" in Figure 2.3). Diagram "B" is an adaption of "A" emphasizing the system's view through the critical relations that define it. The diagram centralizes the subject of study: the industry of reuse (practice) and clusters these relations into four categories: social, economic (here separated from "social & economic"), reserves (another name for "resources"), and adds technological as the transformative means (resources into products) affecting changes in the system discussed in Section 2.1.

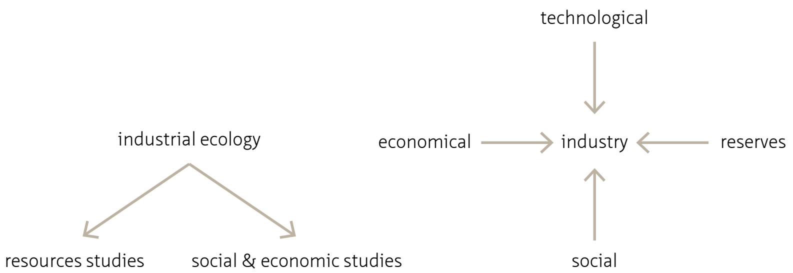


FIGURE 2.3 Holistic view of the relations affecting reuse of building materials (A left, B right).

As discussed in Chapter 1, there is not an overview of how the industry of building product reuse relates to material reserves in existing literature. Material reserves are in this case the study of the housing stock in the Netherlands. On the one hand, the social interface that defines demand for used products, as well as the economic and technological means influence the industrial system. On the other hand, materials accumulated and released from the housing stock influence the industrial metabolism regarding types, speed and amounts to harvest for reuse. Furthermore, contrary to natural reserves, socio-economic and technological aspects influence how building stocks expand through new constructions and releases materials through building withdraws; also technological aspects influence types and concentrations of materials relevant for material supply for reuse. The study of reserves, in this case, is a study of the housing stock, relevant for present and future development for the industry of reuse.

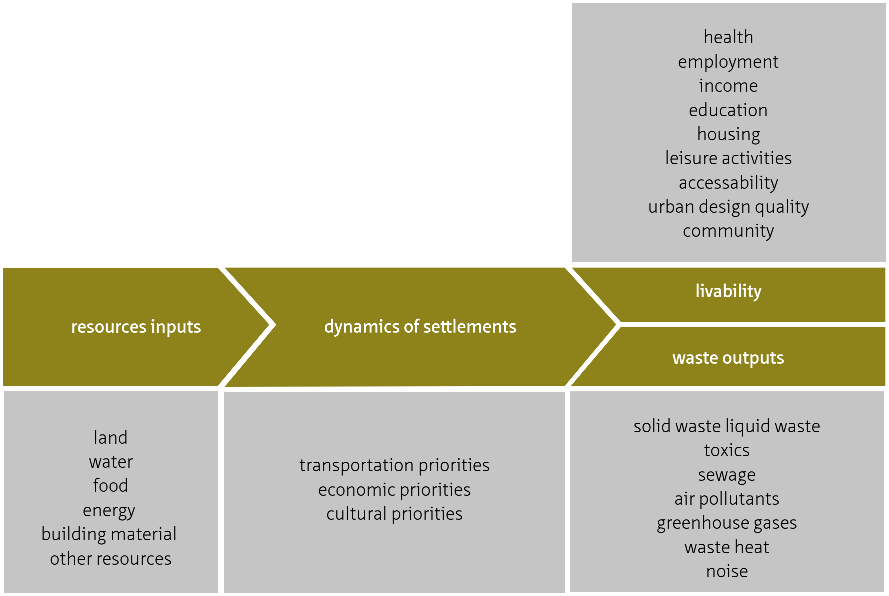


FIGURE 2.4 "*The extended metabolism model of human settlements*" (adapted from Newman, 1999, p. 220).

Different techniques have been proposed to understand the dynamics in secondary material reserves. For Müller (2006), some of the existing techniques to estimate input and output of materials do not include the complexities that affect material cycles. Some of these complexities are intrinsic to particular dynamics within the structure of the construction industry or are forces that act in the socio-economic context where the flows exist or by characteristics of the actual material or product (product lifespans).

Newman (1999) (Figure 2.4) proposed the "extended metabolism" frame combining the flow analysis with economic, environmental and sustainable indicators aiming that whereas flows reduce, livability and human health quality are maintained or even improved.

"*The metabolism approach to cities is a purely biological view, but cities are much more than a mechanism for processing resources and producing wastes, they are about creating human opportunity*" (Newman, 1999, pg. 222). The integration of the "human factor" with accounting models was a leap towards better understanding consumption trends and also an essential link to a better representation of reality. Beyond the mathematical analyses of flows and transformations of matter, according to Kennedy et al. (2007), the definition of metabolism in cities synthesizes the description of urban material metabolism placing the resident (human behavior) at the center of the activities or as a driver for consumption trends and consequently material transformation.

"The changing metabolism of cities" which updated the definition of urban metabolism to 'the sum total of the technical and socio-economical processes that occur in cities, resulting in growth, production of energy, and elimination of waste'. It introduces the essential component of integration of both technical as well as social perspective" (Kennedy at al., 2007, pg. 44).

For Song et al. (2017, pg. 12) whereas the quantitative nature of urban metabolism methods are appealing for sustainable design and planning, the more aggregated model forms (black and gray box) do not directly meet needs of urban designers towards more sustainable outcomes. From this perspective, the evolution from Input/ Output models to more qualitative analyses results from the combination of the accounts of material flows with changes in the stock being services, lifestyle (human behavior/ culture), technology or economy. The level of aggregation describing the dynamics in a system could also be interpreted as part of this evolution. In this context, the description of the stock and material consumption and discharge (input and output) relates through the perspective of causes (drivers), interpreted in this research as part of an evolutionary path within material focused metabolism studies.

Detecting and evaluating how these relations affect changes in flows and stocks can support decisions on what feedbacks to prioritize for desirable changes or improvements in the system itself, offering means to manage and "control" these same flows and their accumulation. By combining material accounting with social behavior through the selection of drivers, reinforces the role of social developments in the material metabolism (Fischer-Kowalski, 1998; Fischer-Kowalski and Weisz, 1999).

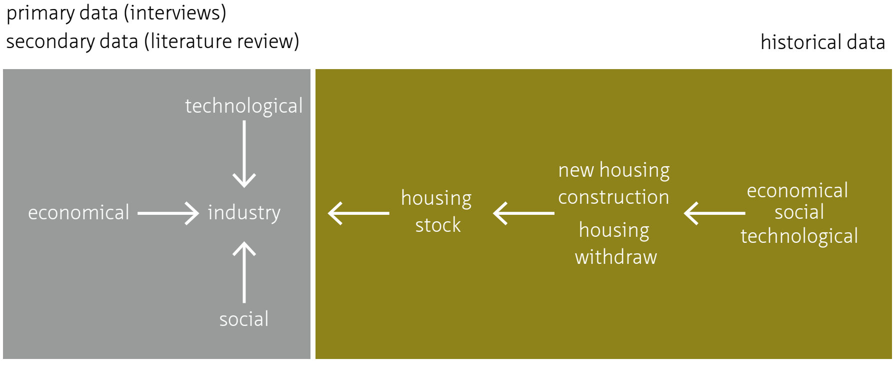


FIGURE 2.5 Data collection organized by categories adapted from the Industrial Ecology theoretical framework.

Moreover, departing from the IE theoretical framework, some adaptations have to be considered to develop a metabolic model for the industry of building product reuse, which will be influencing the research methodology. From the reserve or "supply" perspective (right hand side of the diagram in Figure 2.5), these adaptations will focus on studying patterns of flows and stocks that could lead to the understanding of the throughput of several products and components and the time intervals shaping these patterns based on new housing construction and demolition.

Figure 2.5 describes a structure of how information is gathered to achieve the research goals. This structure shows how the theoretical framework developed towards a composition of concepts that represents the system in focus, and how data collection departed from clustering information structured by the preconceived theoretical framework. From the industrial system's or "demand" perspective (left-hand side of the diagram in Figure 2.5), qualitative information derived from secondary data from previous studies and interviews with experts and stakeholders is applied to identify the relations influencing the industry of reuse. In other words, social-economic and technological aspects influence the housing stock dynamics that in turn affect the supply of reusable products, as well as define the commercial operation of reuse in the Netherlands and consequently the capacity to prevent waste.

Most studies found in literature focused on the analysis of construction material flows and stocks have different purpose and have used different methodologies to understand and account material flows. According to Augiseau and Barles (2016), common purposes in these studies are (combined of isolated):

- Studying urban metabolism
- Estimating the present stock
- Estimating the future stock
- Studying the stock evolution
- Estimating and locating flows
- Forecasting future output flows
- Forecasting and comparing future input and output flows
- Studying the influence of several factors on future flows

The main methodological aspects that distinguish previous studies to this current one are the limited or excluded description of the industrial processes to treat output flows, as well as a more detailed quantification and qualification of stocks and flows at the product level.

Studying the factors associated with the industrial process of reuse in this research is a way to identify ways that influence the demand ("pull"[43]) for used products, aiming to illuminate the paths that motivate the extraction of products from the building stock for reuse. Also, harvesting products for reuse are not only related to amounts of supply of reusable products, but to other criteria sensitive to a more thorough physical description of these products. To understand the methodology proposed in this study in reference to the previous methodologies mentioned above, the purposes are summarized as follow:

- Estimating the present stock (for reuse)
- Studying the stock evolution
- Studying the influence of several factors on stock (past new housing construction and withdraws)
- Studying the present industrial organization of reuse as well as factors influencing its commercial operation.

Another methodological distinction is that little is known regarding building obsolescence that leads to building withdraw and consequently the release of materials from the stock. Therefore, in place of focusing on a generic life expectancy of buildings associated with macro socio-economic indicators, this study investigates different information that could characterize the process of building obsolescence associated with a more detailed physical description of the stock.

The lack of information regarding the industry of reuse, the material composition of housing stock at the product level, housing survivability are challenges to consider in this study. This study combines information derived from previous quantitative models with qualitative information based on literature and interviews, where the combination of different data sources and their measurability lead to a qualitative analysis of real-world data based on statistical, literature information and knowledge provided by actors in the practice of reuse. Forrester (2003, pg. 333) noted, "... *little consideration of information flow in models but, in many situations, the information paths can be more important than the money flow*".

Ultimately, visualizing the relations influencing the industrial process is a mapping procedure, which is prioritized in this current research in place of the development of a mathematical model for long-term input and output of material flows. Nonetheless, the identification of relations has to be founded on data evidence. For the study

43 In reference to "Push and Pull " manufacturing (Mazahir et al., 2011).

of reserves, the identification of patterns is the result of historical data analysis of changes in the housing stock associated with a number of factors (socioeconomic and technological) including an investigation of the evolution of building typologies and correspondent physical characteristics. For the study of the industrial system, relations are the result of three qualitative methods generated including idiosyncrasies and comparison with the context of experts and stakeholders in the Netherlands: literature and document reviews, semi-structured interviews with practitioners and indirect stakeholders and observation from field research.

The representation of the relations found in the analysis evolves from the structure originated in Figure 2.3 and subsequently in Figure 2.5. The theoretical framework is used to contextualize the MRQ (Beck and Stolterman, 2016) and to organize the sum of relations evolving to a conceptual model for building product reuse in the Netherlands. The premise of this study emerged from the context given by existing studies made in the field of building product reuse, as seen in Section 1.4. However, with the appropriation of the theory of IE in this study, reuse has to be contextualized within the field of urban metabolism, resource efficiency and in parallel with other concepts of waste-to-resource.

The tools applied in IE studies are subject to discussion and adaptation in the research process as indicated before. Adaptations proposed from existent models are directly related to the research's objectives and to the nature of the subject itself (reuse of products). Points to be tested more specifically are:

1. The characterization of material throughput in the accounting phase that can best associate to the analysis of product reuse;
2. The study of a less generalized (compared to generalized life expectancy) end of life process for residential buildings;
3. The development of a conceptual model that represents the non-linear relations for building product reuse.

The theory is used as a methodological tool in the way it influences how data is collected as "heuristic device" (Jackson, 2005; Sovacool and Hess, 2017), organized, coded, adding rigor to the work (Beck and Stolterman, 2016), and it provides the basis for the research design. The research evolves from exploring what forces act on the decision to reuse building products (some of them already generated by previous studies) and related material reserves.

The mixed method approach proposed to build the conceptual model is not incommensurable, but it represents the different nature (units/ data) of the objects in study (Maxwell, 2011; Hesse-Biber and Johnson, 2015). It epitomizes the system's orientation manifested in a multidisciplinary research developed from the theoretical aspects integrated in the field of industrial ecology (Figure 2.2).

For Andriessen (2008, pg. 128), the world of human action and organizations differs from the world of nature, evoking Weick (1995) to direct that, "*the social world does not behave according to general laws*." Therefore, to study the practice of reuse combined with the material reserves, this research combines theory-driven concepts and mixed methods (Figure 2.6). The research design is constructed to describe specific elements to tackle the problem in focus: the lack of a holistic view of the practice of building product reuse in the Netherlands. Although the premise of the study establishes that socio-economic and technological factors, as well as changes in the reserves, influence the practice of reuse, the knowledge generated in this study is embedded on the implications of these factors upon the performance of the practice of building product reuse.

The study of the reuse strategy through its practice or phronesis (Eisner, 2002) demands the involvement of actors that embody different social realities, and different perspectives of the object in focus, and as consequence subjectivism become an inherent component in the research. The approach used in this study is based on finding evidence from the sum and comparison of these different perspectives from actors and knowledge previously developed in the field of building product reuse. This methodological pluralism (Eisner, 1993) evolves in parallel to the construction of a holistic visualization of the practice of reuse as represented by the IE concept, acknowledging that in the complexity of the real world context, many factors can determine how flows of materials are reused or not. The study of the material reserves, on the other hand, reviews existing elements proposed by previous IE studies (analysis of in-use stock, inflow and outflow of materials and lifetime) aiming to assess accumulation and discharge of materials in time. Because few of these previous studies have focused on reuse, some adaptations are considered and will be discussed in more detail in Chapter 3.

Despite the adjustments proposed in Figure 2.3 the results of the research do not intend to question the theory, but primarily to answer the main research question. As discussed in above, relevant concepts and tools offered by the IE framework are processing and carrying capacity; process chain perspective, complex system theory, life cycle perspective, material flow analysis, urban and industrial metabolism.

Whereas the IE theory offers the theoretical background for this study, it is possible that other means would also lead to a different answer to the MRQ. The theory of Sociotechnical Transitions (Geels, 2011) for instance or the Social Practice Theory offer a more complex structure to examine the social forces within a system compared to earlier IE studies that abbreviate the social component by indicators to later associate them with material flows balance, system's performance, and design. Although these approaches could lead to generating data with stronger evidence regarding the social interface, it is questionable if they would be a more suitable choice for this study. The study of metabolic processes within the IE is part of a body of knowledge associated to the ecology of construction that investigates the construction systems, the design of buildings and related products, as well as the services provided by them and how they are used. The choice for the theoretical background is a choice to contribute to an existing field. In this case, bringing the study of reuse under the light of the IE is an effort to open a discourse not only focused on the (internal) relations of this practice but also on setting an entire urban and rural system constituted of built structures in continuous transformation as an integral part.

The social forces in the design of different paths towards sustainable development have been subject of discussions among scholars (Ehrenfeld, 2008; United Nations 2015[44]), and found critical to reaching a balance between human habits and the natural environment. Similarly, as previously discussed, scholars have evoked better integration of social science within the urban metabolism framework (Newman, 1999; Kennedy et al., 2011). The research approach described above is predominantly qualitative, exercising the "*opening the black box*" process. Whereas According to Song et al., (2017), there is still a gap in the quantitative correlation with urban metabolism and sustainability factors. The aim, however, is not to establish an "*either-or*" discussion between quantitative or qualitative approaches, but on incrementing knowledge to the understanding of human behavior as actors in metabolic processes, which demands meaningful narratives with an explicit value (Kvale, 1996; Allen et al., 2001).

Moreover, qualitative research offers policymakers "*a theory of social action grounded on the experiences the world view of those likely to be affected by policy or thought to be part of the problem*" (Walker, 1985, pg.19), or assists practitioners to adapt current practices. Quantitative research is also included to identify patterns in the housing stock associated with socio-economic and technological aspects that will further relate to supply of reusable products and reinforces qualitative analysis.

For Graedel and Allenby (2010, pg. 35) while concepts in the IE theory are important, they also become more quantitative and rigorous as the field matures, which makes this qualitative overview an appropriate initial step to assess the practice of reuse towards visualizing attainable priorities and targets. The recent developments in top-down approaches by the European Community to implement a CE generated several questions

44 http://www.un.org/sustainabledevelopment/

among scholars regarding clarity on how to measure, to implement, and to define different aspects within the CE concept in the micro (product), meso (industry) or macro (city, region) levels (Kirchherr et al., 2017; Blomsma and Brennan, 2017; Bocken et al., 2017[ab]; Cullen, 2017). The results of this study, therefore, aim to support knowledge development of the practice of waste prevention through reuse, in the transitional phase to a circular economy and to generate feedback to the actual concept and practice of building product reuse as mentioned in Section 1.3. This research tracks the context of how implementation could be feasible and continuous from different dimensions. Finally the diagram bellow summarizes the research design introduced in this chapter.

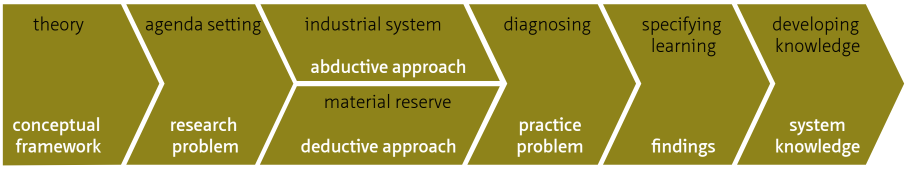


FIGURE 2.6 Knowledge stream (adapted from Andriessen, 2008).

§ 2.3 Reliability and validity

Reliability regards if research findings are dependable. Reliability is in this research assured by the research based design method presented in the previous sections. The subjectivism inherent to interview process and quantitative data derived from official organizations were iterated according to their sources. Not all information found during the research is published in this dissertation for confidentiality motives.

The study of the industrial system investigates key players and activities to construct a description of the supply chain of used products in the Netherlands that represents existent practice. In this process, the "*engaged scholarship*" pursues to have the perspective of a subject from different key stakeholders (Van De Ven, 2007).

The method to assess the industrial system is from the empirical domain. Primary data will be derived from observations and interviews conducted with different groups of stakeholders listed by type of organization and specialty (see Annex 2.3 and 2.4).

Although different types of organizations, specialists, and scholars directly or indirectly related to building product reuse and housing stocks were identified, the central role in the practice of reuse remains in the hands of demolition companies. The results of the study, however, are not focused on the interests of demolition companies, but it is focused on a broader audience and divergence in information collected from demolition companies, and other experts are relevant for verification purpose in this study.

An inventory of demolition companies related to reuse of building products was derived from VERAS (*Sloopaannemers/ Branchevereniging Breken en Sorteren*), the largest association of demolition companies in the Netherlands. An inventory of retailers of used building products companies derived from *Stichting Milieunet* _ the only website directory in the Netherlands listing the companies commercializing reused building products under a special category "*Kringloopnet*", and from specialized website (Marktplaats.nl) and broad internet search. The "*Kringloopnet*" has last been updated in 2009 (and ceased activities in 2010) by the time interviews were planned for this study.

Through a bottom-up approach, information provided by interviewees (Annex 2.4) is also compared to different data sources when available , including literature references some of them mentioned in Section 1.4. Literature review (Table 2.1) showed that the practice of reuse has changed through time, so it is expected that opinions during interviews may change compared to previous studies.

This process to crossing information from diverse sources is also a technique to enhance the validity of findings, as well as an approach to understand the subject through different dimensions. Different studies are used as reference to respond RQ 3 when building products studied in the references are comparable to products available in the Netherlands (e.g. ceramic bricks) and similar with housing constructive systems.

Whereas actors in demolition and deconstruction activities are defined groups, numerous niches can represent consumers. The end user group of used products were represented by designers specialized in building with used products, and experts in the retail of used products and academics. The collected information was based on interviews and secondary data. Surveys directly involving consumers and Internet trade platforms would require a more extensive time frame and should be included in future studies to improve knowledge in this segment, reflected in the existing limited literature regarding this subject.

Primary data are planned in the form of semi-structured interviews. Significant part of the content of the interviews centralizes on potentials and constraints that involve decision-making together based on past and currently available knowledge:

TABLE 2.1 Literature review by type and subject.

SUBJECT	TYPE	METHOD
Practice of the building product reuse (in the Netherlands)	Systematic Review [1] State-of-the-Art Review [2]	Scientific studies > the Netherlands> Abroad > General Scope> Specific Scope (socioeconomic and technological aspects) > Practice> Non-scientific studies (reports, guidelines, Internet search)
Metabolism of building materials	Methodological Review [3]	Scientific studies > the Netherlands > Abroad > Type of stock > Type of material
Housing stock	State-of-the-Art Review [2] Historical Review [4]	Scientific studies in the Netherlands > Entire stock > Types of housing stock
Reusable products	Systematic Review [1]	Scientific studies > the Netherlands> Abroad > Non-scientific studies (reports, guidelines, Internet search)

[1] Overview of existing evidence related to the research question: studies that applied pre-specified methods to identify and assess research topics and data analyze regarding these topics.
[2] Current matters and approaches.
[3] Investigation of different research approaches, data collection and analysis techniques.
[4] Historical review focused on examining evolution of the housing stock.

– Description of operational aspects of the practice of reuse of building materials such as typical process to harvest, logistics, types of materials and used products harvested for commercialization, harvesting processes, economic framework, regulatory participation, company's background, advantages in reusing, prognosis, new experiments, potentials and barriers in the current environment, critical aspects of commercialization of used products in the interface with consumers, technological means to reuse.

– Average amount, of materials and products recoverable for reuse according to housing type and construction year.

For the study of reserves, both qualitative and quantitative secondary data based on a bottom-up approach are used to understand housing survivability, the characterization of the housing stock, dynamics of housing stock size. Top-down approach was also applied to gather information for the trends in material consumption. Secondary data concerning housing demolition and construction in the Netherlands is provided by governmental agencies: CBS, ABF Research, Syswov, (previous) *Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer* (VROM), *Senternovem*, *Binnenlandse Zaken en*

Koninkrijksrelaties. Besides the CBS data based classification, other types of housing stock classification, as well as housing architectural plans and reference houses are also investigated. Some deductions are made to construct a characterization of housing type plans and yearly withdraw rates respective to each housing group.

For data of input and output flows at national level according to the economic sector, and subcategory "housing" a list of governmental and private sector is identified. Four types of data sources are classified by the knowledge focus described in Annex 2.5. For all groups, the focus of investigation regards trends in product and material consumption per year for the housing sector. For each material type, national governmental data is the first source of information and followed by European and national associations as well as private companies manufacturers of plastic, wood, steel, ceramics and concrete building products (see Annex 2.5).

The content of the interviews are divided into the following topics:

- Consumption trends in materials and products for the housing segment
- Physical characterization of the housing stock
- Withdraw housing accounting and motivations
- Main housings construction systems in the Netherlands
- Accounting system in the Netherlands at the product level
- Waste accounting system in the Netherlands

In summary, regarding the internal validity or credibility of results, based on the method of cross-checking data from multiple sources (O'Donoghue and Punch, 2003), described above, two types of triangulation (Denzin, 2017) are applied in this research: i) data source triangulation; ii) method triangulation. The external validity or transferability concerns the generalization of findings. The presentation of results is represented in the construction of the conceptual model, which generalizes the findings in this research, with the aim that the conceptual model can be further explored in different contexts and different levels of complexity. The IE theory as discussed in Chapter 1 is the derivation of what narrative will be developed regarding waste prevention through reuse. In Chapter 6, transferability and applicability will be discussed in the final conceptual model.

Chapter 1 displayed how literature review leads to the formulation of the main research question and research goals indicating that the study should develop a holistic view of the critical relations affecting the practice of building product reuse in the Netherlands. The theoretical framework set by the Industrial Ecology was then presented as a basis for the current study and adapted to the research design.

The combination of tools offered by the IE concept used in this study and described in the previous sections is visualized in Figure 2.7. The research evolves to build a conceptual model with the goal to visualize how different factors are involved in the decision process that defines how products are reused in practice in the Netherlands, from the factors influencing the practice of reuse to the supply of reusable products available in the building stock.

The diagram bellow evolves towards the representation of a composition of relations in the industrial system (more concentrated on the left part of the diagram), with the dynamic in the material reserves (concentrates on the right part of the diagram). The middle part reflects changes occurred in both extremes combined, defined by the amount, time and type of products harvested for reuse. To assess both industrial system and material reserves, existent tools will be adapted to the scope and nature of this study discussed in the following chapter.

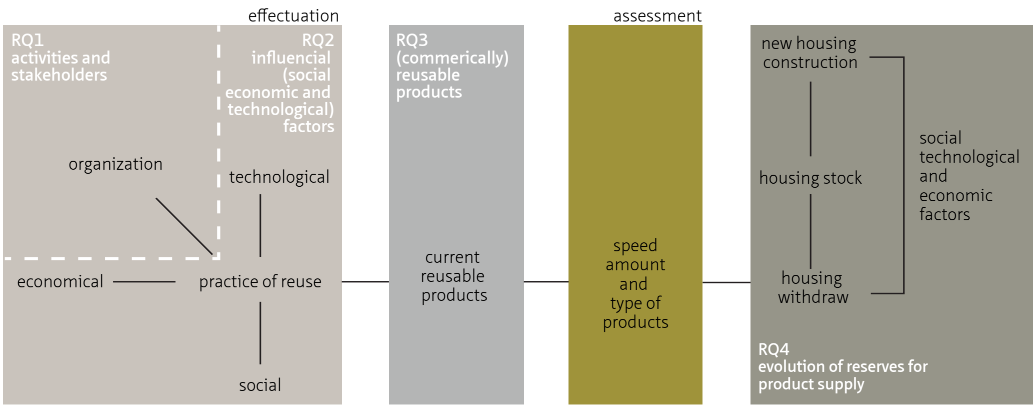


FIGURE 2.7 Structure if the assessment of the practice of building product reuse in the Netherlands.

3 Metabolic Analysis Approach

Based on the theoretical framework, two segments are proposed to answer the MRQ. The first one describes the social-economic and technological factors influencing the industrial system centered on commercial activities of building product reuse, in other words, it describes how and what products are commercially reused. For Patel (2010), understanding the commercial source of restrains in practice and the constraints in each step of the same chain is a critical aspect encouraging reuse. Ayres and Simonis (1994, pg. 3) described the economic system as a core "*the metabolic regulatory mechanism*," influenced by social, technical or even political forces.

RQ1 investigates how the supply chain of used products operates in the Netherlands identifying main activities and stakeholders involved. The result sets the background for RQ2 to identify and describe how economic, technological and social forces in place justify the commercial reuse of products in the absence of political support as mentioned in Section 1.3. Although the proposed approach does not directly include the study of policy instruments, the findings of the analysis could be the object to later communicate or test scenarios for specific policy stimuli. RQ3 investigates which products are commercially reusable in consequence of the economic, social and technological influences discussed in RQ2.

The second part of the research describes the dynamics within the building stock or the reserves of reusable products that could influence the supply for the reuse process. Changes in the building stock can affect the supply of reusable products in types and condition of products, amounts, and speed they are released from the stock. Consequently, to improve the visualization of relations affecting the waste prevention through reuse also relies on better understanding the changes in the building stock. The overview provided by this map of relations, and its analysis, aims to reveal possible paths for the industry to adapt to a dynamic context.

Section 2.5 discussed that the methodological aspects that distinguish previous studies to this current one are the description of the industrial processes to treat output flows and information (quantification and qualification) of stocks and flows at the product level. This chapter describes the system's boundary to study the present operation and multiple factors associated with the industrial process of reuse, to estimate the present stock (for reuse), and the stock evolution. It also describes the tools proposed to investigate each one of these elements according to the nature of the subject and data availability.

A mixture of attributes found in previous studies is adapted to assess the strategy of building products reuse to answer the MRQ. The system's description is organized as follow:

1. Spatial boundary,
2. Temporal boundary,
3. System activity,
4. Industrial operation,
5. Reserve trends.

§ 3.1 Spatial boundary

The literature review showed that metabolic studies could be extended from local to different geographic boundaries (Brunner and Rechberger, 2002; Moffatt and Kohler, 2008 Ferrão and Fernández, 2013). The geographic boundary for this study is national, the Netherlands, for both segments described above. For the first part, the characterization of the industrial practice is focused on interviews with local practitioners and experts. Available literature originated from the Netherlands and abroad is used for guidance and comparison when applicable.

For the material reserves, the focus is the housing stock in the Netherlands. Fischer-Kowalski and Hüttler (1999, pg. 113) noted that national level boundaries in urban metabolism studies have "*delivered the most productive approach in terms of conceptual development and empirical research*." For material flows accounting on a national scale is more largely publicized (Delahaye and Nooteboom, 2009), regional or municipal level accounting of building material flows are less consistent.

The country boundary is also unified by an economic, waste policy and building regulatory system. Ferrão and Fernández (2013), however, questioned if the national level disregards essential peculiarities in the urban system. On the one hand, waste management in the Netherlands has evolved towards "*scale increase, consolidations, vertical integration*" and a stronger influence from centralized national government policies (de De Bree, 2006, pg. 25). On the other hand, the national building code in the Netherlands, named *Bouwbesluit*, has been in force since 1992. It coordinates building construction regulations and harmonizes technical specifications to be followed by all municipalities. Additionally, the country is not affected by substantial climatic or geologic changes due to its size (when compared to other large countries as China, Russia, United States or Brazil).

The focus on city or regional level analyses (Schremmer et al., 2011; van Timmeren, 2006; Decker et al., 2000; Brunner et al., 1994; Quinn, 2008) is often more connected to evaluations of the city (region) itself rather than an activity or function or peculiarities of a particular location (Tanikawa and Hashimoto, 2009). Unlike other studies, this research does not evaluate the city form and its organization (Decker et al., 2000; van de Weghe and Kennedy, 2007; Kennedy et al., 2010; Quinn and Fernández, 2010). Nonetheless, in the Netherlands, there is a distinct population concentration in the *Randstad* region (West), where most of the metabolic activities are concentrated. In this context, to lower generalizations, the housing stock can be classified into subgroups according to regions in the country to identify different characteristics in the housing stock activities (new added and withdraws).

§ 3.2 Temporal boundary

For the study of the industrial system, the composition of information generated from interviews with specialists, academics, available literature, and past and present practitioners determine the characterization of the practice of reuse in place of a rigorous historical delimitation.

When studying material flows and stocks, there are four main methodological approaches regarding time: dynamic or static, retrospective or prospective (Müller et al., 2014) according to the goal of the study and the period of the data analyzed. Static models work with a time scale of one year. Modeling the behavior of material flows and their accumulation in stocks can be used to draft trends of consumption and waste patterns that support future scenarios (Hendriks et al., 2000; Kleijn et al., 2000; Müller et al., 2004; Bergsdal et al., 2007; Hu et al., 2010). In this perspective, results generated from dynamic material flows could benefit planning infrastructures related to waste management or foreseeing economic and environmental impacts from resource consumption. "*Long term simulation of the material life cycle of buildings... point to the so far largely neglected potential of reducing the life cycle material flows and surges in demolition wastes associated with the material dynamic of the built urban environment*" (Weisz et al., 2010, pg. 188).

Two variables can define time setting: either focused on a period where material flows are measured (Hashimoto et al., 2007; Warren-Rhodes and Koenig, 2001; Huang and Hsu, 2003) or by the description of the accumulated materials in stock (Müller, 2006; Sartori et al., 2008; Hu, 2010). Tanikawa and Hashimoto (2009) used 4d

GIS to analyze demolition patterns of buildings through the historic change in the urban stock.

The first one works with data of flows generated by periods of time, where long periods can give more consistent patterns in changes of material flows (Delahaye and Nootenboom, 2009) and their relationships with other entities within a system. The second uses estimations based on time spans in which materials are accumulated and then released from the stock. "*The historic input into use*" according to Müller (2006, pg. 143) is a determinant of waste flows and the lifetime materials (products) are kept in stock (Van der Voet et al., 2002; Müller, 2006; Hu, 2010).

Defining lifespan of buildings affects environmental and economic analyses (Klunder and van Nunen, 2003; van Nunen, 2010), and also defines material flows intervals (Müller, 2006) and trends of outflows of building materials (Müller, 2006). Lifespans of buildings were also associated with the technical end life of structural components (Hu, 2010; Sartori et al., 2008; Nunen, 2010).

Such estimations, however, can be challenging. Kohler and Hassler (2002) mentioned that estimations in Germany had reached an average lifespan of 50 years resulting in 2% demolition rate when in practice the demolition rate on average was 0,5%. Moreover, they disclose that motives for demolition are not only related to the age of buildings (Kohler and Hassler, 2002). Literature has been inconsistent regarding to defining the end of the lifespan of a house (Müller, 2006). Such inconsistencies vary from 50 (Hasselaar and van Battum, 2004; Itard, 2007), 65 (Hofstra, 2006), 90 (Müller, 2006), 120 (van Nunen, 2010) to 300 years (de Jonge, 2005). For Thomsen et al. (2011[b], pg. 327) "*the end-of-life phase of buildings has received little scientific attention so far, although its quantitative and qualitative significance is considerable*."

Frequently, the end of life of the structural component defines the time lifespan of buildings (van Nunen, 2010). However, it is challenging to define when the end life of structure leads to renovation or actual demolition. Moreover, lifespan of products has been related not only to their technical durability but also to several other factors that result in their discharge[45] (Vissering, 2011; Straub, 2012; 2004). Van Nunen (2012) explains how obsolescence of products evolved from technically to socially (functional and economical) driven. For him, the building occupant increasingly has

45 The last report published from SBR (2011) restricted the evaluation of life span of components in seven main points: i) Inherent performance level; ii) Indoor environment; iii) Outdoor environment; iv) Usage level; v) Design level; vi) Execution level; vii) Maintenance level.

more influence in determining the end of a product's lifespan than the product itself. Additionally, it is difficult to establish how much residual life each component may have at the time of an existing building's demolition, assuming some products have already been replaced through the course of time. Van Nunen (2010) concluded in his study that the reference service life of a component does not coincide with the actual period of use. In other words, materials are not only discharged due to the technical span of products but also through the demolition of houses.

TABLE 3.1 Life spans of building layers in years (Crowther, 2001, pg. 10).

LAYER				REFERENCE
Structure	Skin	Services	Space plan	
50	50	15	5-7	Duffy 1989
30-300 (typically 60)	20	7-15	3-30	Brand 1994
40	15	3	5-8	Cook 1972
25-125	25	5	5	Kikutake 1977
60-100	15-40	5-50	5-7	Curwell 1996
60 (assumed max. life of building)	20	7-15	3-5	Storey 1995
65	65	10-40	5	Howard 1994
50 (assumed max. life of building)	30-50	12-50	10	Adalberth 1997
40 (assumed max. life of building)	36	33	12	McCoubrie 1996
-	15-30	7-30	-	Suzuki 1998
40 (for brick veneer house)	12-30	30-40	8-40	Tucker 1990

Crowther, in his *Theory of Layers*, proposes grouping products into systems that have an approximately similar life expectancy, and compared several studies already showing the complexities in specifying life span of building components. Table 3.1 shows how significant these time spans vary. Defining the age of building products in current stock and future cycles that are gradually removed to waste streams requires estimations that would add complexity to the model while the accuracy of the results could vary significantly. For example, estimating wood waste based on the age of singular products, such as wooden floors from houses with a specific typology and construction year, does not guarantee that the original floor has not been previously removed during a renovation or maintenance works.

Ultimately, interval flows of materials can be determined by the lifespan of houses or by estimating the age of products. In this study, the lifespan of buildings will be studied by a combination of yearly historical demolition rates (retrospective) analyzed in different housing groups classified by their construction year and by their physical description, location, demographic changes (bottom-up approach). By investigating how other dynamics (drivers or factors) influence trends in housing withdraws, the approach focuses on the output of products that are not only determined by the lifespan of building structure, which includes products released from stock before reaching the end of their technical life (more information in Section 3.5). In other words, historical housing withdraw data that includes more information about houses demolished also help to illuminate reasons to withdraw and consequently to understand the phenomenon of obsolescence. Measuring housing withdraws guarantee that all product content from the housing unit are released from the stock. Estimations of material outflow through renovations or estimations of life span of products are not included in this research.

It is relevant to mention that it is not assumed that historical trends will remain constant in the future. It is assumed that some consumption trends can be estimated through the combination of historical input flows and housing stock evolution. The estimation of a long-term forecast is not a goal in this research. A retrospective analysis of the building stock after 1900 is compared to the study of flows. However, it is expected that data availability will not match the same time frame (from 1900). In Chapter 6, a static estimation is proposed for a smaller sample of the housing stock to assess the amount of recoverable materials for reuse in one year based on past consumption trends.

§ 3.3 System activity

Brunner and Rechberger (2002) call activity the chain designed to support demand created by trend factors:

"*An activity is defined as a set of processes and fluxes of goods, materials, energy and information serving an essential basic human purpose, such as to nourish, clean, reside, or communicate. Hence, the concept of activities allows one to evaluate the design and management of entire material flows and stock systems with the objective of meeting certain goals such as sustainability*" (Brunner and Rechberger, 2002, pg. 9).

The activity in a system is a transformative development (either natural or human) that changes matter into a different grade (OECD, 2008). In this study, the industrial system includes the processes between the harvest of products from the housing stock to their commercialization. It is at this point unclear which activities take place during this process, including key stakeholders and technical processes involved (see more details in Section 3.4).

For the analysis of supply or reserves, the activities in focus are new housing construction and housing withdraws. Both activities are related to material metabolism trough demand for new housing construction and building obsolescence. The combination of the study of trends in the housing stock and the industrial system both associated with socio-economic and technological variables is proposed in this research approach to identify possible potential and barriers in the future of waste prevention.

A challenge to the study material flows both input and output associated with system's activity is data available that addresses consumption for new housing construction and waste from housing withdraws. Available historical data often aggregate mass of material from different sectors and activities. Section 3.5 discusses the proposed approach to study material flow trends.

Housing renovation is an activity of great importance in mature urban concentrations in northern Europe, such as in the Netherlands, (Hasselaar and van Battum, 2004; Klunder, 2005; Meijer and Thomsen, 2006; Donkelaar, 2007; Sartori et al., 2008; Thomsen and van der Flier, 2009; van Nunen, 2010) regarding the volume of buildings renovated compared to new construction (Itard et al., 2008) as well as the volume of commissions for demolition companies[46] (Table 3.2). However, little information is available regarding time lapses between renovations (Roders, Straub, Itard[47]), types of buildings, types of products and motives of renovation regarding the entire housing stock in the Netherlands. Consequently, renovations could alter the market for building material consumption, which has already affected manufacturers of insulation and roofing[48]. Housing renovation is a phenomenon that deserves particular attention in further research to cover the necessary level of complexity.

Besides renovation, another waste generating activity is construction. Bossink and Brouwers (1996, pg. 57) indicated that the "a*verage amount of the purchased construction materials that ends up as construction waste is 9% (by weight)*", from which 80% accounted to stony products (concrete, stone tablets, roof tiles, mortar, etc.). In other words, an estimated 9% of materials used to construct new buildings in one year are added to total demolition waste in the same year. Though the C&D waste is the material flow type in focus, waste originated from construction activities will not be estimated separately from demolition in this study. Moreover, results from Bossink and Brouwers (1996) study were based on experiments made in 1994 and could be considered outdated.

46 Interview with Hans Oranje (from Oranje b.v.).

47 Email Martin Roders (OTB); Ad Starub (OTB), Laure Itard (OTB).

48 Isobouw phone interview January 2013.

TABLE 3.2 Breakdown of "core" C&D

MILLION TONS	RESIDENTIAL	NON RESIDENTIAL	CIVIL ENGINEERING	TOTAL
Construction	650	975	425	2050
Renovation	1825	425	3025	5275
Demolition	975	4425	1175	6575
TOTAL 1999	3450	5825	4625	13900
TOTAL 1993*	3475	7125	7400	18000

Calculated by PRC Bouwcentrum (Symonds et al., 2000)
** Bouwnijverheid, 1999 SBI 93: 45 in http://www.rivm.nl)*

§ 3.4 Industrial operation

Based on literature review discussed in Section 1.4, two main aspects define the research structure: the investigation of the building product reuse process in the Netherlands that includes a description of the operability of extracting products during building deconstruction and intermediary steps before consumption. The second aspect is the visualization and understanding of critical interactions affecting each step in the process of reuse as indicated by the theoretical framework. These two aspects combined structure the investigation of the industrial system.

Identifying the industrial organization (typical supply chain)

The term *supply chain* is used to describe different processes to convert resources into consumable products[49]. Although it is often associated with the transformation of raw materials into goods (Beamon, 1998) in industrial systems (services or manufacturing related), it has also been used to describe processes to convert secondary resources into goods (Geyer et al., 2007; Hemström et al., 2012; Georgiadis and Athanasiou, 2013).

The description of the supply chain, types of practices of building product reuse and key players involved has been proposed by Geyer and Jackson (2004), Fujita et al. (2008) and Hemström et al. (2012). The representation of the supply chain in previous studies

49 *"The sequence of processes involved in the production and distribution of a commodity"* _ https://en.oxforddictionaries.com/definition/supply_chain

was used as a backbone to assess one or more aspects of building product reuse, or it was as a result of physical experiments. Nonetheless, the description of a supply chain identifies a repetition of a typical process from which one can detect constraints, potentials and possible ways to improve it.

The methods and goals that generated the representation of such supply chains also differ in these studies. Hemström et al. (2012) used interaction of actors involved in the supply chain through interviews and workshops while Geyer and Jackson (2004), Fujita et al., (2008) based on supply loop framework and cyclic reuse flows. There is detailed literature dedicated to the study of closed-loop supply chain and reverse logistics (Govindan et al., 2015) for different consumer products. However, because of the limited information available describing the practice of building product reuse in the Netherlands, an assessment of the existent context is relevant. The description of the supply chain of used building products in the existent literature differ in four main aspects:

- Description of an existent supply chain to assess one or more aspects of building product reuse, identifying potentials and barriers (Hemström et al., 2012);
- Description of a supply chain as a result of feasibility experiments (Dorsthorst and Kowalczyk, 2001; Asam, C. 2007);
- Design of an improved supply chain (Fujita et al., 2008);
- Supply chain specific to a pre-determined type of product (Geyer and Jackson 2004) or a generic supply chain (Hemström et al., 2012);
- Description of a closed or open supply chain (Geyer and Jackson 2004; Hemström et al., 2012).

The investigation will focus on identifying key actors and processes involved similar to Hemström et al. (2012), by using interviews with specialists and stakeholders in the practice of C&D waste management and practitioners in the harvesting and commercialization of used building products. It is unknown at this point which products are commercially harvested for reuse, therefore; the description of the supply chain should be generic rather than specific to a type of component. Rather than describing a supply chain associated with a product type, the investigation will lead to represent a typical structure of the processes involved in harvesting used building products for commercialization in the Netherlands.

Moreover, the type and structure of the supply chain is related to the type of product, materials, to its service life, and processes related to them to be reused (Guide and Van Wassenhove, 2002) (Figure 3.1). To specify the type of chain, reverse logistics or closed/ open supply loop chain, more information regarding the final application of the used product should be available.

When confronting the definitions of reuse as described in Section 1.3, it is not known yet how the commercial practice defines products reuse according to the final application[50]. Another unknown aspect regards the point of product return (or if there is a return point), which is relevant to define the chain type.

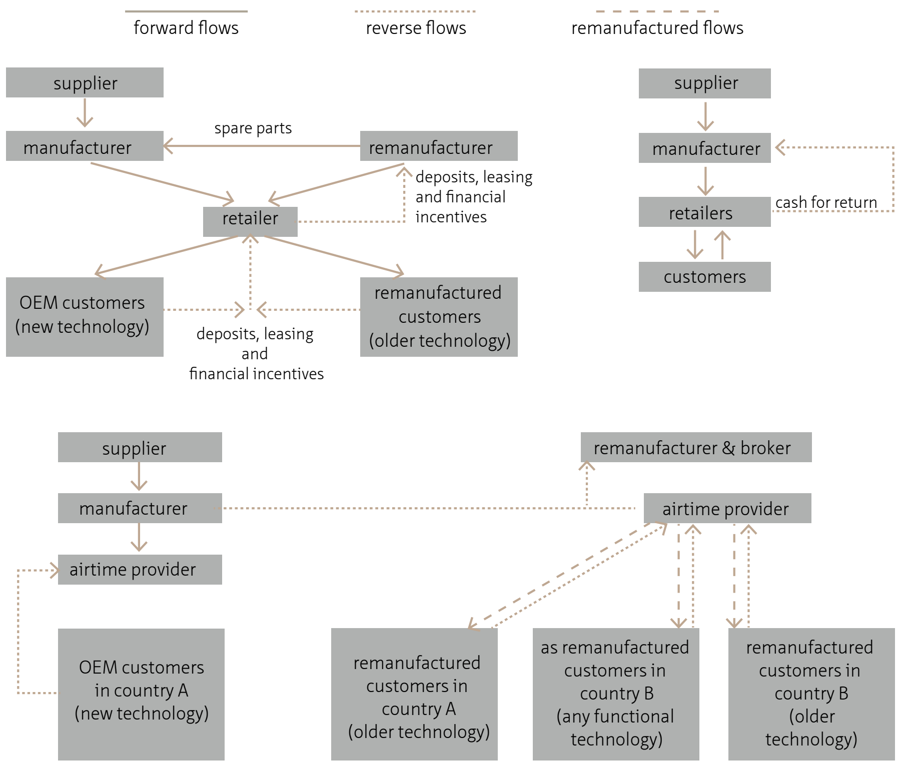


FIGURE 3.1 Different supply loop chain structures according to different products (Guide and Van Wassenhove, "Closed-Loop Supply Chains," in Ayres, Robert U., and Leslie Ayres, eds. 2002, pg. 499, 501 and 503).

In summary, although the term supply chain is applicable in the current study, specificities related to the type of product that affects the chain structure will be generalized when representing a "typical" chain for building product reuse in the

50 *"...supply loop is called "closed" or a "closedloop supply chain" if the supply chain that receives the secondary resources produces goods of the original product type, and it is called "open" if the goods are different, sometimes also referred to as "cascaded use"* (Geyer and Jackson, 2004, pg. 56).

Netherlands. The priority is to identify characteristics in the chain that can affect the capacity to reuse, where the chain is a part of a larger scheme within the system.

Identifying socio- economic and technological relations influencing the practice of reuse

As discussed in Section 2.2, different methods are used to track flows of information, capital, and materials. Identifying the typical structure of the supply chain and actors involved sets the basis to understand the decision-making process to reuse products.

The representation of a supply chain is possible through maps that vary according to the purpose of the representation itself. For Gardner and Cooper (2003), a supply chain map is a representation of connections, related members within the chain and information about the nature of the map. For the scope of this study, the understanding of connections between parts involved in the chain is combined with the description of socioeconomic and technological relations affecting the industrial metabolism, following the theoretical structure.

Ultimately, by identifying such relations, different paths to improve, adapt or implement effective policies can be visualized in this system. The process to identify the multi relations that affect the practice of reuse should simplify the complexity of the real world to generate a comprehensible description.

Based on literature review discussed in Section 1.4, different studies assessed either one or a combination of forces that characterize and affect the performance of the supply chain of product reuse. Political (Patel, 2010), technical (te Dorsthorst and Kowalczyk; 2001; Asam, 2007), economic (Patel, 2010; Geyer and Jackson 2004), or factors more specifically related to the consumer interface (Fujita et al., 2008, Hemström et al., 2012) were identified to be crucial elements in the metabolic process of building product reuse.

The methods used in these investigations vary. Physical experiments based on study cases like te Dorsthorst and Kowalczyk, (2001) and Asam (2007) described economic and technical implications in all steps from building deconstruction to the final application. Hobbs and Hurley (2001), Pu et al., (2006) and Hemström et al., (2012) used interviews and literature to create an overview, identifying patterns that characterize practice and formulate recommendations to improve optimization of building material recovery for reuse.

To identify general and specific factors that affect and condition the commercial practice of reuse in the Netherlands, information derived from literature review is applied as guidance and verification of the results from interviews with practitioners and experts in building product reuse.

Identifying (commercial) reusable products

Previous studies (Hobbs and Hurley, 2001; Lazarus, 2005; Addis, 2012; Bioregional, 2007, 2008[a]; Quinn, 2010) have developed inventories of several building products based on the evaluation of "reusability" through different criteria. These inventories will be compared to assessments focused more specifically on individual products that evaluated reusability through one or more criteria (Patel, 2010; Fujita et al., 2008, Geyer et al., 2007; Gorgolewski, 2006). For example, studies that assessed reusability of steel structure components have produced detailed information in one or more aspects of the reuse process (economic, technical, barriers and potentials). This information will be compared with data generated from interviews with local practitioners in the commercialization of used building products in the Netherlands, with the goal to create a similar inventory of products classified by material type as established by waste accounting references (CBS, Eurostat, *Rijkswaterstaat*) to facilitate comparison with aggregated data of material flows. Products that have been purchased but not used in buildings, or "dead stocks" from manufacturers or retailers, will be excluded from the study.

By understanding how products are defined as commercially reusable through the influences of the relations associated with the supply chain, it is anticipated that 'reusability" is a condition that changes according to dynamics in the industrial system and to material content in the building stock.

According to Hiete et al., (2010), matching C&D waste supply and demand is poorly addressed in the literature. Existing references often predetermine the final application and estimated demand of specific waste flows such as metal scraps and stony fraction debris as new roads, embankments (Hofstra et al., 2006), secondary aggregate (Heiete et al., 2010), automobile industries (Hu, 2010) with limited or no analysis of correspondent internal industrial processes. Understanding what is commercially reused offers a way to visualize vulnerabilities of the practice that response to multiple dynamics at the same time.

Finally, the performance of the industrial chain as proposed by the research approach is sensitive to developments in both the industrial system as well as in the building stock, which is influenced by multiple (social, economic, technological and policy related) factors. Assessing material reserves is essential in upstream industries as it is for waste treatment and the industry of reuse. The evolution of the industrial processes as well as the reserves is reflected on what products are harvested for commercialization is the focus of RQ3, displayed on the central part of the diagram in Figure 2.7.

§ 3.5 Reserve trends

Stocks of secondary materials are dynamic, and fluctuations can occur in size (new buildings added or withdrawn), by type of materials and techniques applied in new constructions, and yet by the speed they are released from the stock according to the survivability of buildings (excluding renovations, dissipative losses).

The accounting method requires a combination of different data sets, determined by the goal of the study (de Haes et al., 1997). Different approaches have been used to study the accumulation and release of materials from anthropogenic stocks, more often to understand their environmental and economic aspects or to forecast long-term capacity to respond to the demand of resources and final sinks for materials released. The assessment of anthropogenic materials depends on accounting systems to evaluate local carrying capacity and plan adequate treatment (Hashimoto et al., 2009). Assessing material trends in the built stock for recovery of secondary resources is relevant for planning strategies for continuity or adaptation of the industrial processes associated to manage future material outflows. It also assists policy change (in this case, towards systematic implementation of a waste prevention strategy). It helps to rationalize "*investments in order to benefit from economies of scale and capacity readiness, or a strategy of low volume but more frequent capacity expansions*" as suggested by Georgiadis and Athanasiou (2013, pg. 56).

Heiete et al., (2010) used optimization model to plan a C&D waste recycling integrated network at regional level based on supply and demand chains to support best economic and environmental options, and to help policy intervention to allocate future sinks for C&D waste based on population trends. The model considers physical accounts of C&D waste and existent demand based on recycling rates.

Hofstra et al., (2006) combined different methods to formulate scenarios for C&D stone based granulate in the Netherlands according to data availability including historical data, plan[51], improved engineering[52] and relationship modeling[53]. For the housing sector, where consistent information (new construction and withdraws) is available, extrapolation based on historical data was their final option.

51 Plan _ relies on planning of new construction and demolition volumes to include in the historic data.

52 Improved _ based on estimation of life span of building entities.

53 Relationship _ based on replacement rates, released amount of waste results from demolition and renovation expressed as a percentage relative to the new building.

Modeling material stocks and flows is a frequent method to assess past, present and future material reserves (Müller et al., 2014). The accounting of materials and substances in metabolic models were applied to analyze economic performance related to selected activities (Leontief, 1967; Fung and Kennedy, 2005; Delahaye[54]), to detect possible symbiotic relationships in a system (Ehrenfeld and Chertow, 2002 Houseknecht et al., 2006; Houseknecht et al., 2006; van Timmeren, 2006; Quinn, 2008) and to identify vulnerabilities in it (Brunner and Rechberger, 2004; Müller, 2006; Hu, 2010).

Augiseau and Barles (2017) classified six frequent quantitative approaches to study construction material flows and stocks applied in previous studies:

- Static bottom-up flow analysis;
- Static top-down flow analysis;
- Bottom-up stock analysis;
- Dynamic retrospective or prospective flow analysis using a flow-driven model (input flows);
- Dynamic retrospective or prospective flow analysis using a stock-driven model;
- Top-down retrospective or prospective stock analysis using a flow-driven model.

According to Hu (2010) stock dynamics driven models (Müller, 2006; Yang, 2006; Bergsdal et al., 2007; Sartori et al., 2008; Yang and Kohler; 2008) is the most suitable for long residence-time goods as buildings, and "*reflects better the understanding that consumption behavior of people is "stock oriented*", (Hu, 2010, pg. 11) compared to flow driven models (Kohler and Hassler, 2002; Bergsdal et al., 2007; Bohne et al., 2008; Hashimoto et al., 2007).

These methods have been used isolated or combined according to the time frame in focus, data availability and most importantly the purpose of the study. Previous studies of flows and stocks of construction materials were more often concentrated on: "*forecasting and comparing future input and output flows, studying the influence of several parameters on future flows, estimating the present or future stock as well as its evolution, studying urban metabolism and analyzing the interaction between flows and stock*" (Augiseau and Barles, 2017, pg. 153).

The research approach proposed adapts some aspects of previous quantitative models mentioned above according to the investigation purpose:

54 Interview with Delahaye (CBS). The Dutch government has invested in new research projects to assess the status of economic performance related to specific material flows in the country.

A Characterization of stock and flows at the product level _ there is not a clear description of the housing stock classified by physical aspects and material composition (compared to efforts focused on the description of energy performance of buildings). Based on literature and interviews with experts, the study of building stocks in this research includes a description of the current housing stock in the Netherlands and historical information of the development of constructive methods and products more commonly found in the Netherlands[55]. Therefore, different studies (Oosterhoff, 1990; Verhoeks et al., 1995; Thijssen, 1999; Straub, 2001; *Novem* 2001; van Battum, 2002; *Senternovem*, 2007; Bot, 2009, *Agentschap Nl*, 2011c; Blaazer and van Gessel, 2011; Noy and Maessen, 2011; de Lange, 2011) that produced segmented descriptions of the housing stock in the Netherlands are combined to construct a characterization of the stock that enables a possible understanding of product composition.

The methodology focuses on clustering the housing stock into different groups based on physical characteristics to facilitate the understanding of product composition. For instance, how the physical characterization of multi-family buildings differ from single-family constructions, and how they vary through time. To study the evolution of the housing stock, the characteristics and sizes of these housing groups are compared based on historical data. By segmenting the housing stock and increasing the number of samples, it is also expected as a result (of a more detailed description) a better understanding of the survivability of houses as discussed in Section 2.2.

Besides the study of the stock evolution, to analyze consumption trends of building products, with the aim to evaluate trends in the housing stock composition, it would be relevant to assess amounts of products consumed and discharged by and from the housing sector. However, the challenges for accounting at product level are various, mainly related to data availability.

At the product level, several materials can come together combined into one product, which increases complexity and uncertainty in the study. Products can come from other parts of the world in different forms either as raw materials, semi-finished or finished products. Other products are within the national boundary only for the transformation phase and then exported (Bringezu and Bleischwitz, 2009), and do not represent consumption trends within a specific geographic boundary.

55 Different sources will be included as investigation of housing constructive methods as described in Chapter 2; energy performance reports of reference houses in the Netherlands, interviews with demolition companies and historic data.

Despite recent discussions (Fischer-Kowalski et al., 2011) focusing on more efficient and more transparent data, detailed accounting information is a challenge in MFA studies.

Accounting of flows can be classified by macro-level MFA, meso-level MFA and micro-level MFA as described in the OECD report in 2008. The macro level is focused on national accountings such as Direct Input flows. The meso-level is oriented around branches of production as NAMEA type of tables (also done for the Netherlands), while micro-level is more concerned with SFA at a local level. Substance assessment is too specific for this research and therefore excluded. For the Netherlands, MFA data of the economy-wide material flow records all materials entering or leaving the economy (Delahaye and Nootenboom, 2009). The challenge at this level of aggregation is to find accurate primary data to visualize the composition of material consumption by economic sector in focus (Delahaye and Nootenboom, 2009; OECD 2008).

Physical accounting of products[56] would be a more suitable option (than national MFA accounting) as an equivalent to the structural demand (Hoekstra, 2010) of the construction industry. Physical flow accounting has been promoted as a valuable tool to estimate environmental and economic relations to material consumption and discharge (Pedersen and Haan, 2006; Hinterberger et al., 2003; Daigo et al., 2007). However, "*no systematic data gathering on the material composition of products takes place in the EU, and available studies mostly focus on specification of flows at a higher level of aggregation*" (Tukker et al., 2006, pg.33). Physical supply and use tables (PSUT) can be used at the industry and product level (OECD, 2008; Schmidt, 2014), and it could be valuable sources of information for this research.

"*PSUTs are constructed in a determined accounting period, usually one year, and for a given geographical area, typically a country. …The supply table shows the flows relating to the production and supply of natural inputs, products or residuals by different economic units or the environment. The use table shows the flows relating to the consumption and use of natural inputs, products and residuals by different economic units or the environment*" (Schmidt et al., 2014, pg. 5 and 12). In this study, the use table from available PSUTs in the Netherlands will be considered as reference for consumption of products by the construction sector.

56 Product classification as identified by Central Product Classification, CPC or as defined by Standard Industrial Classification (SBI).

For the input and output flows, a lower level of aggregated information ideally would include economic (or industrial sector), application and component description. Therefore, different sources of information will be included as described by Baccini and Brunner (1991)[57].

Different information is combined to verify trends in material related to types of product and consumption activity or sector (DMC, PSTUs, NAMEA and PIOTs, consultancies, manufacturers associations of building products in Europe and the Netherlands). Comparison between historical data of material consumption aggregated by industrial type (e.g. cement residential construction) to yearly new houses added is a proxy to estimate consumption trend of materials accumulated in the housing stock. National statistical data is used as a reference to minimize misleading estimations (de Bruyn et al., 2005). Similarly, the yearly input material flows[58] will be used to reinforce which material types are being added to the stock and associated with the list of products derived in RQ 3.

Because of the challenges in identifying input of products in the housing stock, the material flows assessment in this study has an auxiliary role as a verification of material accumulation trend in the stock rather than a central element in the qualitative approach.

Similarly, regarding output flows, there is no official accounting of reused building products in the Netherlands, which is excluded from resource management monitoring and past activities of flows of materials prevented from integrating waste stream (through reuse). Finally, the approach proposed to study consumption trends helps to indicate the status of transparency of resource monitoring and is used as a support for the study of stocks.

B Estimation of capacity of reuse _ information generated from the investigation of the industrial system that determines what is commercially reusable is compared with the study of the housing stock. The recoverable amount of products commercially reusable is compared to the amount of products released from housing withdraws based on

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57 “*Data acquisition – Developed by measurements, market research, expert judgment, best estimates, interviews and hands-on knowledge/ measurement of flows of goods and substances (through market research, expert judgment, best estimates, interviews and hands-on knowledge)*” (Holmes and Pincetl, 2012 pg. 8).

58 Transformation of materials used for manufacture will be excluded from input analysis due to the fact that some will later be exported. In this category, other flows of materials not generated from construction and demolition, such as waste produced by manufacture of construction products, will not be taken into account. Indirect flows or hidden flows are excluded in this study.

historic data of distinct clusters of houses. In this way, different scenarios are produced for amounts of reusable products within one year. The aim is to visualize what could potentially be harvest for reuse in the existing stock (supply)and with the existing industrial structure (demand).

c Study of parameters (factors) that influence changes in the evolution of the housing stock _ Different factors are proposed to study the evolution of the housing stock and estimate possible changes (in size, speed and composition of the stock) that could affect supply of products for reuse. Activities (withdraws and newly added houses) in the stock when associated with changes in socio-economic, cultural entities can help to identify patterns in the material metabolism (Müller, 2006; Yang and Kohler 2008). These factors can, directly and indirectly, influence building material consumption, accumulation and discharge ultimately affecting the practice of reuse now and in the future. For Hu (2010, pg.122) "*annual stock quantities can be linked to annual demand for building service provided to the population, which in turn depends upon socio-economic and demographic parameters*." Therefore historical data of the physical evolution of the housing stock combined with socio-economic drivers is also a way to describe new trends and obsolescence phenomena in buildings.

A system's approach, therefore, includes processes that influence material accumulation and release from stock through the combination of the metabolic drivers. When trying to identify these processes, however, a limited amount of factors can be included in analytical models. Section 3.5.1 discusses the selection process to identify what drivers facilitate the visualization of trends in product accumulation and discharge from the housing stock.

Finally, the methodological approach is predominantly qualitative aiming to identify what are the conditions and relations involved in the supply of reusable products concerning the industrial processes of reuse. It uses both quantitative and qualitative data, and it combines the study of the housing stock evolution through a retrospective approach using top-down stock analysis by dividing the stock into categories; the study of factors influencing changes in the housing stock (new added houses and housing withdraws); and historical data of consumption trends of materials and products compared to yearly new housing construction. The study investigates more than two housing typologies, and although it groups products in material types, it investigates more than two types of materials and more than two types of products according to the inventory of products commercially harvested for reuse.

Temporal dimension in this study does not prioritize long-term forecasting material output but emphasizes the survivability aspect of buildings associated with their physical description (constructive methods, typology, housing size), which is not only related to the aging process of their technical lifespan, but to other qualities that lead to their obsolescence and final withdraw. The study of building obsolescence is compared to consumption trends of products, materials and new yearly-added houses.

§ 3.5.1 Stock influencing factors

Different variables were combined to estimate changes in material flows (Figure 3.2). In this study they are called "factors" and it is assumed that they can influence changes in the housing stock evolution. Although this study includes a limited number of factors for the analysis, in the real world, changes in the housing stock is a phenomenon that integrates several relationships. Van de Weghe and Kennedy (2007) specified different factors to describe the metabolism of GHG (greenhouse gas) emissions related to transportation activities in cities: GDP, oil price, human health, design of cars, city zoning, design of the transport network, and the way users commute through the city as a behavior pattern. The study revealed that by prioritizing the amount of travel the average commuter does in a year would further reduce total emissions compared to the implementation of lighter vehicles. In this context, dynamic models can be affected by socio-economic or technological changes as the factors for the material flows (Müller et al., 2004). For Fernández Ferrão and Fernández (2013, pg. 32), "*…economic, social, and demographic attributes of society such as population, age composition, and household size*" are considered typical to identify driving forces that influence dynamics in a system.

It is desirable for this study to understand trends in the stock that could affect the supply of reusable products to learn how the industrial system is fit to a changing environment (housing stock, consumer trends) with the goal to generate insights or paths that could improve the performance of the practice of reuse.

As discussed in the previous Section, the methodology proposed in the study of trends in material reserves compares yearly changes in the housing stock with a number of factors. It is relevant to understand what are the most appropriate relations to include in the system. The system boundaries and factors should be appropriate for the study (Keys, 1990). As reference, table 3.3 shows different factors used to study influence on dynamic construction material flows.

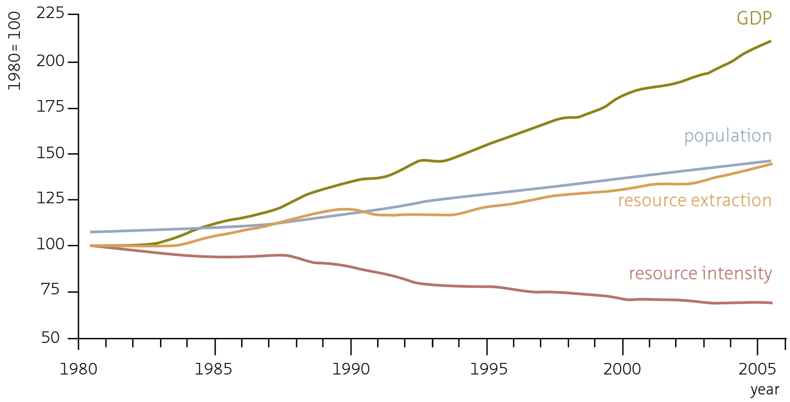

FIGURE 3.2 Relative de-coupling of economic growth from resource use, 1980 to 2005 (Giljum et al., 2010, pg.17) Relative de-coupling of economic growth from resource use, 1980 to 2005 (Giljum et al., 2010, pg.17).

TABLE 3.3 Factors selected by referent studies

REFERENCE	FACTORS
Dominic Stead et al SUME, (2007-2011)	Building level: Materials use for construction Construction year (period) Building function Building typology (multi/single high-rise) Usable floor space per building Floor space index Residual lifetime
Müller, 2006	Household size Average floor area of housing units Population size Useful floor area per capita
Sartori et al., 2008	Material and energy (intensity/ m2), Population and density (persons/dwelling), Dwelling size (m2/ dwelling) Life span of buildings or building's subsystem
Fishman et al., 2015	Population size Dwellings' lifetime
Hu, 2010	Population Per capita floor area Lifetime Material density Gross Domestic Product
Deilmann, C., 2009	Urban fabric typology

Besides the references, other studies in the Netherlands (Hasselaar and Van Battum, 2004; Hofstra et al., 2006; van Nunen, 2010; Thomsen et al., 2004, 2007; Thomsen and van der Flier, 2009) discussed different motives influencing changes in the housing stock. Hasselaar and Van Battum summarize some of them below, (2004, pg. 19) regarding decisions that lead to demolition in the housing stock in Netherlands:

- *"Homes remain in use long in general (average more than 75 years);*
- *Rented houses are more likely to be demolished compared to owner-occupied housing;*
- *Multifamily is relatively more likely to be demolished and in particular the social rented sector;*
- *For each period there are specific reasons that will conclude in demolition or maintenance. Nonetheless, structural issues related to foundations and wood flooring together with insufficient thermal or acoustic insulation, moisture problems also lead to higher demolition rates compared to other technical matters;*
- *The main factors that affect the lifespan of a house are, the structural quality, the size of the home and identity. Accessibility is now an important residential technical criterion"*.

Ultimately, the study of a system is a simplification of reality (Forrester, 2007). It represents simplified relations from a fragment of the real world. As such, a limited number of factors are selected to associate developments in the housing stock relevant to material supply for reuse. For simplification, proposed factors to be tested in this study is a combination of:

1. Existent references in the literature of construction material metabolism;
2. Factors that indicated to influence more specifically housing withdraws and new construction; and
3. Qualities that could be more closed related to physical description of materials and product metabolism in the housing stock.

Despite the non-linear behavior of relations in the real world, the proposed approach does not investigate indirect relations between factors and their level of predominance on housing withdraws and newly added constructions. Such assessment can be developed in future studies based on the information disclosed in this present study. The list below identifies the drives included in the present assessment that will be explained in more detail in Chapter 5.

Tenancy

Tenancy is a relevant classification used to monitor the housing stock in the Netherlands (CBS, ABF Research, Syswov, *Landschap Nl*) and it is also associated with physical characteristics.

Persons per house
Number of persons per house will be assessed separately from housing size[59].

Housing size
Housing size will be analyzed separately from persons per house and population growth.

Population growth
Population growth will be measured by number of inhabitants per year and compared with new housing construction and demolition rates.

Building typology
This factor is relevant to for the description of the housing stock evolution. Information on how buildings are designed and constructed is subject to analysis of material flows (Fernández, 2007). The consumption of building materials is related to the construction of new buildings (or renovations) and how these buildings are physically characterized by their typology and construction methods. Building typology and construction year are related to specific physical characteristics in the buildings and different types of material intensity. According to Hasselaar and Van Battum (2004), building typology also affects building survivability. The classifications of building typology in the Netherlands differ according to different sources researched in this study including single- or multi-family buildings or by a more specific group of characteristics as townhouses, detached, semi-detached.

Construction year
The use of reference buildings (Hu, 2010) and their classification by construction year (Hofstra et al., 2006) has been proposed in previous studies. Besides estimating the lifespan of buildings (temporal outline), construction year represents the age of buildings associated with construction methods and regulations (see Annex 3.1 and 3.2) also influencing the type of product and material intensity (Hofstra et al., 2006). The challenge, however, is the changes in material composition due to renovation cycles. Construction year, as well as Building typology is a relevant factor that physically characterizes buildings but can also be studied to study the phenomena of obsolescence.

59 Service surface per capita was used by Müller, 2006.

Gross Domestic Product and GDP per capita

The relationship between economic development and other factors such as health, well-being (Heun et al., 2015), and environmental pressures are largely accepted (Haberl et al., 2004; Voet et al., 2005; Delahaye, 2004; Bringezu, 2006; Hu, 2010). The European Commission suggested, "*resource consumption and waste streams are related to the gross domestic product (GDP) or related to the actual physical construction activity measured in net area*" (Bakas et al., 2011, pg. 53). Hu (2010) found strong relation between GDP per capita and per capita floor area as well as GDP and developments in the housing stock in her metabolism model in China.
It is not clear if GDP alone can be identified as a relevant factor for activities in the housing stock. Large-scale construction, renovation and demolition are also related to government plans for decayed areas or other large urban projects, which are triggered by economic and/or political incentives (Hofstra et al., 2006). Moreover, mortgage plans are another side of the economic mechanism that can profoundly change the housing market regarding availability and demand and household mobility, consumer power, etc. (Itard et al., 2008; *Nederlandse Vereniging van Banken*, 2014). Although relevant, these aspects could be studied included in future researches.

Location

Some studies described material related metabolism of specific regions (Tanikawa and Hashimoto, 2009; Huang and Hsu, 2003; Schremmer et al., 2011); or countries (Müller, 2006; Hashimoto et al., 2009), or rural and urban areas Hu (2010). The study of the practice of reuse is delimited by the national boundary, but more specifically the assessment of activities in the housing stock is studied separately in the four regions of the Netherlands (North, East, West, South according to ABF Research and CBS[60]).

§ 3.6 Representation of results

The focus on improving or systematically implementing reuse of building products, demands (as in other industrial systems) an understanding of continuity within a dynamic process and the integration of several stages to be repeated within it. "*Mapping sources, processes, and transformations, and sinks in a region, offer a systematic basis for public and corporate action*" (Johansson, 2002, pg. 74).

60 North region: Groningen, Friesland and Drenthe. South region: Zeeland, Noord Braband and Limburg. East region: Overijssel and Gelderland. West region: Flevoland, North Holland, Utrecht and South Holland.

The development of a map of relations, therefore, represents how multiple factors interact in the system, and based on this representation, future strategies could be designed to improve the central part of the diagram proposed in Figure 2.7.

During this research, studies focused on metabolism models advanced towards creating more comprehensive structures for analyses of complex system dynamics to facilitate standardization, comparison, and forecasting. Gathering data to generate quantitative models for further evaluation is a significant challenge when conducting such experiments as discussed in Section 3.6. The approach proposed in this study combines quantitative and qualitative data to understand the system's behavior. This combination responds to the purpose of this study, which concerns the visualization of ways leading to commercial reuse of building products in the Netherlands. The system's behavior is controlled by decisions that are quantitatively evident, and also by choices related to the social realm, for instance, political decisions, marketing, and public perception. Prioritizing a quantitative analysis of flows and stocks would fail the purpose of this research. The interpretations generated from data analysis allow visualization of the processes of matter exchange between built stock and the industrial system to process them, combined with factors that influence this exchange.

Within this framework, the approach proposed in this study aims to improve the existing knowledge of relations within both subsystems (industrial and reserves) that includes the limited current information in the field of product reuse in the Netherlands and accounting of building product in the housing stock. The multi-disciplinary relations identified in the research process are then visualized through the proposed approach provided by the IE concept and adapted into the evolved structure in Figure 2.7 and clustered according to specific distinct themes.

According to Gardner and Cooper (2003, pg. 39) for supply chain management, "a *map is needed to catalog and distribute key information for survival in a dynamic environment. A good map can alert planners to possible constraints in the system*." For them, monitoring the map and the relations in it is a way to direct management focus to link corporate chain strategy; to distribute information in a dynamic environment; to identify necessary integration process, to establish a common visualization of efforts that can lead to an improved supply chain management, among other reasons.

Similarly Georgiadis et al. (2005, pg. 351) discussed the "*need for holistic modeling efforts that capture the extended supply chain*..." to support decision makers to improve efficiency and profitability. Later Georgiadis and Besiou (2008) described how dynamic models based on System Dynamics (SD) methodology is a powerful tool to understand problems in a dynamic process and policy organization.

System Dynamics (SD) is a tool applied in IE studies and it evolved from systems thinking (Forrester, 2007). It makes use of models to visualize and communicate system's structures and understands behaviors that occur in such system (Forrester, 1961; Senge and Forrester, 1980; Sterman, 2000). SD models are a type of maps that support the understanding of the system in focus, communicate the findings and discover paths to improve the system's performance (Albin, 1997). In System Dynamics, the diagram is a representation or the written database that according to Luna- Reyes and Andersen (2003) can be considered as a qualitative branch of system dynamics. The relevant aspect in these references for this study is the proposal of an instrument to identify changes and relations in the system in focus as proposed by the IE theoretical framework.

In system thinking, behaviors are the result of interactions between different entities in the system. The non-linear sequence of events and relations are essential in the dynamics of complex systems. According to Forrester (2003, pg. 331), diagrams describe "*sequences of events progressing in time and not mathematical models for describing a static set of relationships*." Such relations, as mentioned previously, offer means for understanding, managing and controlling the system's performance.

In SD, the identification of such relations is a relevant part of the process that in statistic terms builds confidence for future models (Senge and Forrester, 1980; Richardson, 1986; Radzicki and Tauheed, 2009). Several studies (Forrester, 1968; Randers, 1980; Richardson, 1986; Luna-Reyes and Andersen, 2003; Wolstenholme, 1990; Wolstenholme, 1999; Coyle, 2000; Sterman, 2002) focused on the validity of how these models are structured, questioning the balance between quantitative and qualitative data. Gordon (1960) suggested that some of these relations can be guessed and inaccurate from the reduction of qualitative data to a quantitative form, but the lack of precision should not affect the value of the study. Increase integration between the two types of data followed the diffusion of SD to diverse fields of application, "*... as both a rigorous tool to develop scientific knowledge and a practical tool to improve the performance of organizations*" (Lane and Sterman, 2011, pg. 374). In essence, these debates resonate on the concern to determine the system's behavior that depends on data availability and quality of data and the tools applied to assess them and the level of uncertainty.

The current research is based on a qualitative process that according to Ritchie and Spencer (2002, pg. 309) includes "*mapping the range, nature, and dynamics of phenomena. It categorizes different types of attitudes, behaviors, and motivations*." It finds associations between attitudes and behaviors and seeks an explanation. The patterns within the system are identified by the collection, repetition as well as idiosyncrasies found in the data collected and compared to other available sources.

The description of relations in the industrial system (the left side of the diagram in Figure 2.7 is centered in the stakeholders involved in the commercial process of product reuse and information from existing literature. For the study of the material reserves (the right side of the diagram), the relations influencing housing withdraws and new constructions are more challenging than to identify because of the nature of the object (national housing stock). When interviewing stakeholders in the industrial subsystem, it is feasible to question what are the economic, technological and social reasons that influence or determine that products A, B and not C be harvested for reuse rather than treated as waste. To study the dynamics of the housing stock, however, there is limited available information on the motives of housing demolition, or new added houses. There is disconnected information about different characterizations of the housing stock or specific groups of houses within it, in reports and other documents depicted in different time frames. These can be linked to construct an evolution of the stock and associated with factors that could be related to changes occurred in the housing stock. However, these relations do not necessarily determine causal relations, which would require a robust quantitative model to determine the casualty. Also, quantitative models are bind to work with the uncertainties that changes in the system are being caused by a combination of variables not included in the model in study.

The conceptual model aims to visualize trends identified in the study of reserves that could affect the supply of reusable products. Different scenarios could also be tracked with this information questioning the capacity of the industry to adapt in time. The description of the operations within the industrial system also allows understanding what to prioritize and the connective between actions. In this context, the approach used for the representation of results in this research is a simplified form to disclose a dynamic behavior of a system that relates the evolution of the built stock with the industrial operation to process it.

The overview proposed in this study is a qualitative analysis based on factual information represented in its own terms. The conceptual model is constructed by relations determined through reduction process of the data analysis discussed earlier in this section including both numeric and “soft” unmeasured information. Within the predetermined system’s boundary, information derived from existing literature and interviews are clustered in themes using a deductive approach to content analysis. The interviews are made through grounded analysis that reinforce or contradict previous findings, as well as generate additional information in the study using an inductive approach.

According to Sterman (2002, pg. 521) “*focusing on the process of modeling rather than on the results of any particular model speeds learning and leads to better models, better policies, and a greater chance of implementation and system improvement.*“…"*system* *dynamics is essentially a learning tool and the 'process' of modeling is often seen as more important than the model itself*" (Forrester, 1985 in Featherston and Doolan, 2012, pg. 5).

Moreover, SD models are composed of sequences (or loops) of causes and influences (Sterman, 2002)."*Behaviorally, linear systems cannot exhibit locally unstable behavior and global stability, cannot exhibit bifurcations, endogenous shifts in their modes of behavior, and cannot evolve*" (Lane and Sterman, 2011, pg. 373). Due to the scope of the study, the conceptual model represented in Figure 2.7 is not a conventional dynamic model constructed with loops and polarities, but it should be considered a dynamic map of relations that derive from explanations of how events happen in the real world through the tools described in the previous sections.

Richardson (1986, pg. 164) discussed the problem to define polarities, "*because behavior depends upon rates and levels, unspecified in causal-loop diagrams, universally applicable definitions in terms of behavior appear to be most difficult to invent*". The conceptual model in this research does not include polarization in the representation of relations because it does not focus only on measurable rates. It instead prioritizes the type of influence (economic, social or technological) according to what are the desired changes to be in the system. However, although the polarizations are not represented, the model should describe situations that can change in time, affecting the practice of reuse evaluated by the central part of the model. The condition of relations should be noticeable in the final result for the user to identify the implications of the trends and plan strategies for change[61].

It is expected that the conceptual model not only facilitates understanding of relevant relations in the system, but also it can be a basis for more specific models including quantitative studies in a future stage. In this context, the model is complete as it responds to the MRQ, but it is incomplete because more information can subsequently improve it. It is, in essence, a qualitative way to visualize the significant entities structuring the practice of reuse.

61 An economic factor "X" affects what is reused and the amount of products reused.

4 The Case of Reuse

The goal of this chapter is to answer Research Questions 1 and 2, by investigating the industrial system of building product reuse in the Netherlands delimited by the description of the organization and socio-economic and technological factors influencing how products are reused. The chapter includes the study of activities in the process, key players involved, and the investigation of characteristics of the supply chain; setting the background to investigate the relations defining the commercial practice of building product reuse in the Netherlands.

§ 4.1 Organization of the supply chain of used building products in the Netherlands

RQ1. What activities take place in the supply chain of reusing building products that characterize the practice in the Netherlands?

The investigation methods applied to answer RQ1 were direct and telephone interviews, on-line commerce research, site visits, and literature review.

The investigation methods applied to answer RQ1 were based on primary data collected during interviews and existing literature. The research began by using the current businesses practices, as the reference to describe the process of harvesting and commercialization of used products. The reason to choose the market converges specific forces to make reuse feasible from product availability to demand of such products.

Whereas Ayres and Simonis (1994, pg.3) described the economic system as "*the metabolic regulatory mechanism*," influenced by social, technical or political forces; the knowledge on commercial restraints of reusing is limited in the existent literature. As a consequence, companies interviewed were directly related to the retail sector of product reusing.

Retrieving products to be reused in the same building or "*on-site-reuse*" (Addis, 2012) is not included in the current analysis because it is often restricted to a construction site with little or no commercial activity involved. It also varies according to specific characteristics of each building and each renovation/ construction case, being, therefore, challenging to establish a clear comparison among different cases (Addis, 2012; Ogbu, 2010; Gorgolewski 2008, Jäger, 2010).

Between 2008 and 2013 it was estimated that around 100 small companies practiced harvest and commercialization of used building products in the Netherlands[62]. Although there is not a precise harmonization of types of practices or business models, this investigation focuses on describing common characteristics in the field.

The sector of building product reuse does not have a specialized platform unifying active companies. This fragmentation contrasts with the evolution of the Dutch waste industry that "*include(s) scale increase, consolidations, vertical integration, the formation of multi-utilities and the entrance of a few European waste companies*" (De Bree, 2006, pg. 25; Kemp, 2006). In other words, whereas independent companies operate reuse of building products, mainstream waste management industry has evolved towards the large-scale inclusion of several specialized segments within material flow management such as collecting, transporting, sorting, and recycling, among other activities. Such integration facilitates lobbying for incentives as well as access to investments connected directly to manufacturers (e.g., recycling technology of steel, concrete, gypsum).

According to Bakas et al. (2011), mainstream waste management primarily promoted recycling while limiting the life extension of products through reuse as a stage in material management, consolidating towards a network focused on the high volume of material treatment opposed to reusing, disregarding the environmental and economic benefits of the later one.

Currently, in the Netherlands, there are two primary mechanisms to harvest reusable building products. The first one is operated by demolition companies, that extract products from buildings and sell them when physical storage capacity is available in their facilities. Some of the demolition companies in the Netherlands harvest used products to trade as a side activity from their core demolition business. The other mechanism combines demolition companies that contract secondary companies (or building *strippers*) to harvest products to be reused. These companies are often specialized in the commercialization of used products. Part of the agreement between companies is a negotiable fee paid by the stripper company to the demolition

62 Interview with Erik van Erne (*Stichtingmilieunet*)

company[63]. In this way, strippers are dependable[64] on demolition companies for commissions and need to operate under networks where demolition or renovation tenders take place. One relevant aspect is that commonly; companies that harvest products from the built stock operate the processing (transportation, recondition when necessary) and commercialization of these products. The chain, therefore, is concentrated in activities executed by few major players.

Regarding processes involved between harvesting to commercialization, Chapter 1 indicated that there are different definitions of reuse concerning processes. In practice, items are commercialized with or without any processing by the same retailer according to the type of product and the economic benefits that justify the re-conditioning (description of economic models and types of retail is explained in RQ 2). During the processing, however, some products can also change function, for example from larger structure wooden beans to smaller size rafters. Consequently, in the Netherlands, it is not simple to distinguish the processes to re-condition used products in practice because they are contingent on the physical conditions of the used products.

The combination of key players executing activities in the process of reusing varies from harvesting to retail. In short, the main activities defining the chain are deconstruction (or harvest), collecting (or transporting), sorting, processing, and retail. The list below is a representation of characteristic chains found in practice in the Netherlands.

- Demolition company _ harvest + process or not + retail
- Demolition company _ harvest and supply to retailer (that will process or not + retail)
- Demolition company contacts stripper that _ harvest + process or not + retail
- Developer company contacts stripper that _ harvest + process or not + retail
- Building owner contacts stripper that _ harvest + process or not + retail
- Building owner _ retails via Internet trade sites[64]

As seen above, demolition companies play a central role on managing flows of products for reuse concentrating several activities as a single actor. The integration of tasks under one vertical structure brings economic benefits able to accommodate possible losses in different stages of the chain, but can also result in weak specialization of skills required for each activity, especially when demolition companies operate reuse as a side or secondary service within the company (more information in RQ2). The strippers or more specialized companies in recovering products for reuse, on the other hand, are

63 Interview with Jan van Ijken (*Oude bouwmaterialen*).

64 https://www.marktplaats.nl is a good example of reuse product retail also used by specialized companies.

often submitted to the primary role of demolition companies, as mentioned before in the form of negotiable fees.

VERAS is a national association that represents and in part regulates the demolition sector. The activity of harvesting for reuse either operated by demolition companies or by specialized strippers is not treated as a specific activity or sector, reflecting inadequate legal representation and lack of further support in the form of investments for Research and Innovation.

For small-scale demolitions or renovations, building owners have a relevant role in deciding to access retailing channels of used products without demolition companies. For larger projects, demolition companies are essential to deciding how to proceed with recovered products, which once again, act motivated by economic forces, and other factors as incentives through green labels.

Pre-demolition estimation, in the form of inventories, is a practice officially required to demolition companies in the Netherlands[65]. The inventory contains a description of the building material content and how these materials will be managed with the goal to improve material management and monitor the proper handling of hazardous substances, such as asbestos. A second examination is done post demolition to evaluate the actual selective demolition (or deconstruction) process.

In the future, as part of waste prevention strategies, these inventories could be useful to evaluate the amounts of reusable products to be harvested from demolition sites with a percentage target. However, in practice, these forms (inventories) are less efficient as they could potentially be[66]. One reason is the absence of legal systems to control and evaluate them. When inventories are complete, they are in possession of the demolition companies[67]. These inventories allow waste accounting on site, opening an opportunity to monitor more accurately waste accounting information. In addition, when combining this information with building typologies and construction year of buildings, these inventories could support an updated overview of material stock in the Netherlands. Amounts and types of materials harvested for reuse could also be applied for statistics control in waste prevention strategies and help to establish possible targets.

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65 Interview with John van Herk (*Sloopaanemers*/ VERAS).

66 Interview with John van Herk (*Sloopaanemers*/ VERAS) and Rob Gort (*Bouwcarrossel*).

67 Information about these forms was asked by the author to several demolition companies (81) in order to compare waste flows according to building age and typology with no results.

According to Guide and Van Wassenhove (2002), supply chains are structured in relation to product types. However, comparatively with the chains represented by Guide and Van Wassenhove or by Tonanont et al., (2008), there is no clear connection between the activities after demolition and their original product manufacturers, or any significant relation with manufacturers, retailers or distributors of new products in building product reuse in the Netherlands.

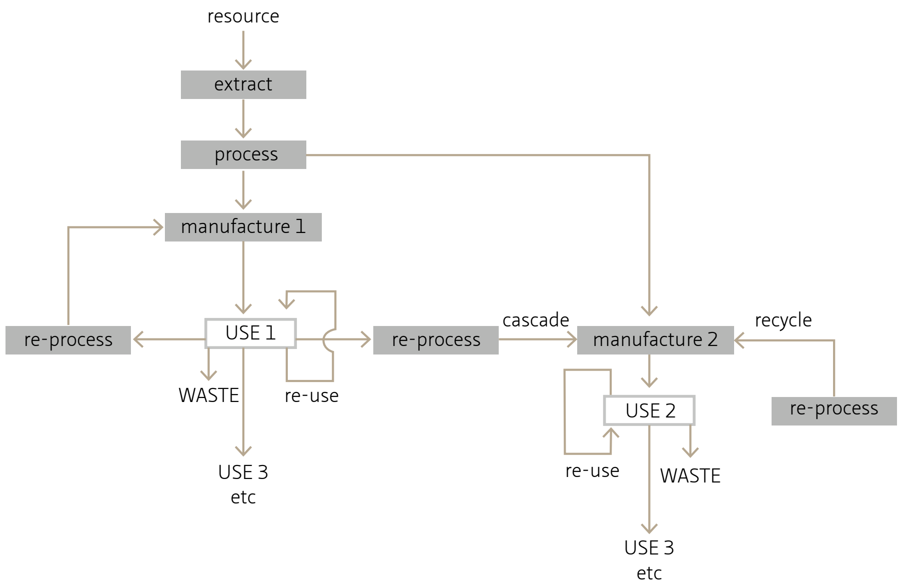

FIGURE 4.1 Industrial Ecology: Cascade of materials (Mellor, et al., 2002. pg. 4698).

Therefore, reverse chain as described by Tonanont et al., (2008) or the Pull type reverse supply model (Umeda, 2013) do not represent the activities found in practice. When products are harvested from existing buildings, activities are configured more similarly to an extension of the former chain as proposed by Mellor et al. (2002) (Figure 4.1), more specifically between "USE 1" and "USE 2". Likewise, a more flexible understanding of reverse logistics described by Govindan et al. (2015, pg. 603) is a suitable way to describe the activities that take place in the practice of building product reuse in the Netherlands:

"*Indeed, reverse logistics, in general forms, start from end users (first customers) where used products are collected from customers (return products) and then attempts to manage EOL products through different decisions are undertaken including recycling (to have more raw materials or raw parts), remanufacturing (to resale them to second markets or if possible to first customers), repairing (to sell in the second markets through repairing), and finally, disposing of some used parts*".

§ 4.2 Answering research question 1

RQ1. What activities take place in the supply chain of reusing building products that characterize the practice in the Netherlands?

The supply chain of building products is frequently composed by the harvest, transportation, possible recondition of products prior commercialization and retail. Key players are demolition companies, building strippers, and building owners, as well as retailers of specific types of products not active in the harvesting phase. Demolition companies not only execute the most typical activities but also other companies rely on them to access the location where demolitions take place. Developers and building owners can also decide what products to reuse by directly harvesting and accessing retail channels. Recent developments in e-commerce, however, indicate that these activities are made between owner and consumer directly. This type of commerce is a relevant subject to be investigated in future studies.

The integration level of activities in the reuse process is related to economic efficiency models. However, whereas the integration of such activities brings economic advantages, it can also lack a higher level of specialization and skills for each activity.

The description of main activities and players in the reuse supply chain is relevant to understand the operative structure of the practice. Therefore, regarding the IE framework discussed in Chapter 2, the findings from RQ1 are added as a theme that also influences the system, and it is represented directly connected to the industrial practice in the model in Figure 4.2.

Extra findings from the investigation indirectly related to RQ1 were:

- In practice, there is no clear division between the various definitions of reuse as established by the Waste Framework Directive. This lack of clarity brings consequences to policy regarding classification of waste and non-waste and how to regulate reuse activities and manage such materials flows.
- Pre-demolition inventories made by demolition companies is a mechanism that could monitor amounts of materials to be reused by type of building, but they are not applied as a tool to assess waste prevention systemically.
- Green credentials incentivize better management of materials during building demolition and deconstruction, relevant for product reuse.

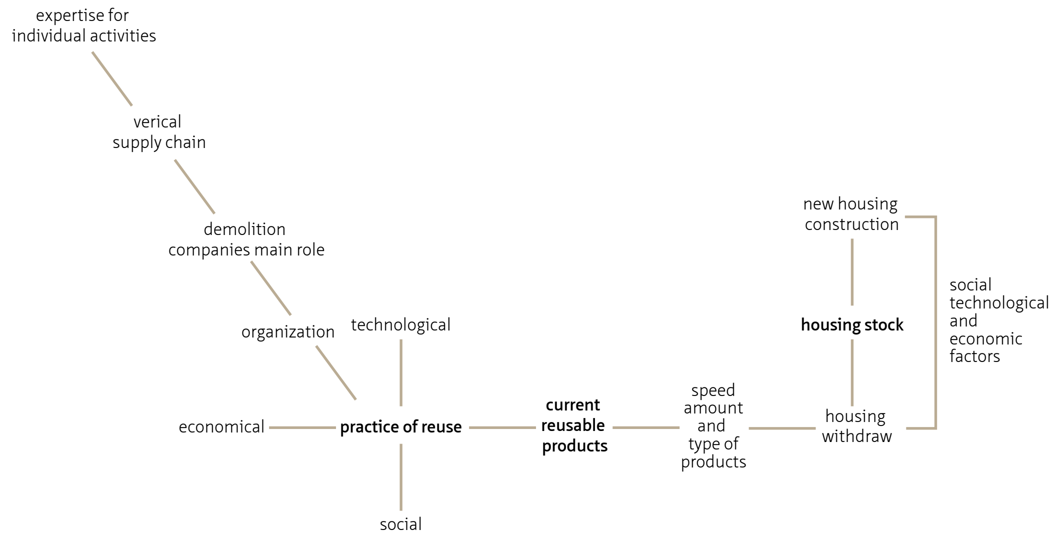

FIGURE 4.2 Practice of reuse in the Netherlands.

§ 4.3 Predominant technical social and economical factors in the reuse process

RQ2. How do different (technical, social and economic) factors influence the process of building product reuse (in the Netherlands)?

Changes in the industrial structure can occur according to technological developments (Nelson and Winter, 1982; Nelson, 1995; Porter, 2007), economic and social changes or yet other developments (Porter, 2007) as policy (Nelson, 1995), competitiveness (Porter, 2007) and market (Schumpeter, 1962; Caves, 1980).

The following sections, investigate which factors influence reuse of building products in practice in the Netherlands based on the structure discussed in the theoretical framework in Chapter 2. The literature review is used to guide the selection and verification of information collected contextualized in the Netherlands.

The description of how economic aspects relate to the practice of reuse in the Netherlands begins with the investigation of the typical types of retail of used building products and which business models justify reusing them in practice through interview with practitioners.

Subsequently, the social analysis depicts some aspects of the interface between users or potential users of used products. The assessment develops on information provided from interviews with experts and existent literature. The assessment of how technological developments affect the process of reuse is grouped into three main stages: i) Technology and reserves; ii) Technology to harvest products to be reused; iii) and Technology as (re) condition to reuse products.

§ 4.3.1 Economic factors

This section describes existent types of markets, their correspondent business models and economic factors influencing reuse in practice. With few exceptions (te Dorsthorst and Kowalczyk, 2001_ study for precast concrete building products), there is limited literature dedicated to investigating the economic advantages of extending the life of products and factors influencing the decision to harvest products to be reused in the Netherlands.

Based on available literature, studies contextualized outside the Netherlands were also used as reference to this assessment: in the UK (Bioregional, 2007; Patel, 2010), in the United States (Geyer and Jackson, 2004; Shami, 2008; Peters, 2011), in Germany (Asam, 2007), and in Japan (Fujita and Iwata, 2008).

Field and Internet research[68] confirmed the existence of different types of markets of used building products as discussed in the literature. The list below presents three of these main types of markets according to business models that justify the commercial feasibility of building products. In practice, companies can operate more than one business model or specialize in one of them.

– Architectural products and antiques
  Aesthetic criteria, in this case, are conditional, including the age of products and rarity. In this category, products are in general more expensive or equivalent to new products applied for the same function. Most of these products are restored or repaired before being sold.

68 These market divisions are also common in other parts of the world as in the UK, Belgium, Denmark, New Zealand and the United States (Papers from *Conseil International du Bâtiment*). These three classifications exclude leasing plans of buildings and products as presented by *Slimbouwen* (interview with Remko Zuidema).

- Reclaimed building products
  These products are reclaimed from demolition or renovation works. In general, they are sold with no or limited reconditioning. Few modifications can take place, as wood parts that are de-nailed or cut into a structural measure. These products are usually sold cheaper than equivalent new ones.

- Cascade reuse
  According to some definitions of reuse mentioned in Chapter 1, the complete transformation of an existent product into a new, different one is not acknowledged as reuse. However, among interviewed companies, when possible, either demolition companies or strippers transform used products to make new ones through more intense processing compared to direct reuse. It is questionable if this type of market should be included in this research. Nonetheless, companies active in the market of Reclaimed products perform several activities in the chain including cascade reuse.

The plurality of consumers of used building products strengthen the practice and raise amounts of products harvested from the built stock. Variations of the categories mentioned above were found to be irrelevant among interviewed companies. As mentioned before, unused products as surplus from construction companies or as dead stock from manufacturing and retail companies although relevant to some retailers are not included in this study. Their physical condition is often as good as new and often priced cheaper than new ones.

The most common type of retailer in the Netherlands offers a mixed type of products in the Reclaimed category[69]. Demolition companies located on the peripheries of large urban areas where storage costs are lower[70] offer competitive prices compared to new ones "off the shelf" products[71].

Reclaimed products are mainly sold after some reconditioning, cleaning or cutting into different sizes. Doors, for instance, are not restored unless required by the client. For commercial projects that demand uniform characteristics and measures for a large volume of products, lack of warranties[72] and standardization of used products[73]

69 Interview with Erik van Erne (*Stichtingmilieunet*), Jan van Ijken (*Oude bouwmaterialen*).

70 Interview with Jan van Ijken (*Oude bouwmaterialen*) and Jonathan Essex (Bioregional).

71 Interview with Erik van Erne (*Stichtingmilieunet*).

72 Interview with Jan van Ijken (*Oude bouwmaterialen*).

73 Interview with Liz Ogbu (former Public Architecture).

becomes a barrier, where reuse it is considered to be more suitable for smaller constructions and renovation projects. The search for a large number of similar products among different suppliers poses logistical complications, making the process increasingly costly.

On the other hand, large amounts of products (standardized or not) are not extracted from the stock even when available due to the lack of storage space and the risk for retailers to not be able to offer a variety of products to their principal consumer group, the DIY segment[74]. This fact indicates that commercial projects could apply used products, but the current market structure is not able to support a supply-demand balance on a larger scale. Hemström et al. (2012, pg. 2) concluded that "*the supply of reused C&D material is limited and varying or non-existing, and initiatives are needed to stimulate both the supply and demand of reused C&D materials*".

A relevant aspect of the construction industry in the Netherlands is that construction of new houses is mainly operated by large commercial developments. These projects are in general managed with a network of suppliers able to provide a substantial quantity of products with a price reduction. Large-scale suppliers are also able to offer direct incentives to construction developers through lobbying mechanisms, making the market of reclaimed materials less competitive in this segment[75].

There have been attempts to integrate the retail of reclaimed products through large size construction product retailers[76]. However, the profit margin from these stores did not cover the expenses involved in recovering and transportation. As the market of used building products is still characterized by consumers from the DIY sector and small renovation works, it partially determines the types and amounts of products that are harvested.

Whereas supply of used products does not match commercial scale constructions, the demand or consumption of used products for smaller works should not be minimized. The Do-it-yourself (DIY) segment[77] was the largest type of consumer for reused building products during the times this research was made. In general, it is a growing market

74 Interview with Fred van Ooyen (*Van Baal*).

75 Interview with Jan van Ijken (*Oude bouwmaterialen*).

76 Interview with Rob Gort (*Bouwcarrousel*).

77 Interview with Fred van Ooyen (*Van Baal*), Jan van Ijken *Oude Bouwmaterialen*), Robert Barclay (*van Liempd*).

amongst smaller construction companies[78], indicating that consumption of products is significantly affected by renovations. In 1997, the DIY sector had a turnover of 3.2 billion Euro and a turnover of 3.7 billion Euro in 2007, however, since its peak, the sector has declined for five years in a row[79].

Teun Stam[80] from Schijf Group noticed that around 1990's whereas small to medium construction companies and the DIY sector characterized their main consumer group, currently, he sees a sharp increase in interior architecture and designers, indicating a shift on the type of demand. Other smaller consumer groups of reclaimed products are from developing countries looking for affordable good quality products[81]; and consumers driven by the environmental concerns[82].

According to van Ijken[83], the introduction of new and affordable building products manufactured in countries such as China was one of the reasons why the market became more competitive, in particular for articles that resemble old ones. Van Ball described a later increase in sales coincided with the economic crisis from 2008, while van Liempd[84] and Restoric[85] were forced to search for other niche markets during the same crisis.

Finally, the most characteristic types of markets of used building products in the Netherlands outlined in the previous paragraphs were based on three main different business models: One that focuses on retail of used products that are more expensive than new equivalent products; one that focuses on retail of used products that are cheaper than new equivalent products; and a third model that focuses on retail of used products that are more expensive than new non-equivalent products. This last model demands a physical transformation of the used object that often results in a new application.

78 Email *Hornbach Bouwmark*t (Nederland) BV.

79 GfK Retail and Technology Benelux B.V.

80 Interview with Teun Stam and Tristan Frese (*Restoric/Schiff Group*).

81 Interview with Fred van Ooyen (*Van Baal*).

82 Interview with Tristan Frese (*Restoric*).

83 Interview with van Ijken (*Oude bouwmaterialen*).

84 Interview with Robert Barclay (*van Liempd*).

85 Interview with Tristan Frese (*Restoric*).

Model 1 “More expensive than new”
Recycling fees **<** *Equivalent new products off the shelf* **< Reuse retail**

In Model 1 as in Model 2, all expenses involved in the process to extract used building products include in the retail price (all models exclude the cost of material certifications when applicable). These products will be often more expensive than equivalents new ones. Like in model 2, individual consumers form the main consumer niche. These products are more commonly found in specialized stores; not typically found in demolition companies. This business model is closer associated with the architectural salvage, antique market. According to Jan van Ijken[86], the “antique” business has not seen representative growth due to the decrease of restoration works.

Model 2 "Cheaper than new"
Recycling fees **< Reuse retail <** *Equivalent new products off the shelf*

Model 2 associates with the Reclaimed building products market. In this model, all expenses incurred in the processing phase are included in the final retail price and are still competitive to comparable new products. A common mechanism found in this model in the Netherlands involves a professional either from a demolition company or a building stripper visiting the project to be demolished, deconstructed or renovated and evaluate the viability to extract products for retail. This professional estimates the expenses necessary to reuse (including processing as recondition or remanufacture, deconstruction costs, transportation, existing market demand, storage). The level of accuracy in this evaluation results in profit margins (or losses). In case a stripping company joins the demolition process, the necessary fee paid to the demolition company is also included in the total costs.

For retailers (often demolition companies), selling reclaimed products is more profitable than other waste treatment options as recycling, *down-cycling* or incineration. The average profit margin ranges from 30% to 100%, even when used products are sold in the market 40% cheaper than new products, or on average 1/3 the price of new products (wood components)[87].

The former *Bouwcarrousel* developed an innovative mechanism where the source of used products was supplied by demolition and renovation projects made by a housing

86 Interview with van Ijken (*Oude bouwmaterialen*).

87 Interview with Fred van Ooyen (*Van Baal*).

association[88] in the Netherlands. *Bouwcarrousel* provided the deconstruction service including transport, cleaning, and storage of products that would be traded back to the housing associations in future maintenance works, as well to the general public. Through this system, *Bouwcarrousel* formed one of the largest used building product stocks in the country in the late 90's. According to Gort, one critical obstacle found during the operation of this model was the cultural barrier both from the general public and the developers operating renovations in the housing association[89]. Also according to van Ijken[90], developers tend to avoid used products even when used products are part of the client's request. The model proposed by the *Bouwcarrousel* was the only in the Netherlands that supported integration between deconstruction and supply of used products on a commercial scale.

Model 3 "More expensive than new" (a variation)
Recycling fees **<** *(Not necessarily equivalent) new products off the shelf* **≤**
Remanufactured products with reused materials (added value)

Product development[91] is the main differentiator factor in this model compared to the previous two. Investments in designing and manufacturing phase are included in the final product cost. One critical aspect of this model is the utilization of products that could not be sold in the conventional reclaim market because of their physical condition, or that the profit margin after remanufacturing are considered higher than if sold as harvested. Within the three models, costs involved in landfill, mixed waste

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88 Housing associations in the Netherlands are responsible for the largest rental-housing sector in the country.

89 Interview with Rob Gort founder of *Bouwcarrousel*. One third of the workforce responsible for the maintenance of buildings was employees from the housing association. The other two thirds were external private developers providing service for the housing association, who did not embrace the concept of buying secondhand products despite being more cost effective for the housing association than purchasing new products. The resistance of developers to consume reclaimed products offered by the Bouwcarrousel caused the business model to fail. Besides the cultural barrier, private developers were able to receive more benefits (bonus, gifts, discounts, etc.) by purchasing products from network suppliers. In the United States, the low-end market showed to have a disruptive factor affecting public perception, bringing negative impact for private business and further development of reused material consumption_ Chini & Breuning (2003). Deconstruction and Materials Reuse in the United States. The Future of Sustainable Construction, 2003. Similarly, the EPA in the United States recognized that by isolating reused products in the low-end market works against the expansion of reuse of C&D (Shami, 2008).

90 Interview with Jan van Ijken (*Oude bouwmaterialen*).

91 This phase lies in between remanufacture and redeployment. Definition of remanufacture: The process of bringing large amounts of similar products together for purposes of disassembly, evaluation, renovation and reuse. (Kapur and Graedel at http://user.iiasa.ac.at/~gruebler/Lectures/Leoben00-01/IEArticle_Leoben.pdf) Definition of redeployment: "redeployment and cannibalization as seen in Chapter 1 Section 1.4.

disposal and recycling[92] are critical references in the decision make process to reuse to create a lucrative margin alternative (see also Table 4.1).

Advantages of Model 3 in comparison with Model 1 and 2 are:

a Low-value materials that would be mostly incinerated are integrated into new products creating positive value for demolition companies.
b Redeployment and retail of new products (made of used parts) avoid the need to increase storage capacity for used products.
c Retail of new products allows companies to create new consumer niches and diversify their core business, helping to overcome economic downturns in the demolition and construction sector.
d Redeployed products reach consumers with a modified appearance, affecting public perception when confronted with used products sold without any reconditioning.
e Reuse of products in their original form and function can technically compromise the performance of other building systems, e.g., window frames with low thermal capacity affecting the energy efficiency of new or restored buildings. As existing products are transformed into new types of products to serve different functions, they can be "cascaded" and be used with inferior technical applications than original (more information regarding this topic is explained on the Section Technology).

Companies that have adopted this model were mobilized by its the economic advantages[93], and started to develop their design and manufacture divisions within their physical facilities. Deciding which products to harvest, which new products to develop and how to set the production chain[94] are key elements are critical elements in this business model to recover investments.

Bosman (2014) investigated large-scale manufacturing of new products from used products. As a variation of model 3, Bosman (2014) and Hermans[95] suggest the potentials to increase manufacture to decrease manufacturing costs yielding more competitive products.

92 Interview with John van Herk (*Sloopaanemers*/ VERAS).

93 *Oude bouwmaterial, van Liempd, Restoric*.

94 Interview with Tristan Frese (*Schiff*).

95 Interview with Kristel Hermans architect for Treck-in cabin (see reference cases).

From the interviewed companies (*Van Liempd*, *Oude bouwmaterial*, *Restoric*) that adopted model 3, furniture manufacturing from building products was the most common type of product developed[96]. Van Liempd started furniture design and production with post demolition materials and within four years invested in diversifying the production into new prefabricated holiday cabins in collaboration with the Technical University of Eindhoven (Figure 4.3 and 4.4).

FIGURE 4.3 Trek-in cabin TU Eindhoven in collaboration with Van Liempd (photo: Tim van der Grinten, Xaviera Burón Klose, Kristel Hermans and Faas Moonen).

FIGURE 4.4 Trek-in cabin

The motivation to harvest used products for retail is affected by different dynamic factors leading to economic profit generated when compared to alternative waste treatments[97]. Table 4.1 illustrates how some of these values are evaluated. These values, however, are an approximation, as variations occur depending on the degree of impurity content and transportation distance. Moreover, prices are volatile based on changes occurred in the general waste management system that is also affected by the prices of raw materials. Previously, the disposal of materials was regarded as costly to waste producers and demolition companies; later, disposing of some types of materials became a source of revenues (van Benthem et al., 2007).

96 Design companies, as Piet van Hein and SuperUse are important references of product developers that are an additional part in the chain described in model 3. In this case new products designed by such companies tend to be commercialized as “more expensive than new” equivalent products (interview with Jan Jongert).

97 Companies that were no longer active in working with reused products have justified the difficulties due to the economic crisis in the construction industry since 2008 (*van Vliet Sloopwerken* and *BZN Sloopwerken* BV telephone interview).

TABLE 4.1 Economic factors that help justifying reuse of building product (interview with Van Baal and Shijf Group, 2012).

	PAY TO DISPOSE WASTE	SELL TO DISPOSE WASTE
Mixed rubble	90 €/ton	
Stony material from demolition to crusher	40 €/ton	
Secondary gravel for concrete production		10 €/ton
Stony materials for road base		4,5 €/ton
Copper		2,75 €/kg
Iron		0,17 €/kg
Steel		0,50 €/kg[3]
RVS steel		1,10 €/kg
Mixed wood[1]	25-30€/ton	x [4]
Wood (to be downcycled in other products)[2]	3-10€/ton	x [4]

1 *Van Baal*
2 *Schijf*
3 *BZN Sloopwerken BV*
4 *In 2004 it was estimated that 22% of total post- consumer wood in the Netherlands was being utilized in the Netherlands, the rest (the rest (almost 1 mill. tons) being exported to energy or board industry (approximately 50% each) in Germany, Belgium, Sweden and Italy. "The trade of post consumed wood varied in this year from 20 – 30 Euro per ton air dry for A-quality and 7 – 15 Euro for B-quality" (van Benthem et al., 2007, page 2).*

Finally, the list below describes how economic factors influence what is economically "reusable" through the description of the business models described in previous paragraphs:

– The existence of a market
The existence of a market for used products indicates demand and therefore the economic feasibility to reuse. According to Asam (2007), even when reusing products is technically possible, economically and environmentally beneficial, there is not yet a market for all types of recoverable products. Culture acceptability (perception) of a used product, public awareness (information), and building regulations (applying reused products in new buildings) are essential elements as well. According to Jan van Ijken[98], demand for used products is the principal barrier in the business.

– Cost to deconstruct
Reclaiming materials can be a workforce and time-intensive process. Contractors often have limited time to accomplish the demolition phase; therefore both demolition and stripping companies find time constraint a bottleneck. For instance, in California,

98 Interview with Jan van Ijken (*Oude bouwmaterialen*).

local authorities regulate that a period (average ten days) must be reserved before the actual demolition with the goal to prioritize the recover of products to reuse[99]. Time to deconstruct is also related to building characteristics and to available technology to deconstruct. Some products are quicker to reclaim than others. Besides recovering products with higher demand in the market, the smaller and less complicated the products, the better the potential for reuse (Nordby et al., 2009[a]) as further handling becomes easier during disassembly, transport and reprocessing.

– Disposal costs
  High tipping fees forced demolition companies to sort materials from demolition and look for alternatives to manage and treat the waste. Mixed material flows (unsorted) represent an economic loss for the demolition company that will try to increase selection of material types as possible. As a development of the Building Material Decrees (Eikelboom et al., 2001) heavily focused on soil and water contamination, the Netherlands currently accounts with one of the highest landfill taxes in Europe (in 2008 landfilling tax were to €88.21 per ton, while there are no incineration taxes). Since the taxation implementation, waste treatment has evolved towards recycling (Figure 4.5).

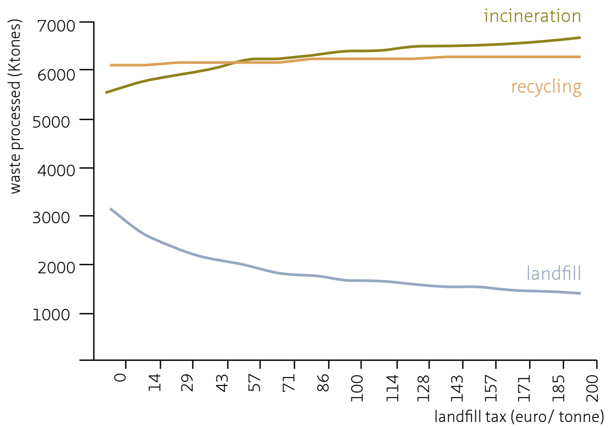

FIGURE 4.5 Waste treatment and landfill tax (with incineration tax rate zero) (Oosterhuis et al., 2009, pg. 22).

99 Interview with Mary E. Williams from Construction and Demolition Recycling Specialist Department of the Environment City and County of San Francisco.

One question that emerges at this point in the investigation is why no incentives have been made directly to reuse? Even when landfill taxes are comparatively lower than in the Netherlands, tax incentives in the United States bring benefits both to the building owner (or waste owner) and to the retailer of used materials[100]. A relevant aspect of the tax cuts system in the United States is that the waste producer, or in this case the building owner, is directly involved in the waste treatment decision. Other for-profit business models are more dependable on the resale of reclaimed materials to justify the costs of deconstruction (McLear and Nobe, 2011).

– Cost of new products
The price of new products is a relevant reference. The introduction of new cheap foreign products became an economic competitor to used products. When used products are valued more expensive than equivalent new ones, they are more often in the Antiques or salvaged architecture category or considered rare materials as some types of wood and natural stones. Price of virgin materials as wood also affects the competitiveness of used products.

– Storage, transportation and recondition
Activities intrinsic to the reuse process as transportation, storage, and different levels of processing involve costs. Workforce and transportation are crucial factors to estimate economic viability to reuse[101]. In the Netherlands, the north part of the country where land is more affordable than highly urbanized areas, demolition companies have more available space for storage and retail of reclaimed products[102].

E-commerce appears as a different way to trade. It also promotes trade of used products directly from demolition sites, or from waste owners direct to consumers. Some initiatives as implemented by the government of the city of Cotati in California created mechanisms that facilitate information circulation to the public through newspapers, email and newsletters, about availability of potential salvageable materials to be recovered on site, decreasing the need for storage by creating immediate retail at the source (Smith et al., 2007). The problem of storage capacity

100 In the American system, the building owner can have tax deductions if reusable products are donated to a non-profit retailer, which are broadly available around the country _ Habitat for Humanity is one of the largest chain in the United States.

101 Interview with Tristan Frese (*Restoric*) and E-mail with Nordby in reference to *Stavne*.

102 As reference, "*One of the main barriers to the reclamation of construction products in the UK is the lack of storage and reprocessing capacity*."… "*The government should match its capital investment in recycling with a commitment to provide the land and broker the partnerships to establish facilities*" (Kay and Essex, 2009, pg. 32).

and matching supply and demand is a recurrent issue discussed during interviews. Tristan Frese (Restoric) in the Netherlands explained that within their operations, transportation is one of the stages that brings more risks for financial losses when compared to other phases in the reusing process.

Fujita and Iwata (2008) calculated the direct implications linking the increase in the number of storage sites, the decrease in transportation costs and an increase of storage costs in their supply chain for reuse of steel structural components in Japan. The study concentrated in developing a type of "Take-back" chain specialized in steel recover and remanufacture. The goal was to achieve an optimal balance between the lowest storage and transport costs.

Regarding reconditioning, most interviewed companies restrict processing to essential modifications such as cleaning (e.g., mortar from bricks) resizing (e.g., wood beams into studs) and de-nailing wood. Cascade reuse is a more intense process as previously discussed and sensitive to the material and product type, affecting final economic profit.

– Waste treatment technology
  Technology able to sort waste more efficiently, recycle materials with the same or similar quality of new ones (Oudejans et al., 2011) or yet technological development resulting in non-toxic materials able to feed other material flows (McDonough and Braungart, 2010) is an object of increase concern as discussed in Chapter 1. Within reason, as these technologies evolve to become more economic feasible, and ideally more environmentally responsive, they will also compete for waste streams that could be reused[103]. Andersson and Råde (2002, pg. 401) discussed about the risks presented by the "lock-in" effect and differentiate between large-scale sustainable (LSS) technologies and constrained technologies. "*The former are cornerstones of a sustainable industrial society. The latter are limited in some ways that disqualify them from being successfully implemented on the large scale for a long time*".

  Therefore, one significant aspect about these two types of technology implementations is the high degree of uncertainties regarding the requirement and availability of materials. Due to significant investments in large-scale infrastructure[104], incineration is still widely in use in the Netherlands.

103 Some of these technologies have so far processed a limited percentage of post demolition materials into new products (concrete 5%, gypsum less than 20%) while the largest percentage focus on post industrial or construction waste for having less contamination fraction.

104 Interview with Ivo Haenen (Waste.org) Gouda.

Material scarcity and/ the complexity to extract primary resources from the earth's crust are not included in the listing above. Mainly because materials used in the construction industry, with few exceptions, are regularly considered abundant (more information in Chapter 6). However, it is expected that in the future, the difficulty in extracting primary resources (Van der Meulen et al., 2005; Kennedy et al., 2007) could play a more relevant role in re-defining waste treatment as we see today in the recovery of metals in the electronic sector (WEEE[105]). Despite disposal tax fees and increase cost to dispose of mixed materials, no other form of policy stimuli was included in this assessment as explained in Chapter 1. The factors above were based on interviews and literature and had not been listed in order of influence.

Main findings on the economic factors

The commercialization of some used products is motivated by the higher economic profit generated when compared to managing material flows through different forms of waste treatment. From this perspective, economic factors set by waste management options including respective subsidies and other lock-in effects as result of existent infrastructure to manage waste streams are also relevant in the decision to reuse. Similarly, the new technological advances enabling large amounts of materials to be recycled with increasing better quality and decreasing costs, play a role in influencing economic advantages and disadvantages in reusing. High tipping fees and fines applicable to dispose of mixed materials are still relevant economic factors within demolition companies.

Moreover, direct costs involved in the process of reusing are relevant factors to compare economic advantages with waste treatments. Therefore deconstruction costs, transportation, reconditioning, storage have to be included in the computation, and each step of this process is related to other economic, technological and social factors further developed in this chapter.

Besides alternative routes of material treatment, the existence of a market is another relevant factor defined by the demand of used products, the types of markets, and it is interpreted in this study also as a social relation.

Moreover, the competitive costs of new equivalent products (related or not with price fluctuation of raw materials nationally and internationally) influence what and how products are reused. New products that offer the same function of used ones are more

105 http://ec.europa.eu/environment/integration/research/newsalert/pdf/186na3.pdf

easily available, certified by new building regulations, and standardized in large scale. Finally, all these factors relate differently according to the type of product, material composition, and physical condition, resulting in different types of markets.

Extra findings during the investigations were:

- Reuse is more commonly associated with the DIY segment than the large-scale commercialization of used products of the same kind. There is an apparent active market of used products directly traded between users through e-commerce.

- Main activities in the supply chain of reuse are concentrated in the role of demolition companies, fewer building strippers, and building owners. Whereas such concentration of activities is economically justified, distributing losses and profits along each phase, the level of specialization to execute each task is questionable.

- Policy stimuli as tax incentives for the reusable product owner to reuse rather than dispose of, high tipping fees, fines applicable to mixed waste disposed of during construction and demolition, and subsidies to other types of waste treatment, influence the economic mechanism to reuse. However, other methods of promoting reuse by increasing time given before demolition can also improve amounts of products prevented from waste.

- Finally, cascade reuse although not considered as a form of reuse by the WFD, co-exists with reuse and is operated by demolition companies and building strippers. Different aspects of cascade reuse overcome some barriers of reusing. Some of them are listed below:

  - Whereas reuse of products in their original form and function can compromise the technical performance of new building systems, cascade reuse allows reuse of products for new applications that demand inferior technical performance than the original.

  - Reconditioning and remanufacturing used products potentially increases final value of low-value products that would be mostly incinerated. Within these processes, design can also be a catalyst of such transformation and consequently improving public perception regarding used products (see the following section).

  - Retail of new products allows companies to diversify their core business and help to overcome downturns in the demolition and construction sector. By creating a new output of products for different consumer niches, it avoids the need to increase storage capacity for used products.

The economic factors related to the practice of reuse in the Netherlands found in this investigation are structured in the research framework as represented in Figure 4.6 Economic factors related to the practice of reuse building products in the Netherlands.

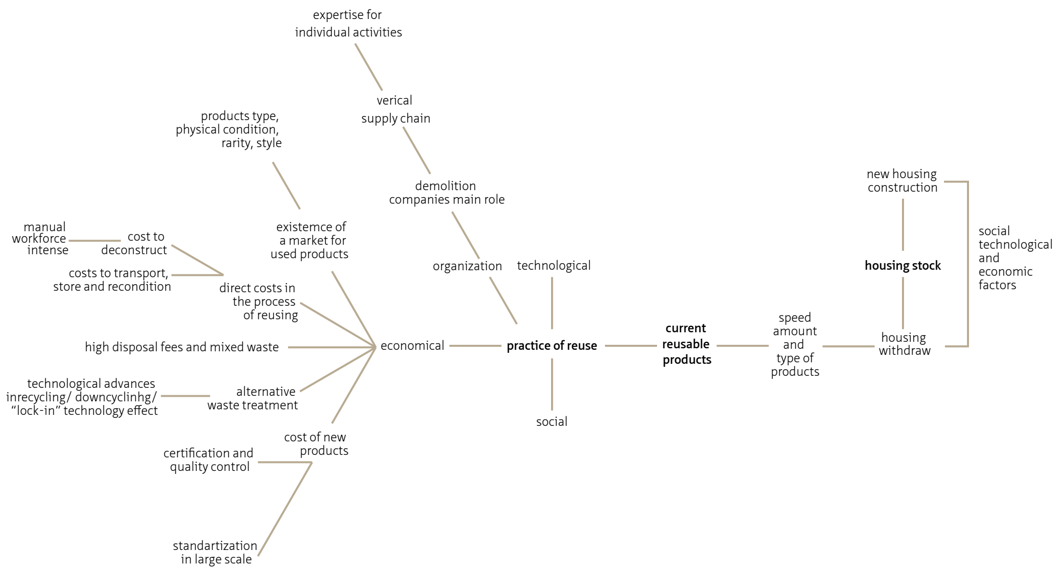

FIGURE 4.6 Economic factors related to the practice of reuse building products in the Netherlands.

§ 4.3.2 Social factors

Within the Industrial Ecology framework (presented in Chapter 2), flows of materials can be affected by consumption behavior. According to Kennedy et al. (2007), the definition of metabolism in cities synthesizes the description of urban material metabolism placing the resident (human behavior) at the center of the activities or as a driver for consumption trends and consequently material transformation. As investigated in previous studies, population (Müller, 2006; Hu, 2010) and workforce (Ayres et al., 1997) have been included as factors that can affect material metabolism. Studies more specifically focused on understanding the consumption of used building products, however, explored different perspectives.

Geyer and Jackson (2004) used different economic scenarios to include high or low demand for used products relative to costs of other waste treatments or new steel components. Chen et al. (2006) narrowed the scope of demand for used products through the perspective of accessibility to information. The subject of information was emphasized in the circular supply chain of steel components proposed by Fujita and Iwata (2008) represented by an information technology database to build an inexistent connectivity between parts of an efficient supply-demand chain. Hobbs and Hurley (2001) also proposed a tool (Material Recovery Notes) to share material audit prior demolition with interested stakeholders. They also emphasized the importance of demolition companies in the process to harvest reusable products and match them with a commercial demand in the light of technical and legal procedures.

Van den Briel and Bolhuis (2013) discussed about the lack of marketing that affects the perception of the final consumer and consequently demand. For Patel (2010), the demand for used products is combined with suggested incentives and legal mechanisms after demonstrating the economic advantages of steel reuse. Gorgolewski and Morettin (2009) and Poelman (2009) investigated ways for architects to systematically engage used products in the design process, which is absent in conventional educational systems. Bakas et al. (2011, pg. 57) suggested "*the need for education and information among all actors, from the early planning stage*" to implement construction waste prevention measures in Europe. Similarly, Dehoust, et al. (2010, pg.66) concluded that a starting point to tackle waste prevention in Germany is to offer information to specific target groups, and that "*often there is a lack of opportunities to exchange experiences between stakeholders (producers, retailers, consumers, government, etc.) in order to realize possible learning effects*." They also point on the importance of good coordination and network of existing activities rather than the development of new instruments.

Although none of the previous studies analyzed the subject of demand as the main topic, they showed that different aspects affect the interest and trade for used products at the same time and that different strategies could improve it.

There is limited information regarding the social interface of building product reuse. It also has not been included as a sustainable action in the existing literature regarding "green consumption", which has mainly focused on recycling, energy saving, and consumer responses to advertising and labeling (Martin and Simintiras, 1995; Kilbourne and Beckmann, 1998; Peattie, 2010) with more emphasis on quantitative methods (Peattie, 2010). Green et al. (2000) proposed to treat each step of the supply chain as consumers towards a "greening economy." Peattie (2010) also described green consumption behavior as a process rather than concentrated at the "final" product user.

To limit the scope of social interface regarding reuse, this study regards the commercial interface between used products and involved stakeholders based on results of previous studies and interviews.

Social forces are an inherent component in the business models as described in Section 4.3.1 by the way the final cost of used products are associated to the value given to them, which differentiate products harvested for their aesthetic value from products that are harvested for being cheaper than new ones. “Value” however can be also added after harvest as identified in the cascade reuse method.

The relative costs of other waste treatments discussed by Geyer and Jackson (2004) were also found to be a relevant factor in the decision making process in the practice of reusing in the Netherlands. The goal, therefore, is to investigate what are the existing factors influencing the perception of used products in the Netherlands.

Patel (2010) investigated existent incentives that could support reuse either by green certificates to different players involved in the practice of reuse or in forms of policy incentives. However, besides green certificates related to demolition companies and waste disposal taxes, it has been found during interviews that no other formal procedure of stimuli was mentioned to incentivize reuse directly.

According to Restoric and van Liempd, the “green” consumer trend influences the choice for demolition contractors that include stripping or deconstruction as part of the demolition tender. In this context, demolition companies target deconstruction for reuse as part of their green credentials when clients recognize the relevance of the practice. Demolition companies recognize the advantages of green credentials when competing for new demolition contracts. Some consumers choose to pay extra for more conscious demolition processes, and green credentials are particularly relevant when bidding for public demolitions[106].

The CO_2 Ladder program helps to differentiate among companies that carry more sustainable initiatives than others, bringing advantages against competitors. The BREEAM certificate has investigated how to include credit counting if the company includes hand picking work, unemployed staff, among other criteria[107].

106 Interview with John van Herk (*Sloopaanemers*/ VERAS).

107 Interview with John van Herk (*Sloopaanemers*/ VERAS).

Regarding consumers, despite the increasing number of interior architects and designers consuming used products from demolition companies as mentioned in the previous section, according to a survey from Arch-Vision[108] for architects in the Netherlands, sustainability is a relevant condition when choosing products during the design phase. However, used products are not considered a sustainable criteria despite the fact that almost half (47%) of the interviewed architects responded that they would pay up to 15% more for sustainable certificates. This result indicates the lack of information regarding the environmental benefit of reusing as discussed by the guidelines in Chapter 1. Information as a catalyst for practical decisions towards reusing is an element discussed both in interviews and existent literature.

Heynen et. al. (2006) discussed different relations between information and the metabolism of cities, including information on consumer awareness for sources of toxic elements and dumping activities, and information on the system to recover obsolete products. Nelson (1970) indicated how the lack of information influences consumer decisions. In the case of reuse, interviews and literature indicated that information is critical in different aspects including where to find used products (Addis, 2012), how to reuse (Gorgolewski and Morettin, 2009; Poelman, 2009) and how consumers respond to used products (Ogbu[109], Peattie, 2010). Disseminating information is critical to build social relations and consequently demand for used products.

Compared to new products “off the shelf” that displays information regarding technical specifications and are associated with known brands that the consumer is familiar with, used products usually do not offer the same level of communication. Unlike new products, no catalogs are featuring technical specifications; no description of a comprehensive inventory of products is broadly available in stores.

Consequently, when information about the product is not available or is poorly visualized in websites or printed material, more time is needed to reach physical sites (stores or individuals), affecting the research phase needed prior purchase, turning into a time-consuming experience for customers, who will finally opt to purchase new products. According to Ogbu[110], these challenges tend to decrease after designers and builders have worked with used products for the first time, overcoming a sense of demystification of the problem while creating a better understanding of availability and demand.

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108 http://www.arch-vision.eu/

109 Interview with Liz Ogbu (Public Architecture) focused on survey made with architects.

110 Interview with Liz Ogbu (Public Architecture) focused on survey made with architects.

Additionally, the way the information is constructed and shared with users influence perception about used products. Either in physical stores or e-commerce, the way and facility to present used products to potential consumers is a recurrent factor discussed in the literature and during interviews. As Chen et al. (2006), Jongert[111] emphasized that physical stores, as well as e-commerce, lack the qualitative components to improve consumer interface and improve information regarding attributes of used products. Some retailers are keener than others to create attractive showrooms and websites[112].

Weak promotion and the way products are displayed to the public, contribute to the stigmatization of reclaimed materials seen as inferior to new ones[113] (van den Briel and Bolhuis, 2013). An experiment done by *Bouwcarrousel*[114] compared new ceramic bathroom accessories with used ones. The results, derived from interviews, revealed that for the general public there was no visual difference, but the preconception of purchasing a used ceramic bathroom product was a barrier for consumers. Also according to Gort and van Ijken consumer perception is an additional element in marketing this type of products.

As mentioned at the beginning of this chapter, in the Netherlands, demolition companies have a central role in reusing from harvesting to retailing used products and consequently defining much of the network, prices, what to reclaim, and finally how to define the interface with customers. The multi-function role of demolition companies vertically integrating several activities within the reuse chain while economically justifiable, it can affect the level of specialization for each task.

The existence of a value-added market also as seen with the antique type of products or cascaded ones is relevant for the business model as it prevents stigmatization often associated with used products. Promoting added-value products is also an informative (educative) tool[115] influencing culture barriers and public perception. Cascade reuse and (re) manufacture could benefit from design tools and guidelines to support creative thinking among designers and architects as discussed at the beginning of this section, specializing the skill today performed by some demolition companies.

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111 Interview with Jan Jongert (SuperUse Studios).

112 Interview with Jan van Ijken (*Oude Bouwmaterialen*)

113 Interview with Jan Jongert, Jan van Ijken, Liz Ogbu, Shannon Goodman.

114 Interview with Rob Gort (*Bouwcarrossel*).

115 In the field of furniture, a long trend of reused materials have increasingly taking more space in the media in the Netherlands and other countries in Europe in special the UK, which is a turning point regarding public perception. Among relevant examples are Piet Hein Eek, Droog and SuperUse Studios Architects, Martino Gamper.

Moreover, forms of commerce as an informational instrument also influence social interface (Guttman et al., 1998; Wang and Zhang, 2012). According to Gort and van Ijken[116], large companies specialized in recovery and commercialization of used products from buildings (*Bouwcarroussel* and *Komu b.v.*), as well as companies listed in the directory of *Stichting millieunet* were no longer active in the market. Nonetheless, virtual access to information has been transforming the retail sector[117].

The format of these services varies from material exchange platforms; store inventories, auctions (such as E-bay) and classifieds.

It is not known the volume of capital and materials generated through e-commerce of used products in relation to physical stores[118]. Some physical retail yards have evolved from virtual platforms in Belgium[119] due to increase of commercialized volume. According to Rob Gort and Jan van Ijken[120], e-commerce is also a form of competition to the brick & mortar commerce, even when demolition companies and specialized retailers advertise their products in the same websites (*Marktplaats*) as general individuals.

User-unfriendly websites[121] and lack of clear specifications also affect consumer perception. Chen et al. (2006) studied the potentials of e-commerce for C&D waste reduction in landfills. Their simulations showed that although the on-line construction and demolition waste exchange system could efficiently reduce C&D waste disposed to landfills and increase the use of recovered materials in buildings and civil works, it also presented some barriers:

- "*Contractors pay less attention to C&D waste reduction;*
- *Information of waste exchange is scattered on many different websites; and*
- *Websites are lacking user-friendly/efficient operational mechanism to pull users*" (Chen et al, 2006, pg.710).

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116 Interview with Rob Gort (*Bouwcarrossel*) and Jan van Ijken (*Oude Bouwmaterialen*).

117 Interview with Rob Gort (*Bouwcarrossel*) and Jan van Ijken (*Oude Bouwmaterialen*).

118 The DIY sector as discussed in previous section is economically relevant for the demand of used products in the Reclaim market, but this study did not include the e-commerce as a separate commercial segment, which includes commercialization of used products by individuals rather than by companies. Future studies could investigate the relevance of e-commerce in regard to number of transactions, amounts of materials and capital exchanged.

119 Interview with Lionel Billiet (*Rotor*, Belgium).

120 Interview with Rob Gort (*Bouwcarrossel*) and Jan van Ijken (*Oude Bouwmaterialen*).

121 Interview with Shannon Goodman (LifeCycle Building Center).

Previous to the diffusion of e-commerce, finding suppliers of used building products depended on directly contacting demolition companies, implying in time-consuming research for customers. Designers can also lose a critical amount of time to research and manage used material suppliers and access appropriate information about products at the design phase; increasing cost at the project level[122].

One method found in the United States was the exchange of information through a broker that connects sources of used products to potential clients. The broker can also function as a design consultant that works closely with demolition sources (Reuse Planet[123], Re- Use[124]).

Once products are released from buildings from demolition sites, it is more challenging for the consumer to localize reusable products (Addis, 2012). One reason is the lack of platforms that publicly announce demolition works. E-commerce of used products in this context has promoted a quicker exchange of products in the reuse market, either between individuals or companies.

Tools originated from the geomatics movement focusing on various aspects of navigation, cartography, environmental assessments, natural disasters, reveal the potential to assess how the building stock evolves with the goal to identify material accumulation for recover. The democratization of information is a relevant condition for bottom-up initiatives to emerge and create networks to direct material flows towards waste prevention as the Harvestmap.org[125] and Opalis.be[126]. As different technologies evolve, information becomes more openly accessible increasing the number of stakeholders involved in the building material metabolism. According to Jongert[127], such information sharing platforms are tools to build spontaneous symbiotic relations among different parties to optimize flows of products by deviating from waste treatment.

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122 Interview with Liz Ogbu (Public Architecture).

123 www.planetreuse.com

124 www.reuseconsolting.com

125 www.harvestmap.org

126 www.opalis.be

127 Interview with Jan Jongert (SuperUse Studios).

One of the largest databases of retailers of used building products in the Netherlands was the http://www.kringloopnet.nl, created and managed by the *Stichting Milieunet* (Erik van Erne), which became defunct in 2000 from lack of subsidies. In Belgium, a similar on-line directory was placed by Rotor, Opalis.org. A more diverse version in the Netherlands is the Harvest Map from SuperUse Studios (Figure 4.7), which combines information about available materials for reuse, showing examples of products made out of used products and sourcing details.

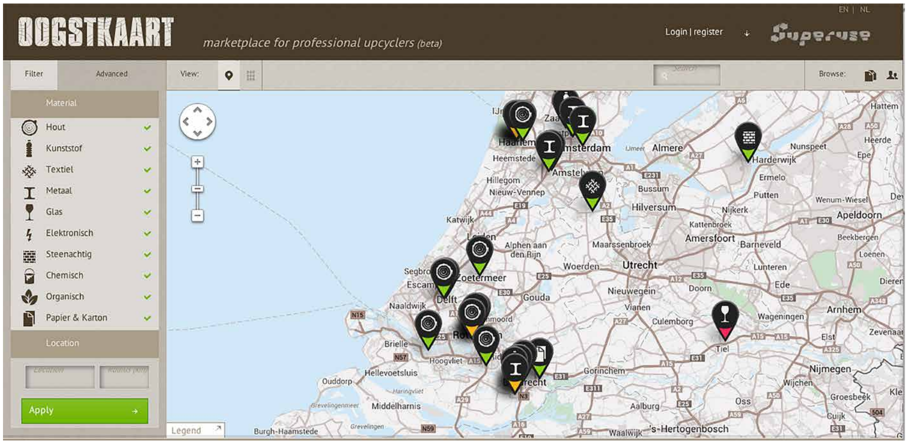

FIGURE 4.7 Harvest map (SuperUse _ Oogstkaart).

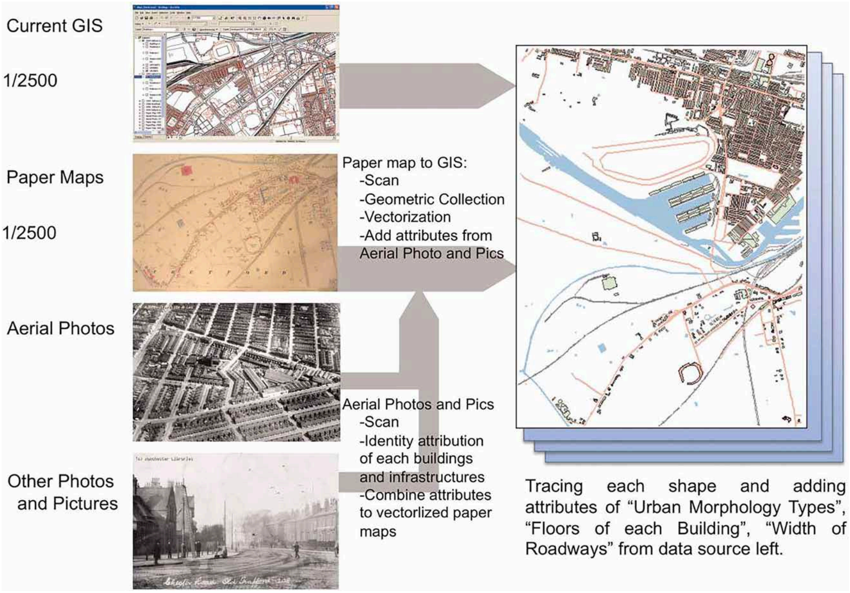

FIGURE 4.8 Establishing the 4d-GIS database for urban areas (Tanikawa and Hashimoto, 2009).

Harvest maps combined by searching engines identify and update data reference of suppliers. Further information about the volume and characteristics of the material or product available for commercialization can be added in the reference link about the supplier.

Another approach is GIS maps displaying existent and historical building stock (Figure 4.8). GIS maps display the evolution of the building stock in a given area. These maps contain information on building typologies, age, and frequent material content. Although not used to extract building products for reuse, Tanikawa and Hashimoto (2009) used 4D GIS with the goal to increase information of demolition patterns and material accumulation to improve building waste management in the future.

A study from the *Bouwkunde Hogeschool* Utrecht developed a mobile phone application to help users to find information on where and what building materials are available for reuse in their geographic proximity[128]. Another initiative towards reducing the search time for sources of used products was done by (former) D- Build.org in the

128 Bas Slager, Thomas van der Veen (*Bouwkunde*,– *Hogeschool* Utrecht).

United Sates, promoting on-line service between demolition projects and potential users by announcing deconstruction projects among group members[129].

Hemstrom et al. (2012) and Fujita and Iwata (2008) also identified that centralization of information through a database system connecting products and several agents is a valuable tool to increase visualization of sources of reusable materials and products through research.

Besides the adaptations to compete with new technology (e-commerce), given challenges to increase demand for used products (Jan van Ijken[130]), mixing old with new products is also a strategy used by retailers (demolition companies)[131]. The advantage to selling new products together with used ones is that it allows a way for customers to purchase products (right on the spot) that can be complementary to their work even as small elements such as screws, nails, pipes, minimizing trips to other stores[132]. The idea to integrate the "off-the-shelf" experience with used products creates a more familiar environment for the consumer[133].

"*There are important lessons to take from the DIY retail approach. These include a recognizable brand, vibrant interior for a broad base of customers and careful monitoring of sales to synchronize stock allocation with consumer preferences*" (Bioregional, 2008[b], pg. 15). Different informational platforms are relevant instruments to increase knowledge in all aspects of the reuse process. Oosterhuis et al. (2009) suggested that only tax reforms might not achieve expected results to improve waste treatment. The absence of larger markets as a reflex of low demand for used products[134] is a critical part of the economic decisions.

This subsection demonstrated how information could affect potential users, how it could change the central roles of demolition companies, and how e-commerce has been disrupting the traditional commerce of used products. Finally, another aspect discussed during interviews and also found in literature is the lack of certificates or

129 Interview with Jan van Ijken (*Oude Bouwmaterialen*) and Rob Englert (D-Build.org).

130 Interview Jan van Ijken (*Oude Bouwmaterialen*).

131 Interview with Fred van Ooyen (*Van Baal*).

132 Interview with Fred van Ooyen (*Van Baal*).

133 Interview with Fred van Ooyen (*Van Baal*).

134 Interview Jan van Ijken (*Oude Bouwmaterialen*).

quality control of used products that can inhibit consumer's will to reuse. This aspect will be discussed in the next section.

Main findings on the social factors

Gorgolewski, Morettin (2009), Bakas et al. (2011) and Poelman (2009) examined the absence of information schemes to engage and instruct architects and designers in more active roles in the practice of reuse. However, other forms of information were found to be also capable of stimulating the practice of reuse that goes beyond more traditional education channels or Environmental Knowledge (Peattie, 2010). Information systems to improve reuse are not only related to green consumption.

Besides green credentials and education as forms of training designers and architects to include used products in new projects, other self-organizing informational systems showed to be relevant to improve demand for used products.

Virtual channels can support the identification of current and future sources of used products, influence time for research, storage costs while increasing competition with physical stores. Moreover, information as improved descriptions of product content, inventories of used products available for commercialization as well as how these products are presented to the potential consumer are relevant regarding consumers that are more used to characteristics of traditional commerce of new products supported by specialized marketing tools.

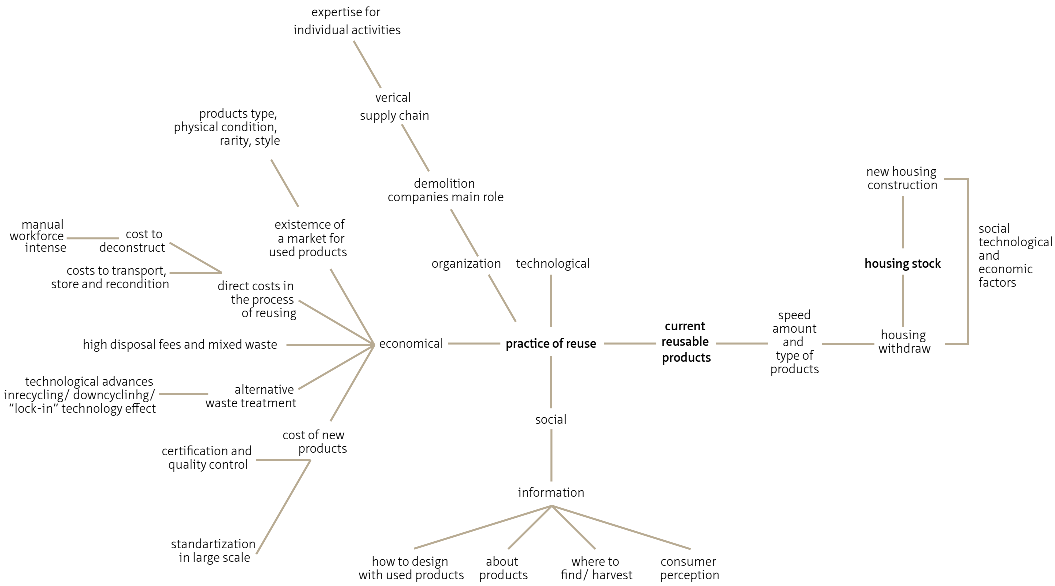

FIGURE 4.9 Social factors related to the practice of reuse building products in the Netherlands.

In summary, there is limited knowledge regarding the interface of human behavior with used products both related to volume as in quality of data. However, it has been shown that improving information systems regarding visualization, localization, and content of used products as a form of decision support to facilitate consumer research and perception, should be taken into account to reinforce the presence and development of a market. Figure 4.9 indicates how these findings integrate the original proposed model.

§ 4.3.3 Technological factors

Technology influences the way materials are processed (Ayres, 1997) and foster critical relation with industrial structures and consequently the economy (Schumpeter, 1962; Phillips, 1971; Nelson and Winter, 1982; Nelson, 1995).

Technology is critical to transform natural resources into products as well as to harvest, process and treat used materials and products generated after consumption. As technology evolves in collecting, sorting and treating used materials and products, it influences the economic value of what is considered waste and what is considered commodity (Johnson et al., 2008; Ayres, 1997). Therefore waste management, "both definition and objectives have changed over time and are still changing" (Brunner and Rechberger, 2004, pg. 17). This section examines the role of technology in reusing building products in different stages:

- (Technology and) Reserve
  Technology as construction systems comprising the existing housing stock;

- (Technology and) Harvest
  Technology applied to harvest products to be reused;

- (Technology and) Application
  Technology as condition for consumption of used products.

1 Technology and Reserves[135]

Harvesting building products for reuse vary according to physical characteristics of the built stock. According to Chini (2005), in the U.S., the characteristics of frequent building typologies, the nature of materials and the way the products are built, determine the level of deconstructability of a project. Consequently, the investigation in this section focuses on the understanding of the transformation of physical characteristics of the built stock and how it relates to the harvest of products to be reused.

Among interviewed companies in this research, prewar houses single-family houses are preferred to be deconstructed for product reuse[136]. This group of houses is more frequently deconstructed for reuse due to the technical feasibility to deconstruct them, as well as the market demand for the types of products that are recoverable. These products are often high-quality hardwood doors, flooring, beams as well as rare ceramic and stony products[137]. Post-war multi-family houses are more concrete intense, and comparatively, to pre-war residential constructions, their products are less likely to be harvested for reuse due to challenges during deconstruction process as well as the lack of demand for the type of products often available in this building category (reuse of concrete based products).

135 Findings described in this section relates with two drives in Chapter 5 (construction year and building typology) in the study of reserves in Chapter 5.

136 Interview Jan van Ijken (*Oude Bouwmaterialen*) and Tristan Frese (*Schijf*).

137 Interview Jan van Ijken (*Oude Bouwmaterialen*) and Tristan Frese (*Schijf*).

The evolution of building techniques reflected by periodically shifts in construction systems and technological innovation is relevant when considering types and amounts of products released concerning reuse. It is also directly related to product demand (or existent market as seen previously) as well as the feasibility to deconstruct according to existing "deconstruction" technology (see in next section)[138]. It is therefore relevant to understand the evolution of technologies in the built stock.

There is limited updated research with an extensive description of the housing stock regarding building technology and material content. Some of them were produced in 1990 and 1971 (van Elk and Priemus, 1971; Thijssen, 1990). Other studies (Verhoeks et al., 1995; Straub, 2001; Feijen, 2003 and van Nunen, 2010) included a description of building materials and products in the housing stock more focused on environmental impacts material consumption during the building's lifespan. Other literature included in this investigation concerns broader historical information of the construction sector (Blaazer and van Gessel, 2011; Noy and Maessen, 2011; Oosterhoff, 1990). Few studies (Diederen et al, 1989; van Battum, 2002; de Lange, 2011) have focused attention on more specific housing typologies or constructive characteristics from specific periods.

Bot (2009) developed extensive investigation of the history of building materials used in the Netherlands during late 1800 until recent times. His work and similar historical reviews helped to locate when new building technologies were introduced, nonetheless, broad diffusion of these techniques was complex to define.

Leupen et al. (2011) have described the most common housing construction systems by classifying structural elements that dominate the output of building methods in the housing sector, shaping the most common post-war housing typologies in the Netherlands. Such approach converges building shape, physical evolution of housing plans and technology.

138 Shifts in material and technology use vary in time and reasons why they occur. Moors (1991) investigated shifts in use of construction products in the period 1984- 1989. In this period he showed how the use of Portland cement, asbestos cement, synthetic paints and lead decreased due to changes in price or environmental concerns.

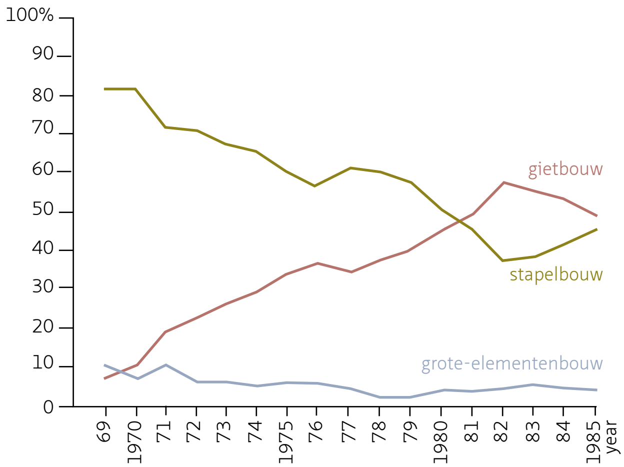

FIGURE 4.10 Shares of *Stapelbouw*, *Gietbouw*, *Montagebouw* 1969 to 1985 (Diederen, 1989).

Material accumulation in the building stock evolved with evolution of building technology. Initially, in the Netherlands, housing construction was mostly based on wood and masonry. The decline of wood consumption for housing construction was in the first place related to fire risk in urban areas and later to price increase of wood during war periods (van Beusekom, 2006), following systematic increase of concrete consumption happened after the WWII.

There are four most common constructive systems applied in housing in the Netherlands and some hybrid combinations: *Stapelbouw, Gietbouw, Grote elementen, Hout skeleton*[139].

Market distribution of the different construction methods evolved over time, varying the frequency and range in which they occur in the stock. Figure 4.10 shows the continued increase in popularity of *Gietbouw* system. According to Cement&BetonCentrum[140] during the 80's, limestone gained a higher share of the market but in the 90's *Gietbouw* surpassed limestone consumption.

139 *Stapelbouw*: construction system mainly characterized by stacking elements as blocks and bricks. *Gietbouw*: Constructions mainly composed by pouring concrete on site. *Grote elementen*: Large size (walls and floors) pre fabricated elements are transported to the construction site ready to be assembled. *Hout skeleton*: Building structure is in its majority composed by wood elements largely including framing and panels.

140 E-mail from Wim Kramer.

According to van Elk and Priemus (1971) in the Netherlands, the most common constructive systems mentioned above can be classified in two main groups:

A Traditional
In this category traditional construction with wooden floors and no cavity walls is most commonly found in constructions before 1950. Concrete floors and cavity walls are also an adaptation of this method. *Stapelbouw* is the common term to define this segment and is mainly characterized by walls and floors being mounted on site by hand. Commonly, the walls are made of blocks and floors are mounted with prefabricated small elements. The most common methods found are *Airey* and *Muwi* (Annex 4.1).

B Non-traditional
Non-traditional construction methods are characterized by increased use of concrete and reduced workforce and time. They are largely applied in housing developments that are built in large groups. *Gietbouw* and *Montagebouw* (Annex 4.2) are in this category. Later wood frame (*Hout skeleton*) system also appears as an alternative constructive method.

In none of the literature references above, building technologies were described from the deconstruction point of view, showing that construction systems evolved more focused on time and economic efficiencies during construction and less focused on the end phase of buildings.

The other group of references found is a collection of periodic reports focused on building energy efficiency, published by Dutch governmental agencies (*Agentschap Nl*, 2011[ab]; VROM, 2000; VROM, 2006; *Senternovem* 2007; *Novem*, 2001), which provided information about the current physical composition of the housing stock according to a large number of collected samples. In this way, the housing stock is a compilation of common existent characteristics[141]. Such reports show that current sustainable building policy in the Netherlands is mainly focused on energy savings (Itard et al., 2008). These energy performance reports commissioned by the government could include substantial data from the building stock with descriptions of building systems and also give indications of renovation cycles. However, such initiative requires government effort, which has more recently been driven by concerns about the housing stock status[142].

141 According to Haico van Nunen (interview) these reference houses do not exist in the stock, as they are the result combination of several common physical characteristics, rather than the description of one common house per se.

142 Interview with Prof. Thomsen (TUDelft).

At the time of this research, there has been no update of the *Basisrapportage Kwalitatieve Woningregistratie* since 2000, which included extensive description of the housing stock from the technical condition point of view.

The reports mentioned above and others produced to support energy saving renovations in the existing housing stock in the Netherlands (Persoon, 2011; Archidat, 2012) are used for comparative analysis regarding building physical characteristics. These two reports were chosen due to the updated information content as well as being common references in construction practice. These references classified the existing housing stock by construction year and building[143] typology. Not all characteristics matched and some approximations were made[144].

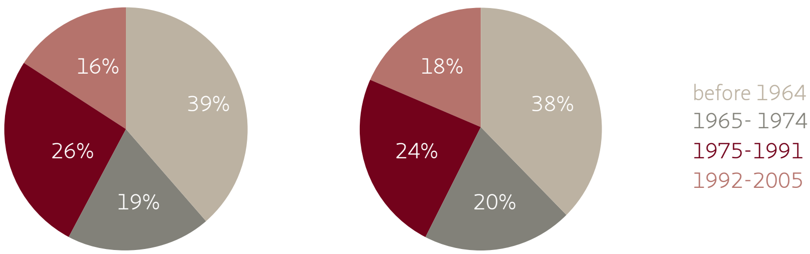

FIGURE 4.11 Share of houses according to construction year in % and share of houses according construction year in m2. (*Agenstchap Nl*, 2011).

Figure 4.11 uses data generated by *Agentschap NL* (2011[a]) to understand the scale of each housing group period in stock and how the stock can be characterized by material and product type content. When combining information regarding material composition and different construction systems, with the description of the existing housing stock according to more current reports as mentioned above, an estimation of what types of materials and products accumulated in the existing housing stock was generated as follows:

143 Single family/ multifamily or detached houses, terrace houses, etc.

144 Investigating the housing stock by construction year will support the stock dynamic analysis in Chapter 5.

- Houses before 1945.
  This housing group is characterized by traditional construction. Floors were constructed of wood foundation and wooden floorboards. The pre-war facades are mainly executed in solid masonry. Pre-war homes are characterized by wooden framed pitched roofs are traditionally manufactured as spores or *gordingkap*. For large spans truss structures were applied. The sheathing (roof deck) was also made of wooden parts. Upper floors were manufactured almost exclusively as wooden rafters with wooden floorboards. The beams were anchored to the walls by dish or hook anchors. These anchors provide a constructive link between wall and floor area. The ceiling often consisted of stucco on a reed layer, which battens to the rafters was connected (see Annex 4.3).

- Early postwar housing from 1946- 1964
  Built in the period immediately after the Second World War. Two-thirds of these are single-family homes and a third are multifamily houses. Despite new emerging building technologies being offered in the market, the construction started slowly with a shortage of building materials and skilled workers. The vast majority can still be considered to be traditional construction techniques. The facades were usually from non-insulated cavity walls. Roof and floor structures are in many cases made of wood, but also due to lack of wood, stone-like materials were applied in special hallways and kitchen area as well. Reinforced concrete flooring was not yet largely applied. To save cost and weight, hollow blocks flooring systems, both pre-fabricated and on-site, are found more commonly on the ground floor after 1950. Houses from this period are often part of the social rented sector and are compared to the pre-war homes generally being relatively small. In this study, using these descriptions, the single family houses from this period will be characterized as having wood structure floors. Window frames are still characterized by wood or steel. An amendment to the Housing Act in 1955 had significant consequences for the restriction in the application of wood floors in apartment blocks (multifamily), due to fire safety and sound requirements. In the area of the sloping roof and finishing, little has changed compared to the pre-war type buildings, formed by purlins or traces. For large spans, the traditional truss structures are increasingly replaced by simpler to implement stitch spans. In addition to performance benefits this type also reduces the amount of construction wood truss. Flat roofs are structurally similar to the upper floors. Roofs are usually not insulated (see Annex 4.4).

- Housing shortage period 1965- 1974
  A radical increase of housing constructions is seen in this period due to population growth and immigration inflows, despite the short period of time. The large multi-family blocks are built in this period. Modernization of building techniques to increase speed and decrease construction prices increased during this time. Today, the two techniques, constructions with large prefabricated elements and tunnel formwork, are the most common construction systems in the country. Facades were mainly cavity walls without insulation. Pre-fabricated stony based material floors and roofs were more commonly used. New techniques, low cost construction and the speed to respond to the large demand caused various technical problems and poor design related issues in the buildings from this period. These houses are mainly non-insulated cavity walls of cheaper and less labor intense larger sized elements (blocks or elements of light-weight concrete, gypsum and limestone). Window frame profiles are more standardized with aluminum profiles and condensation silicone sealants have been applied since the mid-60s and slowly replaced putty sealed windows. Roofing systems have changed by the technical developments as a result of the housing shortage. During this period use of prefabricated roofing increased. These prefabricated roof systems are tailored made for the house measures and not ideal to be reused in a different roof (see Annex 4.5).

- Houses built during the energy crisis 1975- 1991
  Seventy five percent of them consist of single-family homes. The oil crisis of 1973 triggered policy changes in the field of energy efficiency that affected building regulations at a national level. In 1975, the first guidelines were proposed. The U-value for roof and solid walls was adjusted to 1.3 m^2K /W. In 1979, the use of double-glass was required for living rooms, while the upper floor(s) usually were equipped with single glass windows. In 1983 the minimum U-value required for the ground floors was 1.3 m^2K/W, became mandatory. Many houses from this period are made of improved industrialized construction systems of stacked elements, prefabricated elements or poured concrete. Increased standardization was more effective in both ground and upper floor flooring systems. Roof structures were usually performed as an isolated roof system. Insulated elements for roof and flooring are clearly present within these constructions. Although many wooden window frames were used, consumption of plastic and aluminum frames increased. According to Hasselaar (2001) around 1985 plastic window and doorframes were introduced in the market. Because of the reduction of front façade spans due to the energy crisis, pre fabricated roofs partially replaced traditional wood trusses roofing. *Ribcassette*, tunnel construction and concrete channel plates were improved from the energy crisis period and remain until today the major ground floor systems (see Annex 4.6).

Technologies as reserves refer to the evolution of construction systems applied in buildings. What has been seen in the paragraphs above is that residential construction systems in evolved to become more concrete intense and complex to deconstruct with the goal to reuse each independent component. Comparatively, traditional construction systems were also not designed to reuse individual products at the end of their life cycle, however, because of a broader application of wood products, lime-based mortar for brick layering, durable clay tiles, this constructive system are more feasible to be deconstructed with the available technological mean. Either in new constructions or renovations, the focus has been in cheaper, quicker and energy saving strategies and less on flexible use of homes (Brinksma, 2017) and future material cycles.

2 Technology to harvest building products for reuse

Technologies applied in building deconstruction influence time, costs and the conditions building products can be harvested for reuse as mentioned in previous sections. This process is known as selective deconstruction[145] (Chini, 2005, pg.12) or stripping, that in contrast to demolition or selective demolition, it prioritizes collection of products and components rather than at material level for further recycling (and downcycling).

There has been increasing technological development towards remote demolition in contrast to more manual based traditional deconstruction (Patel, 2010). Only few technology focuses on selective deconstruction for reuse (Chini and Bruening, 2005), as result of increased costs of workforce, increase time pressure to demolish[146] (as the recovery of materials is not considered as an economic benefit) and health and safety measures (Hobbs and Hurley, 2001; Patel, 2010). Such evolution also reflects the change in the way demolition companies were organized from "*undercapitalized contractors using a lot of casual hand labor to large highly capitalized concerns using human-operated machines to replace hand work*" (Kay and Essex, 2009, pg. 7).

In general, technologies that substitute manual work in deconstruction for reuse have not evolved as fast as in the demolition practice in the Netherlands, especially for more traditional construction systems as defined by interviewed companies. Deconstruction requires more care and more time to be completed when compared to demolition

145 "*Deconstruction seeks to maintain the highest possible value for materials in existing buildings by dismantling buildings in a manner that will allow the reuse or efficient recycling of the materials*" (Chini, 2005, pg. 12).

146 Interview Jan Jongert (SuperUse studios).

(O'Brien et al., 2006). When comparing different existent demolition methods, Hobbs and Hurley (2001) classified "by hand" the method reserved for product salvaging, characterized by labor intense, slow, expensive and good segregation and make use of portable tools.

Under the Rotterdam Climate Initiative, the theme of including manual work in deconstruction has been discussed as part of the Slim Slope project where more material recovery could be made possible while increasing job creation for critical social groups[147]. The practice of deconstruction has also long been active in training programs associated to social activities (Institute for Social Self Reliance, The Reuse People of America), advocating for job creation and training opportunities for low skilled workers through deconstruction (McGrath et al., 2000, Chini and Bruening, 2005; Dehoust et al., 2010). In Colorado (U.S.), non-for profit organizations are eligible to apply for credit if they show that the output of material donations are reverted to job creation activities (McLear and Nobe, 2011), making deconstruction for reuse a matching recipient for community development and social projects. It is however critical if the employment of low skilled staff is a condition for economic feasibility for the deconstruction process in the long term, which is opposite to increasing sophisticated sensor-based automated technology (as robots[148]) at the sorting and recycling phase with less attention to deconstruction.

The effort in closing cycles will rely on a great effort in technological changes (Dijkema et al., 2000), and hence evolving according to investments from the respective material industries and manufacturers. If development of technologies proposed for material recover and transformation into valuable resource is a precondition to close material cycles (Odegard et al., 2012), one question that emerges is how to assess investments for technology development for building deconstruction at product level considering the differences between a decentralized and informal industry of reuse represented by small size companies in comparison with recycling industry more integrated with the material large scale manufacturers (plastics, metals and cement)?

To understand what are the technical implications for product harvesting for reuse, a questionnaire (see Annex 4.7) was submitted to 81 demolition companies listed in the Sloopaanemers directory (apparently[149]) active in reuse of building products and to specialists in retailers of reused building products. The aim of the survey was to understand quantitative capacity of product reusing associated to commercial

147 Interview with Hans Oranje (*Oranje b.v.*).

148 http://www.zenrobotics.com/product/; http://www.omerh.com/skills/projects/

149 Some of the demolition companies' websites indicated to commercialize used products.

demand, types of buildings, their construction year and available technology to deconstruct. The questionnaire presented a summary of the existing housing stock in the Netherlands as classified by the *Agentschap NL* (2011[a]). The questionnaire also included description of building products by material type and by building system (structure, facade, flooring, etc.) based on the findings of the previous section. During interviews the questionnaire was answered in form of average percentage rates[150].

Both *Restoric* and Van Baal indicated approximate 50% rate of recovered materials for reuse. *Restoric* and *Oude BouwMaterialen* mentioned that prewar houses were the preferred group to deconstruct for product reuse, whereas *Van Baa*l harvests products from a larger range of building types including commercial. The unpredictability to evaluate the condition of products found during deconstruction was the primary justification for an approximate average percentage. Rob Gort (*Bouwcarrousel*) estimated that from 30% to 70% of products in a generic building could be recovered for reuse, but a 40% recoverable rate when considering losses in transportation and recondition. These rates however correspond to products to be reused in their original function. Despite the small number of companies answering the questionnaire (5 out of 81), the former Bouwcarrousel (Rob Gort) provided 450 inventories with recovery rates of building products for reuse from housing deconstruction and housing renovation (see Annex 4.8). The analysis of all inventories resulted a total of 57% of recoverable products from diverse types of dwellings excluding structure. Each rate accounts for percentage of reusable products from the total amount of similar products (e.g. 50% recoverable sinks from total amount of sinks in the building). Recoverable products varied from doors, taps, staircases, windows and most of them wood based components.

Another reference (Gort et al., 2007) focused specifically on post war gallery flat residential buildings in the Netherlands (see Annex 4.9). Despite differences between building typologies and constructive systems from which the inventories derived, the average of recoverable products for reuse was similar (52%).

The inventories mentioned above were the most consistent source of information available. Pre demolition inventories made by demolition companies are also relevant source of information but were not shared by interviewed demolition companies. These inventories are part of formal procedure for building demolition, but could also be instrumental to create descriptive information of recoverable products available in the built stock.

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150 Interviewed companies: Tristan Frese (*Schiff*), Jan van Ijken (*Oude Bouwmaterialen*), Robert Barclay (*Van Liempd*), Fred van Ooyen (*Van Baal*).

3 Technology as (re) condition to reuse products

Technologies applied during the process to recondition used products prior commercialization vary according to material type, product type and condition, as well as to the business model that justify the harvest and level of processing.

In regard to products that are reused in their original function, it is relevant that they should be in accordance to updated building regulations, which demands adequate inspection and quality control. Technologies and specific procedures to evaluate and certify reclaimed building products are deficient, and it is a phenomenon not only limited to the Netherlands[151] (Lazarus and Hillary, 2006; Addis and Schouten 2004; Hemström et al., 2012). During field research, it has not been found in practice a system to evaluate physical properties of reclaimed building products. In the United States, Davis (2012) refers to the lack of proper rating systems in practice for reusable products including wood as the most common reusable type of material. In general, simple eye inspection is a common procedure (*Shijf*[152], The Reuse People of America[153], Oude Bouwmaterialen[154], Biorgional, 2008) to evaluate the condition of used building products.

Poelman (2009, pg. 112) suggested, "*facilities should be available to assess and certify the components related to specific applications*". Testing and certifying procedures imply increase in total costs to the retailer and consequently consumer price, or the costs are passed to a developer that could instead make savings by purchasing new products while minimizing future technical risks (Lazarus and Hillary, 2006). Structurally sound, toxicity, weather proofing, conventional electrical and fire standards are difficult to measure at times without a certain degree of accuracy and should be addressed according to the remaining lifespan of the product (Addis and Schouten, 2004; Hurley et al., 2002; Guy et al. 2006, Bioregional, 2008[a]; Hurley and Hobbs, 2003).

151 "*Practices for virgin materials exist but needs to be adapted for reused materials. Challenges related to quality assurance are emphasized in all studied countries and there is thus a basis to work on these issues at EU level through industry associations, standardizations bodies and authorities. Incentive structures to stimulate the reuse market are also needed. Possible triggers proposed in the interviews are e.g. to include a reuse perspective in public green procurement and in green building certification systems*" (Hemström at al., 2012).

152 Interview with Tristan Frese (*Schijf*).

153 Interview with Ted Reiff (The Reuse People).

154 Interview with Jan van Ijken (*Oude Bouwmaterialen*). All the interviewed demolition companies worked with visual inspection of wood, which is also a common practice in the UK as described in the publications of Bioregional.

Patel (2010) discussed existing methods that could support quality control of used steel structure as the quality standard system of the Construction Products Regulation_ European Commission 2010. In practice, in the Netherlands, no formal system was found to be in exercise when information was collected for this research.

The absence of product warranties poses a barrier to the acceptance of reclaimed building products when compared to new ones (van Ijken[155]). Few developers take the risk to build with products with no warranties and no technical specifications (van Eijke[156]). Being responsible to provide the necessary certifications (Addis, 2012, Jongert[157]) and evaluate technical performance of these products when applied in new construction projects, bring challenges for architects and developers. Therefore, increasing the level of information attached to used products assists consumers to work with a margin of safety.

Determining technical service related to building products, offers validation to generalized estimations (Huffmeijer and Damen, 1995; Straub, 2011, 2012). The inclusion of barcodes in construction products, so that they could be tracked through time and after being extracted from buildings, including information about their supplier, technical specifications, age (Straub, 2001; Chen et al., 2002; Addis, 2012; Nordby et al., 2009ª), could bring benefits when assessing information for further reuse[158].

Certifications and quality standards is also related to how industrial groups push for the introduction of newer and more competitive products[159], making used products gradually less competitive. Additionally, as building products and building regulations change over time, assuming that products should be reused only in their original function restricts other possible applications. Extending the life of products to be reused in their original function in new projects that may trigger inferior technical performance in other aspects of the building should be prevented. One example is the reuse of non-insulated-window frames in new or renovated buildings in relation to the evolutionary changes in regulating building codes towards energy efficient constructions (Beerepoot and Beerepoot, 2007).

155 Interview with Jan van Ijken (*Oude Bouwmaterialen*).

156 Interview with Jan van Ijken (*Oude Bouwmaterialen*).

157 Interview with Jan van Ijken (*Oude Bouwmaterialen*).

158 Interview with Jan van Ijken (*Oude Bouwmaterialen*).

159 Interview with Andreas Kellert (ICDubo).

The concept of "cascade" reuse in this context becomes increasing more attuned with activities and processes that associate with the practice of reuse building products in the Netherlands than reusing products in their original function with no reconditioning process.

Cascade reuse or "cascade utilization" (Haberl and Geissler, 2000), or yet "resource-cascading" (Lafleur and Fraanje, 1997) sets new applications for used products in functions that require inferior technical performance compared to the original one[160]. One example is the case of wood products proposed by Fraanje (1998) (Figure 4.12). In this process, the gradual quality reduction of a product does not impede an extension of use at the material level. 300 years of life extension through reuse and remanufacture prioritized before downcycling should not be under evaluated. The environmental benefits from cascade reuse are not taken into account under current waste treatment and policy to achieve environmental goals by local government (Odegard et al., 2012). Similarly, Barneveld et al., (2016) discuss how policy contradicts environmental goals promoted by the circular economy concept, which includes reusing.

Cascade reuse, therefore, widens the opportunities to use recovered products from the existing stock with possibly less technical restrictions. The term "cascade reuse" is essentially the level of flexibility of products in the building stock to undergo physical transformations in a hierarchical order, where products are transformed to answer less technical demanding functions, and from larger to smaller size products, prior recycling (particle scale)[161].

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160 "*Cascading is an important option that deserves attention in the quest for deciding the approach that needs to be taken to achieve an efficient and sustainable bio-based economy. In this study the concept of cascading is explored and it is shown that cascading can contribute significantly to the bio-based economy; between 10 and 12% of the target emission reduction in the EU of 2,235 Mton CO2 per year in 2030 (compared to 1990) could be fulfilled with the cascading options we explored*" (Odegard et al., 2012, pg. 7).

161 See cases demonstrated in Annex 4.10 Building components transformed into furniture.

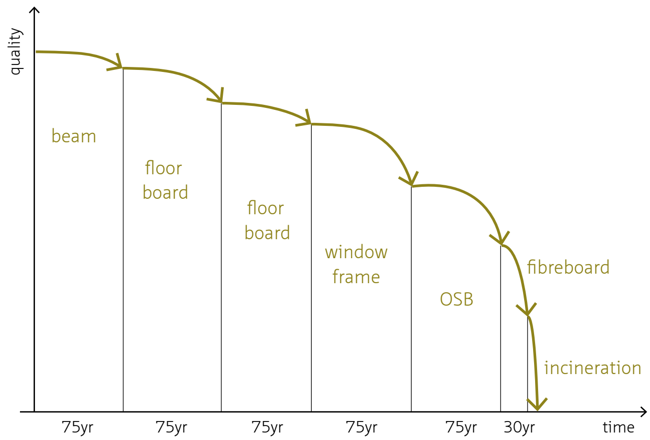

FIGURE 4.12 Potential wood product cascade for pinewood based on Fraanje 1998 (Goverse et al., 2001, pg.66).

Main findings on the technological factors

Three aspects in the technological domain indicated to influence waste prevention through reuse of building products (Figure 4.13). The first one regards technology as construction systems comprising the existing housing stock. It was found that harvesting of products for reuse is concentrated on pre-war housing group. Products derived from pre-war houses have higher consumer demand, as well as deconstruction processes for product reuse is considered more (technically and economically) feasible than non-traditional construction systems. Pre 1964 houses are still the largest housing group in stock, which are in general built with traditional methods (with the exception of the houses built in the first post war years). This housing group, however, tends to naturally decrease and be replaced by newer buildings, more concrete intense and based on non- traditional constructive methods. In essence, housing stock as a reserve of reusable products is decreasing as non-traditional constructions increase and market demand for pre-war used products do not expand to other types of products.

Regarding technology applied to harvest products to be reused, advances have manifested more towards remote demolition, whereas deconstruction for reuse is still mainly based on manual traditional work. This deconstruction method consequently increases health and safety risks as well as time and cost to deconstruct. Through traditional deconstruction methods, 30% to 70% of material content in buildings is considered recoverable for reuse. However, within this amounts products with low consumer demand are also included.

Moreover in the Netherlands, there is no official measure to evaluate and certify used products. Testing and certifying procedures imply an increase in total cost and lower competitiveness relative to new products. Additionally, lack of warranties also increases potential construction risks that will affect developers that are less likely to work with used products. Whereas building regulations updated through time, reusing products in their original function restricts total products to be prevented from waste streams. In this context, cascade reuse is technically a relevant approach for waste prevention.

In short, these factors combined help to define that what is recovered to reuse will depend on the market demand, which in turn is influenced by economic and social aspects. Nonetheless, such conditions could be affected by the integration of formalized procedures to offer certificates or quality standards for used products, maintaining economic competition with new ones. Also, regulating time to harvest products during deconstruction to prioritize reuse and, the improvement of technologies proven to bring economic and environmental advantages to deconstruction for reuse of non-wood based products should also influence the output of waste prevention.

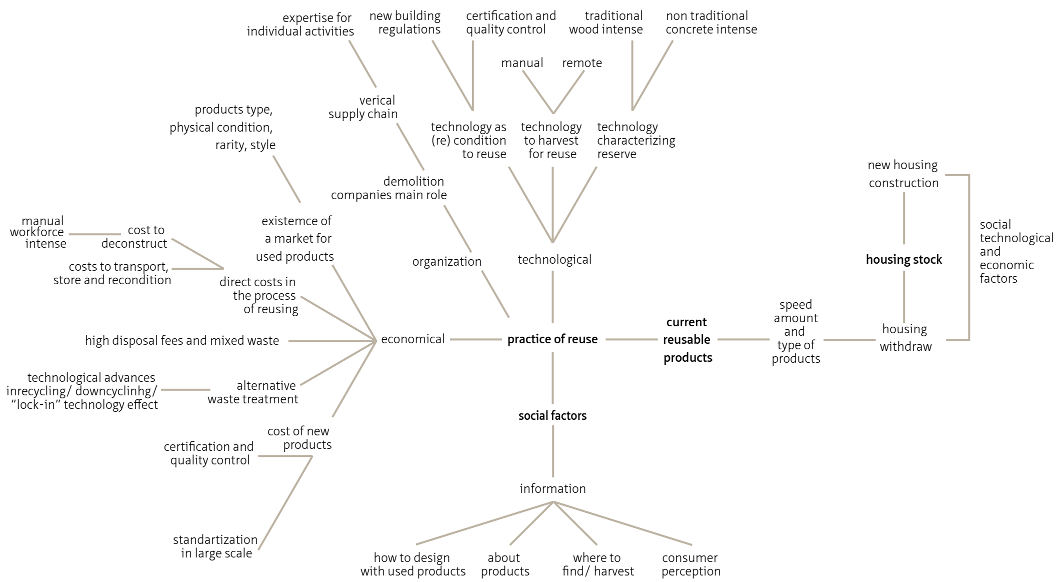

FIGURE 4.13 Technological factors defining reuse of building products in the Netherlands.

Additional findings in this investigation were: Careful consideration of the potentials accessible by cascade reuse and how they are and could be integrated with reuse could improve amounts of materials deviated from waste treatment. Moreover, development in technologies designed to facilitate building deconstruction, did not yet advance to improve building deconstruction for reuse as a more competitive process compared to selective demolition for recycling and downcycling. Investments in technological advances to harvest building products for reuse, able to replace manual workforce would bring benefits for the practice, however lobbying groups and funding for such developments when compared to alternative waste treatments were found inexistent.

§ 4.4 Answering research question 2

RQ2. How different (technical, social and economical) factors influence the process of building product reuse (in the Netherlands)?

This segment demonstrated how social economic and technological factors affect the practice of reuse in the Netherlands. Some of the characteristics identified in this study coincided with results from previous studies describing practices of building product reuse in other parts of Europe and of the United States. The overlapping points found were: a general lack of information about used (or reusable) products; lack of experts to execute specialized functions or enhance outreach about the industry; lack of trust in reusing products; conflict with other existing public policies; technology not yet mature to harvest products for reuse; labor costs influencing competition with new products (made in emerging economies); and limited uniformity and quality standards (Ferraresi no date available; Arold and Koring, 2008).

Although improvements can be made in each specific aspect, it is relevant to understand how they can affect the system combined. The map representing these relations reveals different ways to manage waste prevention through reuse and that adaptation to improve the system's performance have to consider the dynamic character of such relations. Though it was out of the scope of this research, there are clear indications of how the factors are interdependent, (for instance, if social awareness increases affecting the demand for used products, or if technologies improve to disassemble products for reuse decreasing labor costs). The map of relations proposed is a result of the research methodology discussed in Chapter 2, and it is a simplified representation of the actual findings, without revealing the interrelations between them, nor levels of predominance between them. It is recommended, however, that levels of influence between factors as well as a study of feedback loops within factors of the system are explored in future studies.

More complex relations affecting the practice of reuse were shown to concentrate in the economic analysis in comparison to social and technological factors. One explanation is that there is more information available (emphasis) on this topic in literature. Another explanation is that retailers of used products were the most representative group of interviewees, which is particularly motivated by the economic benefits of reuse. The economic cluster in the industrial system studied in this case can be interpreted as described by Ayres and Simonis (1994, pg. 3) the core of "*the metabolic regulatory mechanism*" influenced by social and technological factors.

External factors influence the economic benefit of reusing, which is related to developments in waste management, tipping fees, fines for mixed materials and, prices of primary resources. Direct costs involved in the process of reusing are critical parts in the economic equation including transportation, storage, and workforce to deconstruct as well as costs associated to more or less intense processes to recondition used products for retail.

Comparative costs of new products including the benefits associated with them as certifications; warranties; standardized measures; availability of products by demand; facility to find detailed information about used products and matching updated building regulations are some of the technological factors found to relate to economic forces constraining or competing with reuse.

The demand for used products is also related to the interaction between products and potential consumers that are influenced by the type and condition of these products, which determine the value and correspondent the type of market, and the way these products are presented to the public. It is relevant to remark that "value" is a critical component regarding this interaction. It reflects on demand, and it can change in time based on how consumer perception arises about an existing product or about the action to reuse. "Value" as seen in cascading reuse can also be added to a product that has been harvested perceived as low valued.

Other aspects found to be relevant to the practice are the lack of technological innovation focused on building deconstruction for reuse whereas construction technologies of new buildings are evolving towards concrete intense systems less feasible to be deconstructed for this purpose.

Another relevant finding is the rise of e-commerce providing trade of used products between individuals without the mediation of specialized retailers or demolition companies. Future studies could further investigate the volume of capital and materials traded through these platforms that could surpass traditional commercialization, reviewing the apparent decay of conventional commerce of building product reuse.

Moreover, it has been found that in practice cascade reuse is a relevant activity associated with reuse offering economic benefits and more efficient use of materials by adapting used products to new applications more adequate to their current technical performance. It is therefore also suggested further investigations focused on the potentials of enhancing cascade reuse in future strategies with the goal to improve existent initiatives already proved their feasibility.

Finally, previous studies discussed the relevance to educate designers and architects on the benefits and the application of used products. Additionally, green credentials given to architects and demolition companies with the goal to improve reuse are also a form of incentives. Information in a broader manner is critical to promote, understand and act in all stages of the chains, connecting waste owner to consumer. Lack of knowledge about products, where to find, how to use them and how this information is exchanged affects the commercial fluidity of reuse. Some of these aspects are the consequence of the internal industrial relations or how demolition companies concentrate several tasks within one business structure. It would be relevant to increase specialization of each one of the activities involved in the reuse process through marketing and product (re) development.

Once again, the dynamic character of how these relations occur in the real world also influenced by external forces have to be taken into account to comprehend the status of building product reuse and foresee future adaptation. The map of relations described in this chapter aims to simplify the findings described in this chapter, representing a generic mechanism that can adapt according to different levels of detail and specificity of the subject in focus.

Whereas this chapter identified how organizational, social, economic and technological forces influence the process of reuse, the following chapter continues to examine how these relations are bounded to define what products are considered commercially viable for reuse. Understanding what products can be commercially reused in the existent context is a reference to estimate the capacity of the industry to deviate materials from waste streams, and to later reflect on the stock trends of such products in the country scale (Chapter 6).

5 Evaluating Reusability of Building Products

RQ 3. Which building products (and respective material types) are more prone to be reused in the current context in the Netherlands?

Chapter 3 described how dynamic relations conditioned by the industrial organization; economic, social and technological factors affect reusability of building products. This chapter investigates how these conditions are associated with more specific types of products. The goal is that the answer to the research question 3 serves as a reference to understand how trends in material accumulation and release from the building stock could affect supply for reuse.

Information available in the international literature combined with an inventory of products commercialized by interviewed companies and research-based on specialized Internet websites available in the Netherlands was collected to answer the research question 3. As discussed in Chapter 1, existent literature can be classified by their central focus. More commonly, technical feasibility case study focused (de Haas et al., 2002; de Vries et al., 2005; Gort et al., 2007), or mixed subjects regarding building technology and deconstruction (Hurley et al, 2003; Chini and Bruening, 2005); environmental aspects of deconstruction for reuse (O'Brien et al., 2006; Nordby et al., 2009a, 2009[b]; Kuikka, 2012), business models, policy intervention (Hobbs and Hurley, 2001; Patel, 2010; Geyer and Jackson, 2004, Bakas et al., 2011) or design practice (van Hinte et al., 2007) have been some of the knowledge already generated in this field. The main reference literature used in this study was selected based on similarities with construction systems in the Netherlands and listed in Table 5.1.

TABLE 5.1 Case studies focused on reuse of building products.

REFERENCE	PRODUCT (AND MATERIAL) TYPES	MAJOR FOCUS
Geyer and Jackson, 2004	Steel	Supply management
Thormark, 2000	Bricks, roofing tiles	Environmental impact
Thormark, 2002	Entire building	Environmental impact
Roth 2005	Concrete products and ceramic bricks	Environmental impact
Nordby et al., 2009a	Bricks	Technical feasibility and environmental impact
Hemstrom et al., 2012	-	Supply management
Krutwagen and van Broekhuizen, 2010	Various materials	Environmental impact
Asam, 2007	Prefabricated concrete	Technical feasibility and environmental impact
O'Brien at al. 2006	Various materials	Technical feasibility and environmental impact
Pun et al., 2006		Supply management
Kristinsson et al., 2001	Concrete elements	Technical feasibility and environmental impact
Addis, 2012	Several materials	Design process, supply management and technical feasibility
Gorgolewski and Morettin, 2009	-	Design process
Sára et al., 2001	Various materials	Environmental impact
Kuikka, 2012	Brick, doors, steel doors, teak doors, windows, gulam beams, sinks, ceiling tiles	Technical feasibility and environmental impact
Ogbu, 2010	-	Design process and supply management
Roth, 2005	Wood, bricks and other ceramics, concrete and steel	
Poelman, 2009	-	Design process and supply management
Fujita and Iwata, 2008	Steel	Technical feasibility, environmental impact and supply management
Nakajima and Murakami, 2010	Wood	Technical feasibility and environmental impact
Quinn, 2008	Wood	Environmental impact and supply management
Hurley and Hobbs, 2003	Several materials	Technical feasibility, supply management and policy
Bioregional 2008	Several materials	Technical feasibility and supply management

Although the knowledge generated by other studies (Habraken, 2003; Roders and van Gassel, 2004; Durmisevic, 2006; Yingying and Beisi, 2011) is relevant in the field of building deconstruction, the focus of this study is the deconstruction of buildings based on applied technology having as reference the existing housing stock, rather than new construction methods to improve easier and quicker deconstruction or adaptability of buildings. The focus is to understand what is commercially harvested for reuse. The references used to verify the frequency materials occur in the housing stock were Meijer (2006) (Table 5.2) and the references mentioned in Chapter 4. In Table 5.2, Group 2 is considered non-reusable due to physical characteristics (glues, resins, sand, paints, hazardous substances).

Given the complexity of different products existent in buildings, they were clustered according to their predominant material type. Hence "bricks" are classified in this chapter under the category "ceramics" together with clay roof tiles and alike. The following sections identify main material groups and correspondent products.

TABLE 5.2 Common materials found in the reference house in the Netherlands divvied in groups 1 and 2 (adapted from W/E Adviseurs, 1999 in Meijer, 2006).

GROUP 1			
Material group	**Material type (group 1)**	**Amount (kg)**	**Material group amount (Kg)**
Stone based (mainly cementitious)	Concrete	91800	163400
	Sand lime bricks	67000	
	Gypsum (application not specified)	4600	
Stone based (ceramics)	Bricks	6200	7560
	Ceramics	1360	
Wood based	Pinewood impregnated	2000	5675.3
	Multiply	1370	
	Pinewood	957	
	Meranti	548.3	
	Chipboard	470	
	Hardboard	330	
Mixed metals	Steel	1864	3509
	Steel enamelled	950	
	Steel galvanized	209	
	Aluminum	150	
	Copper	95.9	
	Zinc (application not specified)	67	
	Stainless steel	57.2	
	Brass	44	
	Lead	29.9	
	Copper primary	27	
	Cast iron	15	
Glass (and insulation)	Glass	910	910.68
	Glass wool	0.68	
Polymers	Polyvinyl chloride	122	333.1
	Polyethylene high density	47	
	Polyethylene low density	99	
	Polyurethane foam blown with pentane	51.4	
	Polyurethane foam blown with air	11	
	Polypropylene	2.7	
Others	Electronic	8.4	8.4
	Rockwool	236	236
	Bitumen	83	83
	Cardboard	148	148

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TABLE 5.2 Common materials found in the reference house in the Netherlands divvied in groups 1 and 2 (adapted from W/E Adviseurs, 1999 in Meijer, 2006).

GROUP 2	
Material type (group 2)	Amount (kg)
Sand	61000
Sand mortar	12700
Mortar	5200
Gypsum plaster	906
Glue, sand lime bricks	664
Paper	410
Polyester concrete	140
Glue	85
Plastic coating	80
Polysulfide (adhesives)	61
Acrylic paint	46
Alkyd paint	44.5
Polybutylene (pipes)	16.4
Polyester (several applications)	10.6
Acrylonitrile-butadiene-styrene {pipes}	8.7
Enamel	5.4
Ethylene propylene dipolymer	3.1
Glue water based	2.9
Polyamide (nylon, small products such as hinges, rolers)	1.93
Zinc coating	1.14
Chloroprene	1.1
Anodizing layer	0.262

§ 5.1 Wood

The use of wood in housing construction in the Netherlands is dating from 1600 and became increasingly scarcer (Blaazer, 2011). Barriers for reusing wood today are the competition between incineration with energy recovery, manufacture of low-value wood-based[162] products and problems with hazardous substances (Alakangas et al., 2009; Biointelligence et al., 2011).

TABLE 5.3 Information source for reuse of wood based building products.

Literature _ study cases focused on reuse of building products in practical experiments.	Kuika, 2012 Hemstrom et al. 2012 Lazarus and Hillary, 2006 Hurley and Hobbs, 2003 Thormark, 2000 Giglio, 2002 Shami, 2008 Addis, 2012 Guy et al. 2006 Olympic Panel, no date available[1] Nakajima and Murakami, 2010
Literature _ study cases focused on reuse of building products in the market.	Addis, 2012 Shami, 2008 Bioregional (2008[a]) Lazarus and Bioregional, 2002 Hurley and Gilli Hobbs, 2003 Roth, 2005 Hemstrom et al., 2012
Interview _ current market of reused building products in the Netherlands.	(Tristan Frese) *Schijf* (Jan van Ijken) *Oude Bouwmaterialen* (Robert Barclay) *Van Liempd* (Fred van Ooyen) *Van Baal* (Rob Gort) *Bouwcarrossel* (Jan Oldenburger) Probos (Ted Reiff) The Reuse People (Irene Jonkers _ through email) Researcher at the Nyenrode Business Universiteit Center for Sustainability

1 http://www.olypanel.com/common/pdf/Form%20Oil%20Technical%20Bulletin%20-%209-07.pdf

162 Interview with Robert Barclay (van Liempd).

To grade wood to evaluate suitability to reuse is not a straightforward process (Shami, 2008; Davis, 2012). There is not yet an official way to grade and certify used wood to be reused in the Netherlands[163]. Wood in waste streams in the Netherlands is classified according to contamination levels in Type A, B or C[164] (Alakangas et al., 2008; Corsten and Worrel, 2010), which receives different waste treatment according to the category.

There is also no official account regarding how much wood is recovered for reuse in the Netherlands[165]. Table 5.4 indicates recovered wood among different countries in Europe (the original table included 20 countries). The Netherlands was among 8 countries that did not have any data regarding reuse of wood. Although the definition of reuse is not explicit in the document, Merl et al. (2007, pg. 7) exemplified reuse wood "*as a beam or in parts*." Merl et al. (2007) conclude that more attention should be focused on standardizing classifications and definitions in Europe that support data collection and accurate comparison among cases.

163 Interview with Interview with Teun Stam (Restoric).

164 Wood Type A_ Consists of wood that has not been treated with paint, glue, filler, pentachlorophenol, creosote, tar, asphalt or other wood preservatives or treatments (i.e. building structure as rafters, broken pallets, empty spools, crates, scrap lumber are common sources of untreated wood wastes). Type A wood will be "recycled" into medium density particleboards or fibreboards, plastic timber, flooring components, woodchips, animal bedding and fuel. Type B_ It is considered treated with paint, glue or varnish. B-wood waste will have to be treated and removed from other materials as screws and nails. Doors, kitchen cabinets, window frames, soft board ceilings, pressed wood like chipboard, MDF, OSB are in this category. End use of these products: mulch, landscape surfaces, animal-bedding products. Type C_ Wood type C is divided into three groups: wood treated in form of impregnation (makes the wood useful for outside purposes) either called CCA, when it contains copper, chromium and arsenic; or CC in case it does not contain arsenic and therefore not considered hazardous. The second group wood is treated with hydrocarbons and tars. Third group wood is treated with fungicides, insecticides, boron and quaternary ammonium[2]. Mixed wood waste is also classified, as type C. Only A and B wood can be applied as secondary material in construction industry and as fuel as in bio energy power stations. Category C of wood is landfilled but it can still be incinerated under specified conditions (Landelijk afvalbeheerplan 2009-2021).

165 The term reuse, as mentioned in Chapter 1 is applied for different activities in practice, making difficult to gather quantitative data in regard to reuse as defined by other references in Chapter 1.

TABLE 5.4 Used (recovered) wood in tons/a (%) in involved countries of Task VI in BioNorm II plus Sweden and the Netherlands according to Merl et al., 2007 in Alakangas E. (ed) (2009).

	AUSTRIA	FINLAND	GERMANY	GREECE	NETHERLANDS	SWEDEN	TOTAL EUROPE (COST E31)
Reuse	38.750 (5)					19.600 (3)	535.143 (2)
Recycling	310.000 (40)	360.624 (48)	906.224 (15)		755.525 (60)	19.600 (3)	10.872 384 (37)
Energy	325.500 (42)	383.163 (51)	4.119.742 (69)		459.000 (37)	705.600 (90)	9.996.395 (34)
Landfill	15.500 (2)	7.513 (1)	11.924 (0.2)			19.600 (3)	3.125.083 (11)
Composting	77.500 (10)		47.696 (1)			19.600 (3)	916.823 (3)
Others, unknown	7.750 (1)		876.414 (15)	450.000 (100)	349.25 (3)		4.147.127 (14)
Total of country	775.000	751.300	5.962.000	450.000	129.450	78.4000	29.592.955

Despite contamination as result of wood treatment techniques, older types of wood are considered to have better quality than new ones (Lazarus and Hillary, 2006). Prices of used wood vary significantly according to the type of wood and products type[166]. The most common products reclaimed from the average Dutch house are floor beams, roof structure (beams, joists, wood-based panels) and floorboards[167].

All interviewed companies (Table 5.3) de-nailed the wood before commercializing and at times resized them from large beams into dimensional lumber compensating the manual work involved. Reconditioning of floorboards is also a common practice, and the commercialization goes beyond national borders[168].

166 Interview Jan van Ijken (*Oude Bouwmaterialen*).

167 Interview with Tristan Frese (*Restoric _ Schijf Group*).

168 Interview with Jan van Ijken (*Oude Bouwmaterialen*).

According to interviewed companies, doors both external as internal were found to be abundant in the reuse market and found in almost any condition and quality. Doors are removed generally quickly and when possible the frame is also removed together. Most of the interviewed companies do not recondition doors except under request. As for most reused building products, the lack of standards is a barrier for clients that look for purchasing large numbers of the same product. Therefore, for large-scale applications, transporting doors from different locations and recondition them to standard sizes may be costly when compared to new low-cost doors in the market (Lazarus and Bioregional, 2002).

Window frames are reclaimed in smaller amounts[169]. Most of the reclaimed window frames contain decorated glass, and at times the frame is not included. They usually do not carry insulated glass. Multiplex and similar panels are commercialized. Laminated floors and MDF are not reclaimed[170].

Used wood products are available in different types of markets for being relatively easy to extract from buildings and, to recondition and repurposed into new products, allowing transformation through the cascade reuse. New applications avoid challenges in grading and certifying the wood (Davis, 2012; Shami, 2008). Table 5.5 summarizes reusable wood-based products found in the housing stock in the Netherlands and commonly available in the reused products' market.

169 Interview with Jan van Ijken (*Oude Bouwmaterialen*).

170 Interview with Jan van Ijken (*Oude Bouwmaterialen*).

TABLE 5.5 Current reuse of wood based products from the housing stock in the Netherlands.

Material type group	Product	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Possible blocking factors
Products derived from housing deconstruction/ renovation (not new)					
Wood	Joists	Common	Cascading reuse possible	75 years [2]	Assessing technical condition of wood. For reuse as structure, degradation of wood must be taken into consideration (age, nails, hazardous substances, moisture, etc).
	Beams	Common	Cascading reuse possible	75 years [2]	idem
	Studwork	Not Common	Cascading reuse possible	75 years [2]	Comparative low cost of new products and vulnerable to damaging during deconstruction
	Scaffolding wood	Common	Cascading reuse possible	-	Assessing technical condition of wood.
	Façade cladding	Not Common	Cascading reuse possible	15-60 years [2]	Wood cladding applied in housing construction is concentrated in more typically found in few areas in the country or in rural construction.
	Structural laminated wood	Not Common	Cascading reuse possible	75 years [2]	-
	Timber (frame)	Common	Cascading reuse possible	60 years [2]	Assessing technical condition of wood.
	Various wooden floor types (floorboards, strip floor, parquet)	Common	Cascading reuse possible	40-50 years [1]	Parquet removal is labor intense. Only valuable ones will be recovered.
	Landscape elements (fences)	Not common	-	75 years [1]	-
	Doors	Common	Cascading reuse possible	15- 40 years [1, 2]	Incompatible with updates building codes.
	Window	Not common	Cascading reuse possible	35-60 years [1, 2]	Building codes quickly updated regarding building insulation.
	Staircase (internal)	Common	Cascading reuse possible	50 years [2]	Difficulties in matching dimensions from original staircase and new building. Incompatible with updates building codes.
	Wood shingles	Not common	-	15-30 years [2]	-
	Foundations	Not common	Cascading reuse possible	75-100+ years [2]	Not commonly applied as its original functions.

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TABLE 5.5 Current reuse of wood based products from the housing stock in the Netherlands.

Material type group	Product	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Possible blocking factors
Products derived from housing deconstruction/ renovation (not new)					
Wood based materials	Plywood	Common	Cascading reuse possible	15-40 years [1]	-
	MDF (application not specified)	Not common	-	20-35 [2,3]	Comparative low cost of new products.
	Composite doors	Common	Need more experiments with cascade reuse	25-30 [2]	-
	Chip Board (application not specified)	Not common	-	30 years [3]	-
	Laminated floor	Not common	Cascading reuse possible	20 years [1]	Vulnerable to damaging during deconstruction.
Other wood products	Forms for concrete in situ (plywood, coarse wood)	Common	Cascading reuse possible	-	Risk of contamination by use of reactive concrete release agents.

[1] Huffmeijer and Damen, 1995.
[2] Vissering et al., 2011.
[3] BCIS, 2006.
[4] http://www.nachi.org

§ 5.2 Ceramic

TABLE 5.6 Information source for reuse of ceramic based building products.

Literature _ study cases focused on reuse of building products in practical experiments.	Kuikka, 2012 Hurley et al., 2002 Hurley and Hobbs, 2003 Gommans, 1990 Mulder, 2005 Addis, B., 2012 Mulder, 2008 Lazarus and Hillary, 2006 Nordby et al., 2009a Park and Butler, 2013
Literature _ study cases focused on reuse of building products in the market.	Addis, 2012 Bioregional, 2008 Roth, 2005 Hurley and Hobbs, 2003
Interview _ current market of reused building products in the Netherlands.	(Tristan Frese) *Schijf* (Jan van Ijken) *Oude Bouwmaterialen* (Robert Barclay) Van Liempd (Fred van Ooyen) Van Baal (Rob Gort) Bouwcarrossel (Lionel) Rotor (Richard ?) Source 4 u Limited (Leo Gommans) TUDelft

In the Netherlands, retail of used bricks is often found mixed with other architectural products such as roof tiles, floor tiles, and wall tiles. Most of the bricks reclaimed in the Netherlands are extracted from buildings constructed before 1930's, when the use of lime-based mortar was still frequent, making deconstruction easier in comparison to the cement based mortar[171].

171 Interview Jan van Ijken (*Oude Bouwmaterialen*).

Nordby et al. (2009a) showed advantages in applying lime-based mortar in new masonry buildings in contrast to more energy intense solutions involving steel and other metal-based dry connections for brick walls. Studies focused new technologies[172] on reclaiming bricks with cement mortar were found, but the results are still emerging[173] (Mulder, 2005; Nordby et al., 2009a; Biointelligence et al., 2011).

Demand for reclaimed bricks is mainly focused on renovation and restoration works. Historic restoration works that request rare types of bricks is, however, a segment in slow decline in the Netherlands[174]. Newer used bricks (after 1930) do not compete well with prices of new bricks, which in general are comparatively low. In Belgium, in the UK and Eastern Europe (Lazarus and Hillary, 2006) there is an established market for used bricks. Reclaimed bricks are used as façade elements rather than load- bearing structures. In the U.S. there are few specialized companies that "slice" reclaimed bricks to be applied as finishing wall tiles. Nordby et al. (2009a) have analyzed the salvageability of bricks according to four different brick layering systems and four different criteria (historic brick masonry, brick from insulated cavity wall, brick veneer walls and the IRCAM and SRB_DUP methods). The results showed the potentials and advantages to salvage and reuse individual bricks, however quality tests in historical bricks should be carefully considered.

There is also a consistent market for reclaimed ceramic roof tiles, but as with bricks, they are mainly found in architectural products that are often more expensive than new products. In the Netherlands, each village or region is characterized by a certain type of ceramic roof tiles that are often substituted by reclaimed similar ones than new tiles[175].

Used ceramic bathroom toilets and tubs are also reclaimed for commercialization. There is, however, a cultural barrier related to purchasing reused sanitary for private use as previously mentioned. Wall and floor tiles are found more often among rare products. Similarly, decorated cement floor tiles are part of architectural products and at times antique store. Table 5.7 summarizes reusable ceramic-based products commonly found in the housing stock in the Netherlands and available in the reuse market.

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172 *Gamle Mursten* is a company in Denmark specialized in brick production advertises vibration based technology that secures effective cleaning of bricks from mortar_ http://www.balticgpp.eu/old-bricks, and reuses bricks also dated from after 1930's.

173 Interview with Lionel Billiet (*Rotor*, Belgium).

174 Interview Jan van Ijken (*Oude Bouwmaterialen*).

175 Interview Jan van Ijken (*Oude Bouwmaterialen*).

TABLE 5.7 Current reuse of ceramic based products from the housing stock in the Netherlands.

Material type group	Product	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Blocking factors
Products derived from housing deconstruction/ renovation (not new)					
Clay and ceramic products	Bricks	Common		10-50 [1] years	Cement mortar difficult to clean off bricks. Labor intense. More often bricks are harvested from constructions pre-1930s. Only facing bricks are reclaimed in Nl.
	Flooring bricks (landscape)	Common	Easy to harvest	10-40 [1] years	More common from urban infrastructure than housing sector.
	Wall tiles	Not common	Difficult to harvest	75 years [2]	More common in the antique market.
	Roof tiles	Common		75- 100+ years [2]	More common in the antique market.
	Floor tiles	Common	Difficult to harvest	25-50 years [1]	More common in the antique market.
	Sanitary appli-ances	Common	Potential to be used in public bathrooms	40 years [1]	Cultural barrier

§ 5.3 Cement

TABLE 5.8 Information source for reuse of concrete based building products.

Literature _ study cases focused on reuse of building products in practical experiments.	Hurley and Hobbs, 2003 van Dijk et al., 2001 Te Dorsthorst and Kowalczyk, 2001 Asam, 2007 Roth, 2005 Addis, 2012
Literature _ study cases focused on reuse of building products in the market.	-
Interview _ current market of reused building products in the Netherlands.	(Tristan Frese) *Schijf* (Jan van Ijken) *Oude bouwmaterialen* (Fred van Ooyen) *Van Baal* (Rob Gort) *Bouwcarrossel* (Claus Asam E-mail) *Technical University of Berlin*

There are several studies under development focused on increasing secondary content in new concrete (Oudejans et al., 2011), which in 2012 was regulated to less than 20% of rubble fraction content for new concrete[176]. Although the majority of these studies have not yet been proved to be economically feasible either due to technical aspects or other interests, there are indications that some of these technologies could become mainstream[177] in the future. The aim to include concrete as part of this chapter is to illustrate the technical, cultural and market aspects involved in the reuse practice.

Few studies focused on reuse of cement based-products. One of them had the participation of the Technical University of Delft in the 1990's, a period when reuse was part of government package to sustainable construction and development in the Netherlands. Van Dijk et al. (2001), Te Dorsthorst and Kowalczyk (2001) analyzed the potentials and barriers of deconstruction and reuse of prefabricated structural concrete elements.[178] These elements would be used to build single-family dwellings

176 Europese betonnorm EN 206-1, NEN 8005. *Paragraaf* 5.3.2 in Boehme, L. at al. (2012). ValReCon20-Valorization of Recycled Concrete Aggregates in Concrete C20/25 & C25/30. *Leuven: ACCO*.

177 Interview with Leo Gommans, TUDelft.

178 The study of reuse in this research was one part of a larger scope including renovation of post-war buildings, addressing sound, size, draft, thermal comfort, etc.

surrounding the original building. Challenges were found when elements were not built according to original drawings, leading to difficulties for disassembling. Additionally, damaging of products during the deconstruction and transportation, storage, as well as safety risks and time [179] to execute the process were among challenges found during the study case.

In a second study case (Middelburg, the Netherlands) challenges were concentrated on the reuse of elements in the new project causing a cost increase of 18,7% compared to using new construction products. From the researchers' point of view, the reuse of large-scale concrete elements was not feasible mainly due to barriers along the deconstruction process and technical and safety guarantees resulting in economic strains[180].

Another reference was developed outside the Netherlands, by the Institute for Rehabilitation and Modernization of Buildings (Asam, 2007) at the Technical University of Berlin in Germany relatively in the same period. This study focused on pre-fabricated concrete elements (pre-stressed concrete slabs type WBS 70) deconstructed from post- war housing complex. Tests included made in cutting the used parts, trimming and adjusting new joints (Figures 5.1, 5.2, 5.3 and 5.4). The results showed a cost saving of 26% through optimal application of the building carcass including logistics issues and remounting plans. However, to make the process economically possible, the elements should not exceed a 300 km radius from the demolition site to the new application site. The deconstructed elements were reused as load-bearing interior walls, exterior walls, and ceilings after reconnected, insulated and finished. The study concluded that the environmental benefits reached with reuse of these elements and technical and economic viability was possible under certain conditions. Moreover, the design of new houses had to comply with the geometry to the existing elements.

Asam (2007) pointed out that major difficulties were the lack of market demand for these products and the absence of regulatory systems that support the process regarding regularizing and prioritizing reuse before recycling.

179 Interview with Ton Kowalsczy (former TUDelft).

180 Interview with Ton Kowalsczy (former TUDelft).

FIGURE 5.1 Prototype at the TU Berlin (Claus, 2007).

FIGURE 5.2 Pilot house in Mehrow near Berlin (Architecture bureau CONCLUS) (Claus, 2007).

FIGURE 5.3 Pilot house in Schildow near Berlin (Architecture bureau CONCLUS) (Claus, 2007).

FIGURE 5.4 Pilot house in Berlin-Karow (Architecture bureau CONCLUS) (Claus, 2007).

Other concrete prefabricated elements are reclaimed such as staircases, wall copings, lintels, but there is limited market demand for such products in the Netherlands[181]. Concrete floor tiles and other stony based products as natural stones, setts and cobblestone are commercialized mixed to other products or by specialized retailers[182]. Natural stones[183] are not commonly found in the housing stock in the Netherlands[184], but are more commonly harvested from other non-housing constructions. Commercialization of concrete precast floor elements and concrete slabs are rare[185]. Concrete roof tiles can be reclaimed but not commonly commercialized due to the low cost of new ones and risk of damage during deconstruction[186]. As the housing stock evolves (as shown in the Section 4.2.3) becoming increasingly concrete intense, it is relevant to reflect on the possibilities and the future of reuse of building products.

181 Interviews with Tristan Frese (*Restoric _ Schijf Group*); Fred van Ooyen (*Van Baal*); Rob Gort (*Bouwcarroussel*).

182 http://www.slimbestraten.nl; http://www.twenteklinker.nl; http://www.jvernooy.nl; http://www.reijndersbestratingsmaterialen.nl; http://klinkerconcurrent.nl; http://www.klinkercentrale.nl

183 Interview with Fred van Ooyen (*Van Baal*) and Jan van Ijken (*Oude Bouwmaterialen*).

184 Most of aluminum products are derived from commercial buildings, interview with *Van Baal*.

185 One company was found in the north of the Netherlands _ devriesstenen.nl

186 Interviews with Tristan Frese (*Restoric _ Schijf Group*); Fred van Ooyen (*Van Baal*); Rob Gort (*Bouwcarroussel*).

TABLE 5.9 Current reuse of concrete based products and natural stones from the housing stock in the Netherlands.

Material type group	Product	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Blocking factors
Products derived from housing deconstruction/ renovation (not new)					
Stony based materials: Concrete and natural stones	Staircase	Not common	Can be reused for landscape	100+ years [2]	Comparative low cost of new products.
	Structural pre cast concrete products (col-umns, beams, portal frames, floor planks)	Not common	Need more ex-periments with cascade reuse	100+ year [2]	Large size components have complex for deconstruction. No market demand. Cost to handle and equipment may be a barrier for cascading.
	Concrete floor tiles (external)	Less common	Easy for reuse	30 years [1]	Cheap price for new component.
	Concrete roof tiles	Not common	Need more ex-periments with cascade reuse	40-50 years [2]	Cheap price for new component. Although relatively common in post war housing projects, concrete roof tiles are generally not reclaimed in the country.
	Lintels	Not common	Need more ex-periments with cascade reuse	100+ years [2]	Comparative low cost of new products.
va	Natural stones (floor/ wall/ staircase, land-scape)	Not common	Natural stone components are more often found among architectural elements. Some components are possible to be cascaded	75 years [1]	Problems with lime mortar, difficult to deconstruct.

§ 5.4 Metals

TABLE 5.10 Information source for reuse of metal based building components.

Literature_ study cases focused on reuse of building components in practical experiments.	Patel, 2010 Fujita and Iwata, 2008 Lazarus and Hillary, 2006 Durmisevic and Noort 2003 Lazarus and Bioregional, 2002 Hurley and Hobbs, 2003 Kuika, 2012 Addis, 2012
Literature_ study cases focused on reuse of building components in the market.	Patel, 2010 Geyer and Jackson, 2004 Fujita and Iwata, 2008
Interview_ current market of reused building components in the Netherlands.	(Jan van Ijken) *Oude bouwmaterialen* (Tristan Frese) *Restoric* (Fred van Ooyen) *Van Baal* (Robert Barclay) *Van Liempd* (Rob Gort) *Bouwcarroussel* (Jan Jongert) SuperUse Studio (Eric van Erne) *Stichtingmilieunet*

Used structural steel components are commercialized, however, the housing segment in the Netherlands is not the most significant source of this type of products. Reconditioning structural steel profiles are sand blasting, fabrication, and coating (Lazarus, 2002).

Patel (2010) investigated potentials of reusing steel structural components in the United Kingdom. The study suggests that large-scale commercialization of steel used products should include the costs of testing and certifications into the overall costs and that there are existing legal means to reinforce reuse of steel building components that are beneficial in both economic and environmental aspects. The results also reflected on the benefits and possibilities to extend reuse of steel in Europe, and she concluded, "*The current reuse market is constrained by nonfinancial barriers such as time constraints at demolition and health and safety concerns*" (Patel, 2010, pg. 7). The interviewed companies in the Netherlands confirmed the economic benefits of reusing structural steel components (*Van Baal*, *Schijf*, BZN *Sloopwerken* BV).

Nonetheless, Geyer and Jackson (2004, pg. 65) have identified several constraints in the reuse chain of steel components. One of them regards fluctuation in volume of input of reclaimed products hindering large-scale developments; "*limited feasibility* *of deconstruction, limited feasibility of re-fabrication, and limited market demand for re-fabricated sections*". According to interviewed companies in the Netherlands, this challenge is applicable not only to steel products but all other types of used products. Patel, Geyer and Jackson (2004) concluded, "*cost savings of reuse are not insignificant*" and ..."*at the current state of our analysis, it is inexplicable why there is no automatic, economically motivated shift towards increased reuse*" (Geyer and Jackson, 2004, pg. 64).

Finally, as a result of interviews and literature, the most significant barriers to reuse steel products are not only based on economic constraints, lack of standardization and quality control. Some of the barriers reside in the lack of knowledge and awareness of the potentials of such market from all sides, including lack of demand from the user side and under supply from the supplier's side. Such barriers are partially related to lack of information, lack of legal means to support transaction and reuse of building components and the weak industrial structure as it is currently established.

Fujita and Iwata (2008) developed an information system (DB/database) to harmonize demand and supply of steel parts in Japan. The DB (database) system is a centralized information mechanism formalized in a virtual database system, proposing a highly specialized market for a specific type of product; opposed to the more current market of used building materials in the Netherlands that carries a variety of products with little technical specification. In this structure, new steel components would supply gaps for used components demand when necessary, more as part of TAKE-BACK models (Toffel, 2003).

In the TAKE BACK model, the fabricator embodies a critical role re-incorporating several specialized tasks, which would still depend on the remuneration and performance of demolition companies (Fujita and Iwata denominate reclamation Audit). In the TAKE BACK model, quality control and certifications are assumed to be available for consumers, different from buying used products from a demolition company. This type of supply chain has been found more often associated with studies of reuse of steel with no similar reference in practice in the Netherlands.

Moreover, there were no further studies found regarding other types of metals. Other products found in the reuse markets with smaller relevance were aluminum frames and radiators. The former presents risks to deform during deconstruction, especially regarding to frames[187]. Radiators are found both in the market of "*cheaper than new*" or as antique. Table 5.11 summarizes reusable metal components found in the housing stock in the Netherlands and commonly available in the reused products' market.

187 Interview with Fred van Ooyen (*Van Baal*).

TABLE 5.11 Current reuse of metal based components from the housing stock in the Netherlands.

Material type group	Component	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Blocking factors
Products derived from housing deconstruction/ renovation (not new)					
Metals	Tubes, plates and bars	Not common	Cascading reuse possible	-	-
	Staircase	Not very common	Cascading reuse possible	100+ years (internal) [2]	Heavy component to be transported and difficulties related to matching dimensions
	Handrail/ fences/ gates	Common	Cascading reuse possible	75 years [2]	These components are more commonly found among architectural salvage products.
	Radiator	Common	-	25-40 years [1]	Complex for cascading. Risk of toxic paint, leaks
	Windows	Not common	-	35-75 years [1, 2]	-
	Doors	Not common	-	35-50 years [2]	-
	Lintel	Not common	-	75-100 years [2]	
	Structure	Common	-	75- 100+ years [1,2]	Hazardous substances from sprayed products for fire protection. Although it is an appreciated component to be recovered and sold in the market, it is not commonly found in the housing segment.
	Panels (cladding)			30-50 years [2]	
	Forms for concrete in situ	Not common	Cascading reuse possible	-	-
Aluminum	Window	Not very common	-	25-75 years [1, 2]	-
	Door	Not very common	-	35-50 years [1,2]	-
	Panels (cladding)	Not very common	-	20-60 years [2]	-
	(Panels roof)			40-60 years [2]	

§ 5.5 Plastic

TABLE 5.12 Information source for reuse of plastic based building components.

Literature _ study cases focused on reuse of building components in practical experiments.	-
Literature _ study cases focused on reuse of building components in the market.	-
Interview _ current market of reused building components in the Netherlands.	(Jan van Ijken) *Oude bouwmaterialen* (Tristan Frese) *Restoric* (Fred van Ooyen) *Van Baal* (Robert Barclay) *Van Liempd* (Rob Gort) *Bouwcarroussel*

There was no literature reference found focused specifically on reuse of plastic-based building components. Exception for PVC window frames, plastic based products are not representative of the reuse market in the Netherlands. It is also not often included among products harvested by aesthetic criteria. Most plastics found in the reclaimed retail sector are in the low-end category (cheaper than new products). The most common plastic-based products reclaimed and commercialized are windows and doors; excluding pipes, cabling or synthetic floor types. Table 18 shows the most common PVC based products in construction. Insulation products are recovered as EPS _ expanded polystyrene[188].

188 Other types of insulation as glass wool and rock wool are also recovered if in good condition, see Table 5.15 in “Insulation materials”.

TABLE 5.13 Typical composition of PVC components (adapted from Prognos, 1994, 1999, Totsch 1990 in Plink et al., 2000).

APPLICATION	SHARE OF THE COMPONENTS (WEIGHT %)				
	PVC polymer	Plasticizer	Stabilizer	Filler	Others
Rigid PVC applications					
Pipes	98	-	1-2	-	-
Windows profiles	85	-	3	4	8
Other profiles	90	-	3	6	1
Rigid films					
Flexible PVC applications					
Cable insulation	42	23	2	33	-
Flooring (all)	184	72	4	81	2
Synthetic leather	53	40	1	5	1
Furniture films	75	10	2	5	8
Leisure articles	60	30	2	5	3

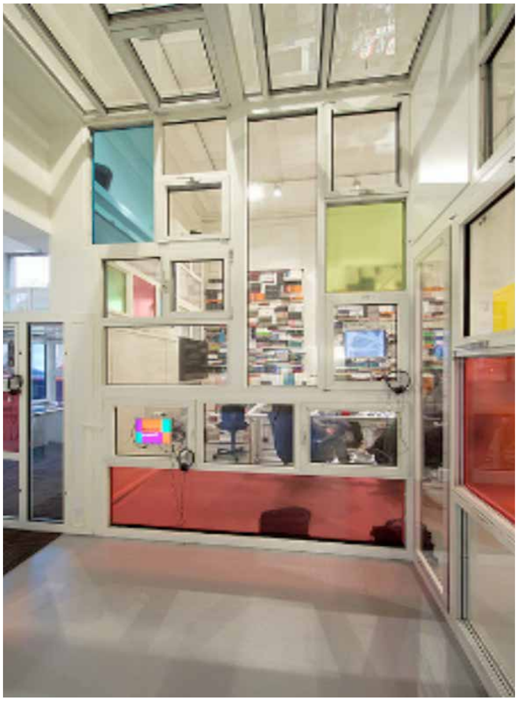

FIGURE 5.5 Internal office partitions made with reused PVC window frames by SuperUse studio (www.superuse-studio.com).

FIGURE 5.6 PVC office partition (www.superuse-studio.com).

The most substantial type of plastic present in construction waste flows is PVC, in several different applications (Table 5.13[189]). Consistently available data regarding recycling of PVC building components in the Netherlands are not updated and concentrated on pipes, cables, and flooring. The Dutch government is focusing on improving waste management of PVC ducts, pipes, cables, leads, and moldings, including frames (VROM, 2010). Recycling of PVC windows and door profiles is active in Belgium[190] and Germany, where the first one has been a large exporter of PVC windows to the Netherlands (Plinke, 2000, pg. 15).

Cascade reuse of PVC frames is not as straightforward when compared to reuse of wooden frames. Figure 5.5 and 5.6 show an example of cascade reuse where reused PVC windows are used as internal partitions avoiding risks of being exposed to weather and having to comply with updated insulation requirements. The life expectancy of PVC window frames is in average forty year (Huffmeijer and Damen, 1995), which should also be considered when reusing in the original function. Table 5.14 summarizes reusable plastic products found in the housing stock in the Netherlands and commonly available in the reused products' market.

TABLE 5.14 Current reuse of plastic based products from the housing stock in the Netherlands.

Material type group	Product	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Blocking factors
Products derived from housing deconstruction/ renovation (not new)					
Plastic	PVC window	Common	-	25- 40 years [1] [2]	Recommended non- original reuse
	PVC door	Common	-	20 years [2]	
	Vinyl flooring	Not common	-	10 years [1]	-
	Plugs/ sockets	Not common	-	30+ years [4]	Complex for cas- cading
	Carpet	Not common	Cascading reuse possible	10 years [3]	-

189 For the average construction in the Netherlands EPS is a large plastic based products (Meijer, A., 2006; Krutwagen and van Broekhuizen, 2010).

190 *Veka_ Deceunink.*

§ 5.6 Others

Thermal insulation products as rigid Expanded Polystyrene (EPS), Polyisocyanurate (PIR), mineral wool, and glass wool (in lesser amounts), were also found in the market of used building products. Insulation panels, in particular, are often found in the market of used products sold cheaper than new equivalent products. According to interviewed companies, used glass is commercialized in limited amounts, mostly when already combined with window or doorframes. Used glass panes are often harvested from commercial deconstruction projects. Double- glazing is almost not commercialized in the reuse market without being framed into another product. Glass walling blocks can be harvested for reuse but are not commonly found in the market and not specified as a characteristic product in housing stock in the Netherlands[191]. Products such as lamps, faucets, mechanical and electrical services such as boilers, lifts, fans, fixtures, and plumbing are found in the reuse market, but it is not included in this research due to the relatively small amount of material they represent from the entire building. Cabinets were considered as furniture and therefore excluded in this research. All other products not mentioned in the previous sections were considered to be not common in the market of used building products in the Netherlands.

Sand is not available in the reuse market of building products, whereas asphalt, pipes cables are mainly harvested for recycling.

Table 5.15 summarizes products not commonly found in the housing stock in the Netherlands or commonly available in the reused products' market.

191 Products such as lamps, faucets, mechanical and electrical services such as boilers, lifts, fans, fixtures, and plumbing are found in the reuse market, but it is not included in this research due to the relatively small amount of material they represent from the entire building. Cabinets were considered as furniture and therefore excluded in this research. All other components not mentioned in the previous sections were considered to be not common in the market of used building products in the Netherlands.

TABLE 5.15 Not currently reused components from the housing stock in the Netherlands.

Material type group	Product	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Blocking factors
Products derived from housing deconstruction/ renovation (not new)					
Glass	Flat glass	Not very common	Cascading reuse possible	75 years [2]	Not recommended as window pane
	Insulated glass	Found combined with windows/doors frames	Cascading reuse possible	30 years [2]	Building codes quickly updated regarding building insulation.
Insulation materials	Polystyrene based	Common	-	75 years [2]	Building codes quickly updated regarding building insulation.
	Glass wool	Common	-	75 years [2]	-
	Rock wool	Common		75 years [2]	-
	PUR	Not common	-	75 years [2]	-
Electric/ electronic cables		Not common	-	35-50 years [1]	Technical condition size differences.
Others	Taps, knobs, fixtures, lamps, cabinets...	Not included in this study (difficult to evaluate due to differences in material type...)	-	15-40 [4]	-
Available in the reuse market but more often derived from other types of buildings than housing					
	Polyester panels Polycarbonate panels Trespa and other composite panels Lighting system Metal roof panes Structural steel Carpet/ carpet tiles Linoleum (difficult to handle, possible to crack) Sandwich insulated panels Aluminum siding				
Rarely available in the reuse market					
	Optic fibbers and cables Fiberglass Glass blocks Glass roof tiles Tubes, plates and bars Metal cladding				

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TOC

TABLE 5.15 Not currently reused components from the housing stock in the Netherlands.

Material type group	Product	Availability in the market or reused building products in the Netherlands	Stimulating factors	Lifetime	Blocking factors
Not available in the reuse market					
	Asbestos and waste containing asbestos				
	Drywall				
	Concrete blocks (also aerated concrete blocks)				
	Sieve sand				
	Stucco				
	PVC pipes				
	Ceramic pipes				
	Electric cables				
	Blasting grit				
	Roof membranes				
	Thatch				
	Felt sheets				
	Paintings, sealants, etc.				
	Dredged soil				
	Packaging materials				
	Gypsum				
	Tar asphalt				
	Asphalt shingles				
	Contaminated soil				
	Containers of paint, adhesive, sealant or resin				
	All other hazardous substances				

**The list tried to do not focus on architectural salvage as antique articles, but on the most common products. Package materials were not included in this table.*

§ 5.7 Answering research question 3

RQ3. Which building products (and respective material types) are more prone to be reused in the current context in the Netherlands?

The inventories of commercialized used building products emphasized how economic, social and technological factors discussed in Chapter 4 defines "reusability" in the Netherlands (Figure 5.7).

Wooden products are widely commercialized for reuse, particular in case of rare wood types. Wood is considered a flexible type of material to recondition (also after possible damages occurred during deconstruction), resize and remanufacture and more flexible to cascade reuse. Technical means to cascade reuse wood are more feasible when compared to re-processing challenges related to stone-based products or metals, affecting overall costs. The deconstruction process and transport of products that are smaller or can be sized are less complex when compared to more cumbersome products. The benefit to remanufacture or cascade reuse is critical to overcoming barriers related to the extension of life service of products in their original function.

Ceramic products such as wall bricks, some wall tiles although reusable, shown to be partially limited by the process of removing mortar, which is an intense work process and economically feasible for specific consumer niches as historical renovations. Clay roof tiles and other wall tiles are also more often limited to the renovation of historical projects in the Netherlands and that similar to bricks, shapes, and amounts vary significantly.

Steel components (mainly structural) have been the focus of previous studies, showing considerable economic and environmental benefits. However, steel structures are not frequent in housing constructions in the Netherlands, similar to aluminum-based products as window and doorframes.

The most significant fraction of products (in weight) available in the reference residence constructions in the Netherlands is stone based products as concrete. They are hardly harvested for reuse, as it demands more complex processes for deconstruction, transport, and storage, compared to wood. When considering the lack of market demand, it makes this group of products even more challenging for reuse. Moreover, the development of studies and new technologies focused on the higher percentage of used concrete into new concrete, poses challenges to reuse concrete structural elements, as they are not designed for reuse. It is also relevant to observe that the economic, organizational and technological forces influencing what is harvested for reuse are distinct by how products are perceived and therefore valued by social forces.

Results in this chapter emphasized findings discussed in Chapter 4, reinforcing how economic and technical feasibility to reusing depends on the existence of market demand. This chapter demonstrated how these forces were more specifically influential according to the types, physical condition, rarity, and style of products.

Based on the results above, the following chapter focuses on studying trends of materials reserves in the housing stock in the Netherlands and discusses how they could influence the supply of such products for reuse through time having.

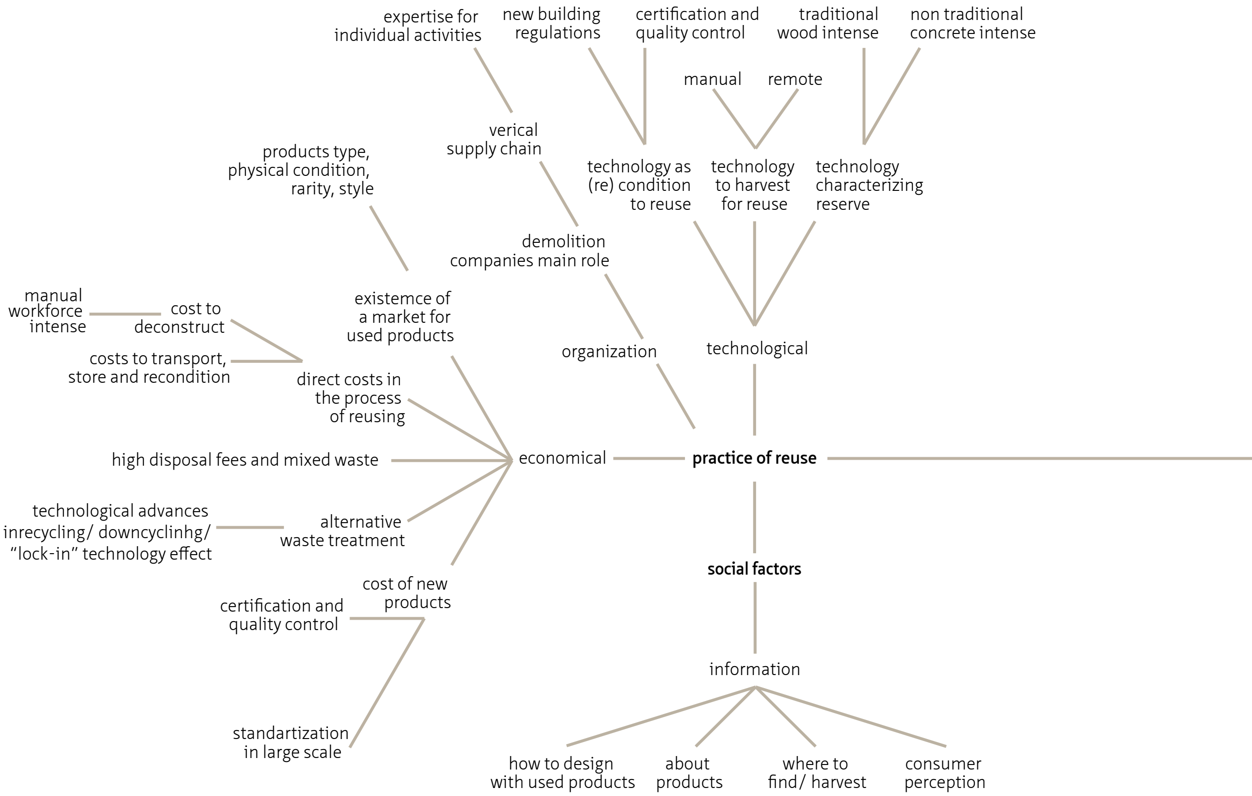
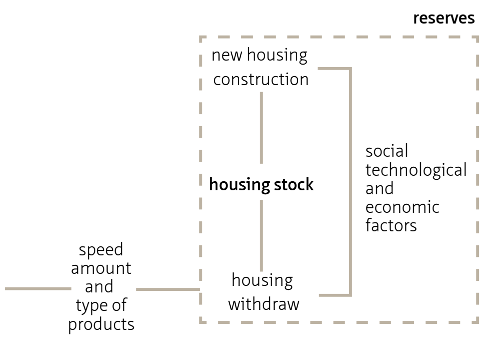


FIGURE 5.7 Predominant products harvested for commercial reuse in the Netherlands.

current reusable products

Wood	Joist, beams, scaffolding wood, timber, (frame), various wooden floor types (floorboards, strip floor, parquet,doors, staircase (internal)
Wood based components	Plywood, composite doors
Other wood components	Forms for concrete in situ (plywood, coarse wood)
Clay and ceramic products	Facade bricks, flooring brocks (landscape), roof tiles, floor tiles, sanitary appliances
Metals	Tubes, plates and bars, staircase, handrail/ fences/ gates, radiator, structure beams
Plastic	PVC windows and doors
Glass	Insulated glass
Insulation	Polystyrene panles, glass wool, rock wool



6 Building Products' Reserves in the Housing Stock in the Netherlands

RQ 4. How do trends in the housing stock affect reuse of building products (in the Netherlands)?

Chapters 1 and 2 reviewed different models dedicated to evaluate material concentrations and flows that could affect future waste management. The evolution of these models reveals the significance to understand material flows and the stocks in parallel with human activities (Fischer-Kowalski and Weisz, 1999; Newman, 1999; Weisz et al. 2001; Moffatt and Kohler, 2008; Ferrão and Fernández, 2013). Changes in the housing stock can manifest in size, content (types of materials and products), and speed materials are being accumulated and discharged. The method exposed in Chapter 3 is an adaption of previous studies to assess how trends in the housing stock affect the practice of reuse of building products in the Netherlands as part of the proposed overview of relations that influence the commercial practice.

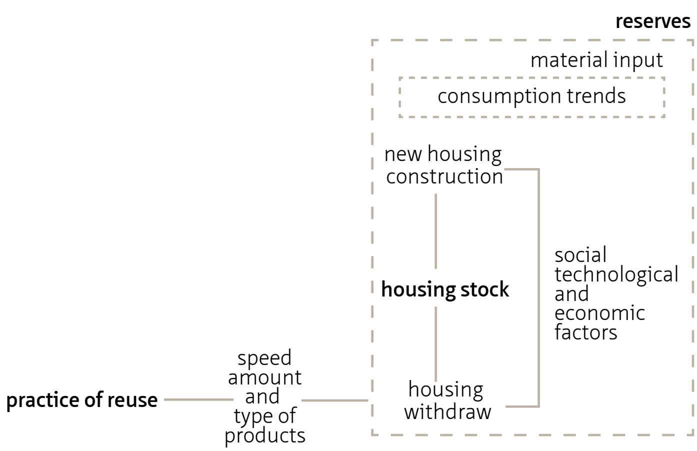


FIGURE 6.1 Study of trends in the housing stock development affecting supply of products for reuse.

Figure 6.1 depicts the study of reserves potentially affecting the supply of products for reuse. As discussed in Chapter 2, the study of activities (new added houses and withdraws) allows assessing the evolution of the housing stock dynamically. Figure 6.1, represents these trends in three-time stages, historical new added housing rates, information regarding the existing stock, and historic withdraw rates, to indicate possible trends influencing the supply of products for reusing. The analysis of material input flows associated with new housing construction is a supportive function to the descriptive information regarding characteristics of new reference houses in the stock.

Regarding housing withdraws[192], Koops and Manshanden (2006, pg.10) concluded that, in the Netherlands, demolition is an uncommon phenomenon that "*often occurs in areas with large-scale concentration of inexpensive buildings*." Combining data from CBS and Hofstra et al. (2006), it is estimated that within 8 years (1995-2003) there were 7 new houses built for every house demolished in the Netherlands. However, in the Randstad, the ratio in the same period was 6.5 new houses for every house demolished while in the rest of the country, this ratio reached approximately 3.7 to 1. Itard et al. (2008, pg.33) also observed that few changes are made in the stock with demolition rates of 0.2% average and new constructions ranging 1% per annum (Annex 6.1 and 6.2). However, Thomsen et al. (2010) concluded that there is limited information in assessing the reasons behind demolition cycles at the European level.

The following sections assess activities[193] in the housing stock associated with socio-economic and technological factors predefined in Chapter 3 to identify how dynamics in the housing stock can influence the supply of products for reuse.

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192 Withdraw rates are classified by CBS in three different basic groups: a) Withdrawal by dwelling reconstruction defined as "*total number of dwellings withdrawn from the stock due construction whereby the number of homes has been reduced*"; b) Property Transfer zoning as "*the number of dwellings withdrawn from the stock due zoning changes*"; c) Property Transfer by destruction as "*the number of dwellings withdrawn from the stock due demolition, fire and / or other disasters*". http://statline.cbs.nl/Statweb/selection/?VW=T&DM=SLN-L&PA=7413&D1=8-11&D2=1-4&D3=a&HDR=G2&STB=G1,T. Within group "c", destructions mainly account for demolitions, while fire and disaster rates are considered insignificant (Email from Kathrin Becker, *Ministerie van Binnenlandse Zaken en Koninkrijksrelaties* 2015). In the Netherlands, activities from group "c" are much higher compared to other withdraw reasons. Additionally, most comparative available information found describing changes in the housing stock do not differentiate between the three types of withdraws. Therefore, total withdraw numbers are used, rather specifying these different groups.

193 "*Pattern matching often leads to wildly erroneous inferences about system behavior, causes people to dramatically underestimate the inertia of systems, and leads to incorrect policy conclusions. For example, a stock can rise even if the inflow is falling (obviously, when the inflow, though falling, remains above the outflow*" (Sterman, 2002, pg. 507).

§ 6.1 Tenancy

Priemus (1978) described that landlords and homeowners have various motives to keep and maintain properties. While the former group is more motivated by profit interest, the second group tends to focus more on the physical quality of their homes. In case of social housing, the balance between physical quality and profit is not so critical. Thomsen and van der Flier (2007) also mentioned that the major interest of developers is on the property redevelopment rather than the characteristics of existing buildings. Withdraw rates in the social sector are average two times higher as in the privately owned segment (ABF Research, *Systeem Woningvoorraad* _ Syswov[194]).

Demolition of privately owned houses is not common in the Netherlands. Private homes tend to be demolished in the course of expropriation as part of local area redevelopment or other governmental driven plans. These large operations are more frequent in times of economic growth (Hofstra et al., 2006). The actual large-scale demolition within the social housing stock is also related to the capacity to organize and finance it, while (small) private landlords and owner-occupiers are less capable (Annex 6.3).

The share of privately owned homes in the Netherlands has been growing (50% in 2002 and 59% in 2012, CBS), and it had one of the most significant shares of social rented dwellings in 2004 (Norris and Shiels, 2004). The total share of privately owned houses changed with the increased volume of new added private owned houses after 1980 (CBS) (Annex 6.4). From 2002 to 2008 there has been growth in the rental new added houses compared to irregular growth in the privately owned sector (Annex 6.4) followed by a disruption trend during the economic crisis culminating in 2009. As consequence of the increase of private houses input in 1986 and higher rental withdraws, the total housing stock evolution shows significant growth in privately owned stock surpassing rentals in 1997 (4.309.213 private owned and 2.908.590 rentals in 2011), while rentals appear to stagnate and slightly decrease (Annex 6.5).

Tenancy through regions

The highest share of housing in the Netherlands concentrates in the West (the *Randstat*). Regarding tenancy, the West has been mainly characterized by rentals, only

194 http://Syswov.datawonen.nl

after 2003, in absolute numbers, the privately owned housing surpassed rentals. All the other regions have mostly been characterized by an increased share of privately owned housing while rental shares have consistently decreased since 1985 (ABF Research, Syswov). As private housing shares increase and as they survive longer than rentals as mentioned, it could affect the average survivability rate of the entire housing stock (Annex 6.6).

In all four regions, private housing shares increased mainly in the West at a faster rate than in other parts of the country (Annex 6.6). All regions maintained a consistent number of rentals since 1985, showing that the total stock growth was mainly in the private segment. In addition, by region, since 1985, the average withdraw rates of rentals are higher than privately owned. This characteristic is more accentuated in the West and less in the East (CBS, see Annex 6.7). Rental housing withdraws increased in recent years except in the North and very sharp in the West (Annex 6.8).

Overall, all regions had a decrease in new added houses after 1995 in the private sector, but in absolute numbers it has been higher than rentals until 2010 while decrease of new rentals started earlier (Annex 6.9). A slight increase of new rental housing constructions occurred in the same period with exception of the North region, which has a large percentage of privately owned houses compared to other regions.

While rental withdraws are consistently more significant in the West region, new rental constructions had decreased significantly. In the same period, newly added rentals have been more proportionally spread in the other 3 regions. It can be concluded that housing withdraw rates in the Netherlands is driven by withdraws in the West region and more specifically in the rental segment.

§ 6.2 Households per house and population

According to the CBS, the term household is defined as: "*One or more persons that reside together in a living, non-commercial, space that meets every-day needs*." The CBS uses this definition to distinguish from institutional households, which includes living spaces such as prisons and elderly homes, which are excluded from this assessment. In various scenarios (Hilderink et al., 2005), the decrease in average household size continues with special share among the higher age groups (ages 65 and over).

According to ABF Research (Annex 6.10), the average household size decreases trough time reflected by the fast growth of one-person household in comparison with the more than 1 person household per house group. The number of one- and two-person households grew exponentially during the second half of the twentieth century due to the rise in living standards. One or two people now live in dwellings that not long ago housed entire families (Leupen et. al., 2011) (Annex 6.11). Considering that the average house surface per person between 1996 and 2006 varied from 136 m² to 139 m² (CBS), this phenomenon consequently affects the average ratio of building material use per capita.

A similar trend can also be seen in other European countries (Annex 6.12). The G4 (Amsterdam, Den Haag, Rotterdam, and Utrecht) apparently has the lowest average persons per household reaching 1.88 with more participation of singles, 51% compared to 36% in the entire Netherlands in 2010 (*Ministerie van Binnenlandse Zaken en Koninkrijksrelaties*, 2010).

This trend will likely continue, reaching a 30% increase in the one-person household segment; and a 9% increase in the two-households per house group in 2030 (CBS in *Ministerie van Binnenlandse Zaken en Koninkrijksrelaties*, 2010). In short, in the Netherlands, "*the sharp growth in the number of households is mainly because more and more people are living alone*." [195] Such trend is forecasted to continue until 2050 (*Ministerie van Binnenlandse Zaken en Koninkrijksrelaties*, 2016).

There is an apparent similar development of yearly-added population and yearly-added households between 1985 and 2011 (CBS). However, these two trends are not visually evident when compared to yearly-added houses and yearly withdraws in the same period (Annex 6.13). When comparing the percentage growth between population, housing stock and the total number of households (Annex 6.14), the increase of housing stock since 1966 is more similar to the household growth than the total population, reflecting the decreasing household per house in the housing stock evolution.

The increase of one-person household trend will become a critical factor in the development of the housing stock together with an aging population (Annex 6.15). The trend between yearly-added new houses and yearly population growth from 1960 to 2010 shows that although new houses and population stock continue to grow, the yearly input slowly decreases.

195 http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl2114-Huishoudens.html?i=15-12

Household through regions

The number of inhabitants per house unit varies per region. Half of the housing stock concentrates in the West part of the country, which is also the most urbanized region in the Netherlands while 40% is on the East and South of the country (ABF Research, Syswov).

The large cities, and especially those with a major university, have a high proportion of single-person households. ...“ *the proportion of single-person households aged 65 or older compared to the total number of single-person households varies strongly between regions*.”[196] In some rural communities, the percentage of single households is also high, such as along the coast of North Holland. These municipalities are attractive for stand-alone elderly[197].

In general, larger cities contain more single households (Annex 6.16) compared to less urbanized areas in the country. The highest number of one-person household locates in the West region followed by the South (Annex 6.17). Proportionally to each regional stock, the share of single households is also higher in the West followed by the North region. However, the fastest growth rate of one person-households was in the South and East, with the slowest growth in the West. The fastest growth in the housing stock since 2000 also happened in the East followed by the West.

Therefore within this period, housing stock growth followed more closely household growth than population growth as seen in the entire stock, which is more visible in the South combining the lowest population growth with the highest one household growth in the country in these years.

When comparing population growth with housing withdraws and new constructions in the four regions, the relation is less clear than seen with the stock evolution. The absolute number of withdraws in the West region from 1990 to 2011 outweighs withdraws from the three other regions together in all years except in 1996 and 2001 (CBS)(Annex 6.18).

196 http://www.pbl.nl/themasites/regionale-bevolkingsprognose/prognoses-in-beeld/huishoudens

197 http://www.pbl.nl/themasites/regionale-bevolkingsprognose/prognoses-in-beeld/huishoudens

§ 6.3 House size

Different studies indicated that housing plans in the Netherlands evolved towards larger surfaces, especially for living areas and the complete ban of rooms without outside openings, which also tended to become proportionally wider with time (Straub, 2001).

Schoonvelde (2010, pg.73) suggested that corner and terraced houses were the housing groups that had the highest surface increase between 1940 and 2008 (Annex 6.19). This housing group also represents the most common typology in the housing stock (see Section 6.4).

Hooykaas and colleagues[198] (Annex 6.20) as well as Rijksoverheid (2009[199]) (Annex 6.21) described similar results, also indicating the growth of the average house surface in the Netherlands. The *Ministerie van Binnenlandse Zaken en Koninkrijksrelaties* (2013) also indicated that the average house surface in the single houses, increased more than multifamily houses, reflecting changes in consumption patterns (Annex 6.22).

The number of rooms[200] and house size in m² are the most common information available regarding housing size. From 1988 to 2011, the highest number of new added houses was with four rooms. However, since 1988 the input of houses in this category has been decreasing, while since 2003 there was an increase of new added houses with three and two bedrooms (Annex 6.23).

More recently available data showed that new added houses in 2012 and 2013 had the smallest percentage in the >150m² group and highest percentage in the 90m² and 90-119 m². Therefore, while the general house surface increased (both single and multi-family), more recently the number of new houses added to the stock with four rooms decreased and houses with three rooms increased. Regarding stock shares, from 1985

198 www.rotterdam-woont.nl. Hooykaas mentioned in an e-mail that despite the reviewed material showed that increase of house surface seemed to have occurred as in Figure 16, more recent data indicatives showed that this house size increase that the surface per person is not growing any more; maybe even decreasing. (E-mail from Hooykaas, 2015).

199 http://vois.datawonen.nl/quickstep/QSReportAdvanced.aspx?report=cow10_109&geolevel=nederland&geoitem=1&period=most_recent_period

200 Room definition according to CBS: Rooms that are accessible by a door and that have at least one window and that it does not include a bathroom, kitchen, toilet, and opened attic and entrance hall.

to 2012 the five room housing share increased as well as the three room, while the one and two and four rooms decreased (Annex 6.24).

Regarding the survivability of houses in relation to size, several studies (Hofstra et al., 2006; Hoogers et al., 2004; Van Nunen, 2010) have indicated that the size of houses is a critical determinant for the demolition decision, showing that demolition rates tend to be higher among the smallest and the largest housing sizes (Annex 6.25 and Annex 6.26). Both in number of rooms (Annex 6.25), as in m² (ABF Research, Syswov), housing withdraws between 1985 to 2013 were concentrated in the group <90m² being (57% in 2012 and 47% in 2013) of the total housing withdraws. Nonetheless, the second housing group with largest withdraws in 2012 and 2013 was the >150m².

Although different studies indicated growth in the average house size in the Netherlands, from 2012-2014, the most common house size in the stock was the category < 90m² (with a small difference to the category 90-119 m²). Hooykaas[201] observed that despite previous studies indicated increase of house surface, more recent data indicate that the surface per person is no longer increasing and possibly decreasing.

Based on the data analyzed in this chapter it is not possible to affirm that the average house surface will continue to grow as it has apparently shown in historical data, but the trends indicated more strongly activities are happening in the <90m² housing group and that the total housing stock is mainly characterized by this housing size group.

Housing size through regions

The predominant housing group in the West is the <90m², while in the other three regions the largest housing group is classified between 90m²- 119 m² (ABF Research, Syswov) (Annex 6.27). The relation between high withdraws of rental houses in the West discussed in Section 6.1 coincides with the large withdraw share of small size houses.

Finally, few conclusions are consistent because the housing stock description by size and region is more often based on the number of rooms rather than surface area (only recent available for 2012, 2013 and 2014). When considering the number of rooms,

201 E-mail from Hooykaas, 2015

data showed that, despite oscillations, in all 4 regions, the largest number of new houses added every year to the stock from 1995 to 2011 were the 4 rooms type despite the continuous decrease, followed by 3 room and 5 room types. Another trend is that in all four regions the three-room group type has increased more than any other group especially in the South followed by the West (Annex 6.28 and 6.29).

The predominance of withdrawals of smaller size houses is also applicable to all four regions and more accentuated in the West (Annex 6.30). In 2013, the largest withdraws happened in houses of <90m² and very similar withdraw amounts of >150m² houses in the South and North (ABF Research, Sysvow).

§ 6.4 Housing typology

Housing typologies in the Netherlands are often generalized in two categories: single- or multi-family. Other classifications also include horizontal or vertical housing (Blom et al., 2004; van Battum, 2002; Feijen, 2003; Den Otter, 2007; ABF Research, Syswov). Alternatively, housing typology is subdivided by a description of physical features of the buildings that directly affect the type of material and amount of material content (VROM, 2003; *Novem*, 2001; *Senternovem*, 2007; *Agentschap Nl*, 2011[c]). In the Netherlands, The right hand column in Table 6.1, shows the most common housing typologies in the Netherlands, but more often is classified as shown in the left column.

A more detailed description of buildings is preferred in this study, leading to a more comprehensive overview of buildings according to products and materials. Certain construction systems are more often applied to one or another type of building (Noy and Maessen, 2011), and therefore are also valuable for material metabolism assessment.

TABLE 6.1 Most frequent building typologies in the Netherlands (*Agentschap Nl*, 2011[c]).

Single family	*Vrijstand*
	2 onder 1 kap
	Rijwoning
(Maisonette is not always considered a separate typology on its own)	*Maisonnettewoning*
Multi family	*Portiekwoning*
	Galerijwoning
	Other *flatwoning*

Three typologies (*Rijtje, Vrijstand, Twee onder een Kap*) of single-family housing represent 84% of the housing stock (in surface area), and only 16% is multi-family houses (Annex 6.31). The share of single- family houses is predominant in the stock and it has been increasing with a small decrease after 2011 (Annex 6.32 and 6.33).

Although the municipalities provide original data, there is limited information on how the seven typologies described by the *Agentschap NL* (Table 6.1) evolve in the housing stock through new construction and withdraw rates. Both references often use the multi-family and single-family classification for withdraws and newly added dwellings.

Three other sources (*Agenstachap Nl, Novem* and VROM, Annex 6.34) also include the seven housing typologies. The classifications however did not entirely coincide between the three reports such as building typologies or construction year, which are grouped differently in each report leading to an approximation.

As a result of the comparison between these three reports: *Novem*, 2001, *Senternovem*, 2007 and *Agentschap Nl*, 2011[c]; *Galerijflats* from before 1966 followed by *Rijwoningen* from 1946 to 1965 had the highest withdraw rates. Highest construction rates concentrated in the terraced housing group, showing a large number of this type of construction in the Netherlands. Single-family housing constructions consume more building material per house unit considering systems as roofs and at times walls that are not shared with other units. More information regarding the relation between building typology and construction methods is in the following section.

When comparing multi-family and single-family typologies (excluding other physical characteristics), new added multi-family dwellings increased after 2004 while new single-family houses have declined (Annex 6.35). However, from 1995 to 2012 the percentage of multi-family houses in the stock has declined (Annex 6.33). Withdraw rates from both categories are similar (1995-2011, ABF Research, Syswov), therefore as a proportion of the total stock, multi-family houses have higher withdraw rates than single-family houses even though they represent only 16% of the total housing stock.

Housing typology through regions

A description of the seven building typologies evolution by region is not available for comparison, while data classified as multi and single-family categories is more consistent. According to VROM (2003) larger cities have a smaller percentage of single-family buildings in comparison to other less urbanized areas in the country. In other words, multi-family houses are more concentrated in the highest populated region, the West (Annex 6.36). However, in absolute numbers, the West also has the highest single housing stock.

Yearly percentages of new added multi-family housing grew in all regions since 1985, but more specifically in the West followed by the South. In the same period, percentages of new single- family added in each region stock decreased (Annex 6.37). The stock evolution, however, showed small differences between the shares of the two typologies from 1998 to 2012, with a small growth in share of multi-family houses in the East and South and a small grow of single-family share in the West.

In absolute numbers, in all regions (less in the East), yearly new added single-family houses have decreased even though they continued to outnumber new added multi-family houses every year. In the West, the percentages of new yearly single houses added over the total new added houses have been inferior relative to other regions (Annex 6.37), with a similar trend in the South. In the West this trend has been stronger since 2004 when new yearly multi-family houses increased reaching similar absolute numbers of new added single-family houses (ABF Research, Syswov) (Annex 6.38).

In absolute numbers, withdraws of single-family houses in all three regions are higher than multi- family houses between 1998 and 2012, except the West (Annex 6.39). However, as the stock of single-family houses is larger than multi-family in all regions, relative to the size of the respective stock, the yearly percentage of multi-family houses withdraws is proportionally higher than single-family houses in the period 1998- 2011 in all regions (Annex 6.40). In the West, the withdraw rates of single-family houses are also lower compared to the size of single-family housing stock than all other regions. Therefore in this period can be noted lower survivability of multi-family houses in general when compared to single-family houses in all regions.

Finally, in the East, North and South, the stock of single family houses are approximately more than four times larger than the multi family housing stock (82% to 18%), and although the stock increased, this pattern had no relevant changes from 1998 to 2011. In the West region, however, the stock pattern is proportionally different where the single-family stock is in average slightly larger than single family housing stock (58% to 42%) in the period 1998 to 2011. Consequently, changes occur in both types of stocks where most activities happened in the multi-family housing stock, both as new added and withdraws, but without significant changes in the overall proportions of each stock.

§ 6.5 Construction year

As discussed in Chapter 4 (Section 4.2.3.Technological factors), the construction year of buildings reveals different information regarding physical buildings characteristics. The evolution of constructive systems affected different types and proportions of materials used (Bot, 2009; Hofstra et al., 2006, Feijen, 2003; Meijer, 2006) and different product's characteristics. In general, traditional construction applied more workforce intense methods (van Battum, 2002) compared to more recent industrialized ones. Some housing construction systems became more popular through time (van Elk and Priemus, 1971; Lijbers et al., 1984), confirming the relevance to divide the housing stock according to construction year to distinguish the material type product.

While assessing waste flows of concrete in the housing stock in the Netherlands, Hofstra et al., (2006) classified three different construction periods characterized by different material concentrations reflecting changes in construction systems: before 1900's, 1900- 1950 and after 1950's (Annex 6.41).

Through extrapolation, they have estimated an increase in demolition of houses from the 1900- 1950 period compared to the other two periods, type and quality of constructions. According to Hofstra et al. (2006), the growth in the volume of waste was mainly due to the increase of demolition of houses built immediate postwar, which were characterized by lower quality constructions built in a period where reconstruction, low-cost building solutions, and high demand were critical factors for housing production.

The increase of vertical housing, flat roofs, and compulsory constructive measures to improve sound and fire insulation of housing units during the postwar period also played an significant role regarding increased consumption of cement based products, later affecting outflows of concrete from the housing stock (Hofstra et al., 2006).

Thomsen and van der Flier (2011, pg. 8 referring to Lijbers et. al., 1984) noted the relationship between obsolescence of post-war housing stock in the Netherlands with four factors: "*design, construction, use and management, where design was by far the main causal factor*."

Constructive systems evolved in housing construction in the Netherlands (Annex 6.42 and 6.43). Construction systems are also related to building typologies (multi-family vertical constructions and low-rise single-family housing). Therefore, by classifying the housing stock according to construction year and typology to study withdraw trends, facilitates to estimate material output flows.

Traditional construction methods are concentrated in single-family houses built before the Second World War. In the post-war period, other building techniques are introduced, generally more stone intense, replacing some share of wood products (*Agentschap Nl*, 2011; VROM, 2003, 2006; *Senternovem*, 2007; *Novem*, 2001, Persoon, 2011; Archidat, 2012; Bot, 2009; Hostra et al., 2006; Feijen, 2003; Meijer 2006). These references indicated that through time, besides the increasing concentration of cement-based products replacing ceramics and wood fractions, there was also the inclusion of a variety of materials many being composites.

As explained in Chapter 3, there are several challenges in defining the lifetime of buildings. For long-term scenarios, comparing historical withdraw rates is limited as rates of specific housing groups will not remain the same through time. However, in this study, long-term forecast is not the main objective, rather to increase knowledge regarding vicissitudes that affect the housing stock.

Different classifications of the housing stock according to construction year and other physical building classifications used in this sections are the same references used in Chapter 4 regarding the technology of buildings. The first one (Hofstra et al., 2006) indicates that between 1995 and 1999 the highest demolition rates in absolute numbers happened in the group of houses built between 1900- 1950 while between 1999 until 2004 the highest demolition rate occurs in the housing group built after 1950 (Annex 6.44).

Based on ABF Research, Syswov, (2013), the stock has been divided into nine construction periods (Annex 6.45). An average decrease percentage rate was calculated from the shares of each different housing group in stock between 1985 to 2012, showing highest withdraws in houses built between 1906 to 1930 and 1945 to 1970 with no building typology specifications. This dataset from ABF Research, Syswov is compared with the dataset provided by VROM and *Agentachap Nl* (Annex 6.46).The results from these three different sources (summarized in Annex 6.46) show *Rijwoning* built between 1946 and

1965 together with *Galerij* flats built before 1966 had the highest withdraw rates since 1985. Without specifying housing typology, general houses built in the periods 1945-1970 and 1906-1930 also presented high withdraw rates.

The assessment confirms how complex it is to estimate the lifetime of buildings. Nonetheless, comparing different demolition rates reveals that the more specified housing groups are described, the more comprehensive becomes the survivability tendencies of each one of them, not only associate with the age of buildings.

Between 1921 and 2011, housing withdraws reached three picks respectively in 1940, 1945 and 2007 (Annex 6.47). In 2007, most withdraws were of houses built between 1945 and 1970 secondly from houses built and prior 1944 (Annex 6.48). As seen in previous sections, most withdraws were also driven by the West and multi-family houses.

In the same period, new yearly-added houses to the stock significantly increased from 1946 with 1593 new houses added in 1973 reaching the highest pick of 155412 new houses. Subsequently, new added houses decreased to 50773 houses added to the stock in 2011 (Annex 6.47).

The stock has been increasing continuously since the post war period. In 2013, 19.5% of the housing stock was built before the Second World War, 26% between the Second World War and 1970, 43% built between 1971 and 2000 and 11.2% after 2001 (ABF Research, Syswov).

Construction year through regions

For the houses built after 1991, the West and East had the highest new housing construction rates. However, the dominant house age group in all four regions was constructed between 1971 and 1990, coinciding with the peak input flows. The West and South regions have the largest share of houses built before 1944, which are characterized by traditional construction systems.

The size of housing stock groups were compared within the period 1985 to 2010 in the four regions to differentiate housing withdraws according to construction year by region (Annex 6.49).

The housing group built after 1992 has been excluded as the withdraw rates were irrelevant. The results indicate that in all regions, housing stock decreased faster within the group of houses built between 1945 and 1970. In the West, the decrease of the housing group built before 1944 is approximately similar compared to the housing group built between 1945-1970. The total withdraws' pick occurred in 2007 in the Netherlands coincided with a pick of houses in the West region built between 45 and 70 and secondly by houses built before 1944 (ABF Research, Syswov) (Annex 6.50).

§ 6.6 GDP per capita

As mentioned in Chapter 3, GDP per capita represents a small fraction of a broader economic scope influencing changes in the housing stock. Annual GDP per capita values were compared as a reference to general economic development within the national boundary disregarding regional differences.

In recent history, annual GDP per capita in the Netherlands has continuously increased until 2008 with a rupture during the economic downturn. Therefore, other ascending developments such as total housing stock, population, households can be directly associated.

Some relations, however, showed to be more evident than others. More specifically, through correlation analysis, annual GDP per capita between 1990 and 2009 had a positive relationship with the total housing stock development, new added private houses in particular new multi-family private houses (Annex 6.51). There was also a relatively stable positive relation with total withdraws (Annex 6.52). Annual GDP per capita in the same period showed a negative relation with newly added single-family in particular single-family private houses and added houses with four rooms.

The time frame for the available data together with the disturbances caused by the economic downturn in mid 2000, showed to be limited to conclude any specific visual relation between GDP per capita over the housing stock and flows.

New housing construction does not show a strong relation with GDP (per capita). Traditionally, the housing market in the Netherlands has been shaped by policy to support affordable housing and ownership (Vandevyvere and Zenthöfer, 2012). In other words, there is a broader and also more specific scope influencing new housing construction, as government policy, trough setting of interest rates and providing tax incentives (*hypotheek aftrek*).

Moreover, between 2003 to 2007, GDP and DMC (Domestic Materials Consumption) grew similarly with no apparent decoupling between economic and environmental variables. However, between 2007 and 2009 there was an absolute decoupling of GDP from DMC, which coincided with most years between the low point of the financial and economic crisis; indicating how the economic crisis affected the material construction input, when DMC dropped much quicker than GDP (Moll et al., 2012).

Consequently, when looking at aggregated data (the European building sector) adding to the time span of the available data (10 years) and the disruption caused by the economic crisis, a macroeconomic indicator such as GDP (and domestic material consumption) allows limited information to identify any consistent pattern (Herczeg et al., 2014) of influence over activities in the housing stock.

The housing withdraws that during period between 1996-2007 had seen a constant increase until 2007 was also driven by policy focused on housing restructuring in developing in urban areas. Most of these interventions were related to housing associations, which since 1999 have been connected with government housing policy (Vrolijk et al., 2014). The decrease of housing withdraws later affected by the economic crisis after 2007 and although decreased until 2013 the total housing withdraws has been still higher than 1988- 1992 (Vrolijk et al., 2014).

Finally, the influence of activities in the stock is related to different factors external to the system, and for a mature economy as in the Netherlands, the analysis of GDP over the housing stock activities through qualitative analysis is limited. A more robust study on housing policy and mortgage plans should be included in future studies.

§ 6.7 Results of housing stock trends

Although it is assumed that in reality, many factors influence trends in the housing stock, six factors were compared with historical information of housing withdraws, new constructions, and the stock evolution. The aim was to identify possible trends in the ways materials are accumulated and discharged that could affect the supply of products for reuse. Also, results from the investigation in Chapter 4, indicated that other factors affect the way materials are accumulated in the stock, for instance, the economic feasibility of some construction systems rather than others and construction regulations.

Based on the proposed qualitative research approach, some selected socio-economic factors indicated to be relevant to activities occurred in the housing stock. The investigation however, does not assume that these trends will remain constant in the long-term future.

Changes in the housing stock related to socio-economic factors described in this chapter occur simultaneously within the system, and therefore, trends in the stock result from the combination of such influences. The most distinct relationships found were:

– Typology+ Tenancy+ Location + Construction year
Withdraw rates in the social sector are in average two times higher than the private sector. Also, the relation between multi-family houses and rentals are strong (Annex 6.53). The share of single-family houses was higher than multi-family in all studied years. Within the private housing group, 83% are single-family houses[202], while three out of four different multi-family typologies had more than 50% rentals in 2011. Most single-family typologies are private homes except of *Rijwoningen* from 1946 to 1991, and most multi-family typologies are rentals (Annex 6.34).

According to Hoogers et al. (2004), excluding houses built between 1931-1945 and between 1985 and 2000, rental multi-family houses had the lowest survivability rate followed by private multi-family houses. Moreover, in absolute numbers the yearly amount of withdraws of rental multi- family houses in the West has been dominant compared to all withdraws in the other three regions.

As the input of single-family houses and private houses increase, it is expected to increase the overall survivability of the housing stock, delaying material output. In the Netherlands, multi- family houses have a lower share of wood and ceramic-based materials, in special in pre war constructions, mostly characterized as traditionally built. Pre-war houses are concentrated in the West, but they have higher survivability than the same group of houses in the other three regions. Withdraws in the pre-war housing group with high concentration of wood are still high but will slowly decrease as this stock naturally decreases in size. Finally, housing withdraws in the West represent the overall activity of housing withdraws in the Netherlands, showing the relevance of this housing group regarding material recover for reuse (Annex 6.54).

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202 http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl2166-Woningvoorraad-naar-bouw-jaar-en-woningtype.html?i=35-173

- Construction year +Typology + House Size
  Building characteristics related to aesthetics, quality, and size of constructions of the early post-war period influence the low survival rates of *Galerijflats* built before 1966 followed by *Rijwoningen* from 1946 to 1965 (*Novem*, 2001; VROM, 2007; *Agentschap Nl*, 2011). Buildings are products of their time, reflecting not only their own age but also characteristics that will lead to early or later obsolescence. As the quality of construction improved from the early post-war period, it is also estimated that the survivability of the housing stock increases.

- House size+ Households + Typology
  Despite a general growth in house surface, the predominant average house size in the Netherlands is < 90m². Also, the increase of single family housing stock and the increase of single households with prospects to increase in the next decades in special for the 65 years old group is an indicative that the housing stock is increasing not only in size but also in material per capita (Annex 6.55). As single household population group increases, it is also expected that the average size per housing unit remains stable in the future.

In this chapter, the study of how housing stock trends relate to supply of products for reuse is summarized in Table 6.2, unfolding the box "material reserve" in Figure 6.1 into a description of the housing stock evolution. With exceptions, the material output from the housing stock in the Netherlands has been driven by withdraws of < 90m² multifamily rental houses in the West region, which are mainly built with non-traditional constructive methods and types of materials that are not commonly commercialized for reuse.

The total housing stock, however, is predominantly composed of single private houses built with non-traditional methods. This housing group tends to increase according to the yearly new houses added. Also, the total housing survivability tends to increase in time influenced by the increase of construction quality compared to recent post-war houses, and increasing number of private-owned houses. This could affect a decrease in the amount of material output per time (from withdraws) on the one hand, but the increase of material per capita or increase housing sizes could offset it.

If survivability increases, the relevance of material output derived from renovations will predominate (as already detected by architects[203], demolition companies[204] and manufacturers[205]). It is relevant to remind that this study excluded material consumption and discharge caused by renovations. Therefore, while housing stock continues to grow and withdraws are stable, the output flows will be still affected by renovations and material intensity.

The analysis showed that each factor influences the housing stock combined rather than in isolation. The degree of influence or predominance of each factor affecting changes in the stock cannot be evaluated with this current research method, nor it has been a goal of this study. In the long term, as the private-owned housing group increases, it is not clear which factor will be dominant to motivate withdraws besides the technical lifespan. Most importantly, the analysis above showed that according to historical data, other factors rather than a pre-established lifespan of the building structure determined the survivability of houses in the stock in the Netherlands. Moreover, whereas the average lifespan of a house dropped from 75 years in 1985 to 60 years in 2000, it is relevant to note that most houses demolished were built in 1950 and that how these buildings were characterized affected their lifespan. Disaggregating information in this process helped to understand the process of obsolescence. For future studies, a quantitative analysis could further evaluate the degree of influence of drivers to understand causality and what factors to prioritize in future analysis of housing stock evolution.

To support the understanding of material trends the analysis of material consumption develops in the following sections. As discussed in Chapter 3, because of challenges regarding data availability, different data are combined to build material input trends at product level associated with the housing stock.

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203 *Economische Ontwikkeling & trends in de Nederlandse bouw en instalatie*, Arch- Vision. Dec 2011.

204 Interview with Hans Orange (*Oranje b.v.*).

205 In 2016 the ratio between new construction and repair together with renovations is approximately 55% resp. 45% (Cement & Beton Centrum).

TABLE 6.2 Trends of housing stock activities in the Netherlands influencing material metabolism.

	NEW HOUSING CONSTRUCTION	HOUSING WITHDRAW	STOCK TREND	MATERIAL IMPLICATION
Tenancy (1985- 2010)	New yearly added private houses became higher than rentals after 1986. After 2003 there was an increase of new added rentals (but still inferior to private). In 2009 during the economic crisis sharp fall of new private added to stock.	Withdraw rates in the social sector are average two times higher as in the private owned segment since 1985, but even higher after 2000.	As consequence of the increase of private houses input in 1986 and higher rental withdraws, the total housing stock evolution shows significant growth in private owned stock surpassing rentals in 1997, while rentals appear to stagnate and slightly decrease.	Rentals stagnate + Private increase + Increase private owned housing stock = Increase housing survivability.
Development by region	New added rental houses have been more proportionally spread in the South, East and North and in consistent decrease, while there was a sharp decline in new rental houses in the West.	Rental withdraws are consistently larger than private in the North and especially in the West region. Rental housing withdraws in the West region every year are in average 1/2 of total yearly amount of withdraws in the Netherlands.	The housing stock in all regions became predominantly private owned, but later in the West after 2003.	Largest stock of rental houses in the West + Increase private owned houses in all regions including the West = Largest amount of withdraws concentrates in the West but increasing overall survivability with time.
Persons/ household per house (1950- 2013) Population (1940- 2009)	Yearly added new houses and population growth showed similar trends (slow decay between 1960- 2010).	No clear relation between yearly changes in population or households with yearly withdraws.	The total housing stock grew faster than population related to faster growth of total households. People living alone are forecasted to have the fastest increase in the coming years.	Increase total household numbers+ increase population = Increase housing stock + Increase material per capita.

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TABLE 6.2 Trends of housing stock activities in the Netherlands influencing material metabolism.

	NEW HOUSING CONSTRUCTION	HOUSING WITHDRAW	STOCK TREND	MATERIAL IMPLICATION
Development by region	–	South, East and North showed significant similarity in absolute numbers of withdraws per year despite the housing stock size in each region. . Withdraws in the West are higher than number of withdraws in the 3 other regions together.	The largest housing stock of 1 person household is concentrated in the West and South respectively. Proportionally, the share of 1 household is also higher in the West followed by the North region. However the fastest growth rate of one person-households was in the South and East, with the slowest growth in the West. Fastest growth in the housing stock since 2000 also happened in the East followed by the West.	Increase single households in all regions with largest concentration in West and South. = Increase material per capita in West and South. Withdraw numbers in the West are higher than all other regions together. = High concentration of construction waste in the West.
House size (1985- 2012/ 1940-2008 /1985-2009/ 1998 -2012/2012-2013)	In 2012 and 2013, the >150m² group had the smallest percentage added and the largest percentage added of houses < 90m2 and 90-119 m². In 2012, the -90m² had the largest % of new added houses. The largest number of new added houses was since 1985 was the 4 rooms type, but it has been decreasing and increase of new added houses with 3 and 2 bedrooms.	The small (<90m²) size houses and the largest (>150m²) have shorter survivability.	Despite the general increase of house surface in the stock, the largest housing group is the < 90m² (with a small difference to the category 90-119 m²). In number of rooms, the largest % in stock is 5 rooms and 4 rooms in second place. Since 1985 only the category 5 and 3 rooms have increased while 4 and 1/ 2 rooms decreased.	< 90m² remains the most common house size in the stock = Decrease housing survivability
Development by region	In 2012 <90m² was the highest percentage new added housing group in all regions followed by 90-119m². There was also decay in all regions of new added 4 and 5 rooms and increase of 3 rooms.	In 2012 withdraws in the <90m² house size group occurred in largest percentages in the 4 regions (varying from 50% to 80% of total withdraws from each region).	< 90m² houses are predominant in the West , with a small difference to the 90-119 m² category, while in the 3 other regions the predominant group is 90-119 m².	Largest stock of small size houses in the country is in the West = Decrease survivability in the West. Recent increase of new added small size houses in all regions = Decrease house survivability all regions.

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TABLE 6.2 Trends of housing stock activities in the Netherlands influencing material metabolism.

	NEW HOUSING CONSTRUCTION	HOUSING WITHDRAW	STOCK TREND	MATERIAL IMPLICATION
House typology (1995-2011/ 1985-2011/ 2001- 2011/ 1998- 2012	Yearly added single-family housing group are higher than multi family more specially terraced houses. New construction trends indicated increase of new added multi family houses and decrease of new single houses after 2004.	. Multi family houses have lower survivability. . Group data: *Galerijflats* from before 1966 followed by Rijwoningen from 1946 to 1965 have presented the highest withdraw rates. . Withdraw numbers from both categories are similar (1985-2011, Syswov).	84% of the housing stock (in surface area) is represented by 3 typologies of single-family housing and only 16% representing multi family houses. The share of single family houses in stock is predominant and has been increasing with a small decrease after 2011. Changes occur in both types of stocks but more dynamically in the multi family housing stock, both as new added and withdraws, but without significant changes in the overall proportions of each stock.	Share of single family houses increases = Increase material per capita = Housing survivability increases = Possible increase share of wood*

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TABLE 6.2 Trends of housing stock activities in the Netherlands influencing material metabolism.

	NEW HOUSING CONSTRUCTION	HOUSING WITHDRAW	STOCK TREND	MATERIAL IMPLICATION
Development by region	Yearly percentages of new added multi-family housing grew in all regions since 1985, but more specifically in the West followed by the South. In the same period, percentages of new single family added in each region stock decreased.	. In absolute numbers, withdraws of single family houses in all three regions are higher than multi family houses between 1998 and 2012, with exception of the West. Relative to the size of each respective stock, the yearly percentage of multifamily houses withdraws is proportionally higher than single-family houses in the period 1998- 2011 in all regions. In the West, the withdraw rates of single family houses comparative to the size of single family housing stock is lower than all other regions. In the West housing withdraw in absolute number are 4 to 5 times higher than withdraws from the single family stock in the same region.	In the East, North and South, the stock of single family houses is approximately more than 4 times larger than the multi family housing stock (82% to 18%), and although the stock increased, this pattern had no relevant changes from 1998 to 2011. In the West region the stock growth pattern is proportionally different where single family stock is in average slightly larger than single family housing stock (58% to 42%) in the period 1998 to 2011. Multi-family houses are more concentrated in the highest populated region, the West. However, in absolute numbers, the West also has the largest single family housing stock. The stock evolution showed small differences between the shares of the two typologies between 1998 to 2012, with a small growth of the multi family share in the East and South and a small grow of single-family share in the West.	High concentration of multi-family buildings in the West = Lower housing survivability+ high percentage stony waste in the West High percentage of withdraws of single families in the East, North and South = Proportionally higher fractions of wood and ceramic waste in these regions than in the West* High concentration of single-family houses in the West + Lowest withdraw rates of single families in the West = Moderate harvest of ceramic and wood

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TABLE 6.2 Trends of housing stock activities in the Netherlands influencing material metabolism.

	NEW HOUSING CONSTRUCTION	HOUSING WITHDRAW	STOCK TREND	MATERIAL IMPLICATION
Construction year (<1900- 2011)	Between 1921 and 2011 new yearly added houses to the stock increased from 1946 to the highest pick in 1973 subsequently decreasing until 2011.	Between 1921 and 2011, housing withdraws reached 3 picks: in 1940, 1945 and 2007. In 2007, most withdraws were from houses built between 1945 and 1970 secondly from houses built between 1906- 1930. More specifically: *Rijwoning* built between 1946 and 1965 together with *Galerij* flats built before 1966 had the highest withdraw rates since 1985.	Traditional construction methods are more clearly concentrated in single-family houses built before the Second World War. In the post-war period, other building techniques are introduced, generally more stone intense, replacing some share of wood products. The stock has been increasing continuously since the post war period. In 2013, 19.5% of the housing stock was built before the Second World War, 26% between the Second World War and 1970, 43% built between 1971 and 2000 and 11.2% after 2001.	Buildings before 1945 High withdraw rates = Higher concentration of wood and ceramics Second largest housing group in the country built immediate after 1945. Higher concentration of stony based materials = High withdraw rates
Development by region	For the houses built after 1991, the West and East had the highest new housing added rates.	In all regions, housing stock decreased faster within the group of houses built between 1945 and 1970. In the West, the decrease of the housing group built before 1944 has been high comparatively to the housing group built between 1945-1970. The total withdraws pick in 2007 in the Netherlands coincided with a pick of houses in the West region built between 45 and 70 and secondly by houses built before 1944.	The predominant house age group in all 4 regions was constructed between 1971 and 1990. The West and South regions currently have the largest share of houses built before 1944, which are generally characterized by traditional construction systems.	Large share of houses from before 1944 is in the West + Low withdraw rates in single houses, high withdraw rates in multi family houses = High concentration of stony based materials in the West = High concentration of wood*

§ 6.8 Building material consumption trends

Material input data is applied in this study as a reference for consumption trends affecting material reserves in the building stock. As previously described, the housing stock evolved from more to less traditional constructive methods, affecting types of materials used. These transitions have been motivated by the will to reduce costs and time during construction in the post-war context periods in the Netherlands (Lijbers et al., 1984; van Elk and Priemus, 1971), and changes in technical construction requirements (Grinberg and Bakema, 1982; Hasselaar, 2001). Historical evolution of construction techniques (see Annex 6.56) indicated how these technological shifts occurred (Bot, 2009; Oosterhoff, 1990; Straub, 2001; Leupen et al., 2011) consequently affecting input flows of materials in the housing stock. Most of these studies, however, did not target quantification of materials consumed in time to monitor material flows nor to evaluate and support resource and waste management.

It is relevant to note that this study also compared historical data of waste flows and housing withdraws. The results, however, were limited to identify relevant implications for the supply of reusable products for reuse (Annex 6.57). Some factors justify this condition. Firstly, even though currently the code description for waste registration at the LMA (*Landelijk Meldpunt Afvalstoffen*) and by the *Agenstschap Nl* is based on the Euralcode system, there was a previous code, which at times companies still use to classify their waste. Regular accounting about this later system is more consistent since 2002. Companies at times have mistakenly registered their waste according to the Euralcode categories description, influencing the final accounting. Double accounting was also an issue where the waste could be accounted by the transportation companies and later by the breaker companies. Also, small businesses did not have to register waste and processed waste that is classified under a different Euralcode.

The definitions of the various material stream types, the classification of these waste streams according to the origin (housing, non- hosing, infrastructure or renovation, demolition, construction) are relevant for this study. These classifications changed through time, affecting the accounting system, and increased the difficulty of tracking clear trends of waste production. Historical data of C&D waste in the Netherlands is also too aggregated regarding visualization of products. However, these classifications are changing and progressing towards more detailed database, which will help future studies. Finally, when comparing total C&D waste production from 1985 to 2011 with housing demolition (Annex 6.57), it is not possible to derive consistent information that supports the objectives of this research.

This section, therefore, concentrates on the analysis of consumption trends of materials and flows that could identify possible relations between stock activities and supply of products for reuse. As indicated in Chapter 3, tracking consumption trends of building products is challenging due to available statistical information (Menegaki and Kaliampakos, 2010; Fischer-Kowalski et al., 2011; Gielen, 1997; Weisz and Steinberger, 2010) and the levels of data aggregation.

Different accounting systems are compared in this assessment: the national material flow accounts, information provided by the industrial sector, and complementary information from available PSUTs (physical supply and use tables). Although longer time frame to study material flows is relevant to estimate the system's behavior (Delahaye and Nootenboom, 2009), the time frame of data collected in this section varies according to availability.

The Dutch accounting system tracks monetary exchange and converts into physical data (Delahay and Nooteboom, 2009). Accessible data during the time this research investigated dated from years 1996 through 2009 and some information through 2011 (Delahaye et al., 2013).

When comparing apparent domestic consumption (extraction + import- export) of materials between 1996 to 2006 with new added houses in stock yearly it is not possible to identify tangible information about products neither to verify the actual consumption rates made by new housing construction in the Netherlands (Annex 6.58). Weisz et al. (2006, pg.689) believe that the low prices of commodities as construction materials, "*and a production structure which often counteracts regulations for data gathering, contributed to a long term development which generated little incentive to accurately represent this category of material flows in national statistics*."

In the Netherlands, the CBS (*Centraal Bureau Statistic*) collects information regarding yearly material consumption by industry types, materials and products,[206] with different levels of accuracy according to estimations from different sources[207]. To identify consumption trends of common building products as discussed in Chapter 4, the current study investigated consumption rates through different paths: type of material (e.g., wood) associated with the manufacture of products (e.g., window frames). Another path was to investigate consumption of specific products (e.g.,

206 Interview with Roel Delahaye CBS, De Haag, 2013.

207 Email with Roel Delahaye CBS, De Haag, 2015.

wood window frames) consumed by the building construction sector for some specific years[208]. Such information is compared to consumption of other products made with different materials consumed in the same year within the sector (e.g., PVC or aluminum window frames consumed by construction industry). The housing sector, however, is still too specific regarding consumption sector[209][210] because there is no systemic account available that indicates the type of products (wooden window frames) consumed by the housing sector per year.

Manufacturers and industrial associations are additional sources of information researched to estimate consumption trend of products both at national and European level. Information when available was collected and described by material type in the subsequent sections. Other information sources are derived from existent literature. Some of the interviewed organizations did not make the information public to this research[211]. Another challenge found during the analysis was matching the time lapse between the available data of different types of products and materials.

§ 6.8.1 Wood

Four hundred years ago buildings were made of wood in the Netherlands. Around 1600 oak became scarce in the region, and many oak forests disappeared (Blaazer and Gessel, 2011). To reduce fire risks, after the official ban in 1669, wooden housing constructions decreased, and in time alternative foundation methods also replaced bearing wood construction (van Beusekom, 2006; Bot, 2009).

208 Interview with Roel Delahaye CBS, De Haag, 2013.

209 Interview with Roel Delahaye CBS, De Haag, 2013.

210 Some of this data has been used to formulate the actual PSUTs, which today the CBS has (currently) available for the year 2010. In PSUTs, estimations were made for use of materials in four levels: 0; less than 100 million kg, between 100 and 1.000 million kg and more tan 1.000 million kg (see Annex 6.59), which does not help to visualize nor to compare consumption trends for the aim of this research. Furthermore, some of the products' codes have changed from 2008 to 2010, which made more complex comparisons between these two years. At the end of 2015, other PSUTs will be published referent to the years 2008, 2010 and 2012_ Email with Roel Delahaye CBS, De Haag, January 2015. Data available for a single year is not sufficient to estimate a behavior pattern trend as aimed in this chapter.

211 NBvt (*Nederlandse Brancheverenigin voor de Timmerindustrie*), *Centrum Hout* and VHSB (*Vereniging van Hout Skeleton Bouwers*), FSC Nederland were extremely negative in sharing any database either through interviews or documents.

After the second world war, many houses were built with badly dried wood and at times lower quality constructive methods, rising negative popularity of wood constructions (Blaazer and van Gessel, 2011). Nonetheless, solid wood applications in construction remained for the manufacture of rafters, roof, floor, window and door frames, doors, wall finishing and pillars (Blaazer and van Gessel, 2011). Previous sections indicated how housing construction systems in the Netherlands gradually shifted towards broadening the use of non-traditional techniques and increasing stony based materials after the post-war period. In that period substitution of costly wood flooring and pillar foundations coincided with the high demand for low-cost housing during the post-war as previously explained (Hofstra, 2006). Regulations focused on sound, and fire insulation improvements in houses also influenced the consumption trend of concrete based products.

There is no official data published on yearly consumption of wood by the housing sector[212]. Müller (2006) compared the stock accumulation of minerals in buildings of 500 tons per capita (t/cap) while wood reached 3 tons/cap while studying material flows in the housing stock in the Netherlands.

Moreover, the Netherlands has limited domestic wood production with a self-sufficiency rate of average 8% (between 2003 and 2014) (Probos[213]). It is the largest sawn wood importer in Europe and one of the largest importers in the world (in 2008), being relevant commercial partners with Malaysia, Brazil, Indonesia and Cameroon (Pepke, 2010). Twenty-five years ago the proportion of wood consumption however was 70% wood produced in the Netherlands, in recent years this rate steadily declined to less than 30%[214]. In the EU-27, it was estimated about 41.5 million tons of wood is consumed by the construction sector (Biointelligence Service, 2011, pg. 88), but substantial differences among the EU_27 on construction systems customs have to be considered.

Therefore, the estimation of wood consumption in 1998 by the construction sector was used as a reference for the estimation for 2008 (Boosten and Oldenburger, 2012). Consumption of sawn wood and paneling by the building sector (housing and utility together) in 2008 was 2.750.000 m^3rhe or 1.4 million tons. (Olderburger et. al., 2010, pg.27), and 841.676 tons of wood and panels were consumed by the building sector in 2013 (Oldenburger, et al., 2015).

212 Probos and CBS were the only two organizations able to provide a limited amount of data on wood consumption, but both Oldenburger (Probos) and Delahaye (CBS) mentioned challenges in determining the accuracy in the existing data.

213 *Kerngegevens Bos en Hout* in Nederland, 2003, 2004, 2005, 2005, 2006, 2007, 2008, 2009, 2011 in www.Probos.nl

214 E-mail CBM *Branchevereniging Interieurbouw & Meubelindustrie*.

In 2003 the Ministry of Transport, Public Works and Water Management (Van der Meulen et al., 2003) estimated that an average of 5% to 8% of newly houses in the Netherlands are timber-framed buildings (Annex 6.60), coinciding with the 5% market share of timber frame buildings in new residential buildings in 1997 (VROM, 1997; Dijk, 1998). The estimation (Van der Meulen et al., 2003, pg.69) also specified the average volume of timber per timber-framed house, indicating higher wood usage in structural components:

- *"wooden frame + plate material: ca. 15 m³*
- *outer window frames and door frames: ca. 1,5 m³*
- *inner doors and frames: ca. 0,5 – 1 m³*
- *any other outer side covering: unknown*

Total volume of timber: ca. 15 – 20 m³
Volume of timber per non-timber-framed house: Ca. 3-4 m³".

In 2003 the Ministry of Transport, Public Works and Water Management (Van der Meulen et al. 2003) also announced a general increase of 15% in wood consumption mainly from the construction sector (including infrastructure). They stated that the increase in wood consumption would depend on the education of designers and the construction industry in general. According to Probos[215], after 2007 general wood consumption decreased with slow recover after 2009 (Annex 6.61) and decreased again from 2011 to 2014 to 125.000 m³ (Probos; CBS[216]). Jonkers (2011) associated the decrease of wood consumption in the Netherlands after 2000 with the substitution of steel (load-bearing steel frames) and plastic products (PVC windows and door frames) in construction. However, Jonkers also mentioned a new consumption trend with the increase wood frame constructions after 2006 associated with the concept of an "environmentally friend" material when certified.

Building construction is a significant market in all three classifications of wood based on data of consumption of hardwood in 2010 (Annex 6.62). Consumption rates of sawn tropical hardwood are in average higher in building construction (37% from total hardwood) and civil engineering (36%) while the DIY and the garden sector has a share of 19% and furniture and interior 3% (De Groot and Oldenburger, 2011). The furniture

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215 *Kerngegevens Bos en Hout in Nederland*, 2003, 2004, 2005, 2005, 2006, 2007, 2008, 2009, 2011 in www.Probos.nl

216 http://www.clo.nl/indicatoren/nl0070-balans-voor-hout-en-houtproducten-voor-nederland

and interior design (24%) and building construction (23%) were the main recipients of temperate sawn hardwood consumption market in 2010.

Within the building construction market, CBS PSUT[217] for 2010 (Annex 6.63) indicated the following consumption rates of wood and wooden based products as follow (in million kg):

- *Hout primair* (Sawmilling and planing of wood, impregnation of wood) 49
- *Triplex ed.* (Manufacture of veneer sheets and wood-based panels) 22
- *Fineer/plaat* (Manufacture of veneer sheets and wood-based panels) 52
- *Ramen kozijn* (Manufacturing of wooden doors, windows and frames) 160
- *Deuren* (Manufacturing of wooden doors, windows and frames) 128
- *Ov.timmerwerk* (Manufacturing of wooden doors, windows and frames) 211

Carpentry, windows, and doors show relevant shares of wood consumption by weight. In the 90's wooden window frames had an average market share of 80% in new residential construction (de Bekker, 1998; VROM, 1990). Approximately 90% of wooden window frames of tropical hardwood were applied in all new building segments in the 1980's (de Bekker, 1998). However, "*in 1995, the market share of wooden window frames for all buildings dropped to 53%*" (De Boer, 1995, pg.62)(Annex 6.64). Goverse et al., (2001) estimated an increase use of aluminum and plastic window frames in renovations and non-residential buildings in the Netherlands. Despite the lack of consistent figures, wooden window frames in residential construction are popular in the Netherlands followed by plastics and aluminum (Annex 6.65). However, it is expected that the proportion of synthetic material will rise in the future (Bouwkennis, 2012[218]).

In the external door segment, renovation works were the most important consumer market with more than half considered of "very good quality", while in the new housing segment, only 24% were considered "very good quality" and the majority considered "standard" quality (Bouwkennis, 2012[219]). Most of the wood used in the production of window and doorframes is hardwood Meranti (Jansen and Eppenga, 2000), other types of wood classified by common applications can be found in Annex 6.58.

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217 From email Roel Delahaye.

218 *Bouwkennis*. "*Whitepaper marktomvang deuren*." (2012). Available at: http://www.bouwkennis.nl

219 *Bouwkennis*. "*Whitepaper marktomvang deuren*." (2012). Available at: http://www.bouwkennis.nl

Wood consumption in housing projects has also accounted for 10% for inner leaf and 1% outer leaf in façade applications in 2007[220]; and in 2006 it had a 6% share for upper construction flooring and 4% share in 2007[221]. Limited information was available for other wood applications in buildings. Consumption trend of the wood floor and wall finishing is also limited and is accounted as furniture and interior market rather than building construction (de Groot and Oldenburger, 2011, pg. 16).

To track flows of wood consumption as demonstrated in this section is challenging due to limited data availability, affecting the accuracy of actual mass unit consumption per year, component unit per year, or yet consumption figures focused on the housing market. With the mentioned available data, it was not possible to formulate a distinct evolution of wood input flows in the housing stock. What can be concluded, however, is that in the housing segment, wood is still commonly used for windows and doors mostly hardwood and in greater amount for the carpentry works. Few indications show that wood frame constructions in the Netherlands are limited (5% to 8%) but with prognostics to grow.

Finally, through the study of input flows of wood, it is not clear to determine if there was an increase or decrease of wood consumption in the housing sector, neither if buildings are more or less wood intense as discussed in previous sections. However, it can be affirmed that despite the economic downturn, the highest consumption shares of hardwood and temperate wood is represented by building construction (33%) compared to all other wood consumption markets in the Netherlands, indicating that the building stock is accumulating valuable wood for possible harvest and reuse in the future.

220 E-mail Wim Kramer (*Cement & Beton Centrum*)

221 E-mail Wim Kramer (*Cement & Beton Centrum*)

§ 6.8.2 Ceramic and clay products

Production of ceramic products for construction relies on the availability of local resources (Biointelligence, 2011). Van der Meulen et al. (2007) estimated that there is a national exploitable stock of 12.3 to 18.0 (± 2.0) km³; or an average of 6000 times the average annual consumption[222]. In the Netherlands as within the EU-15, non-refractory clay bricks constitute the most common ceramic product followed by wall and floor tiles by weight (European IPCC, 2007). Production of bricks is estimated to be the most significant among other ceramic products in the Netherlands (European IPCC, 2007).

Information of yearly brick consumption is available and often classified between buildings and street pavement bricks. In 2014, the production of construction bricks was 72% and 28% of street bricks[223]. The types of bricks within the first category are not always available (*Vereniging Koninklijke Nederlandse Bouwkeramiek*, 2004-2014) and therefore, façade and non-façade bricks are combined in this assessment. The market share of brick façade in housing construction slightly decreased from 81% in 2002 to 79% in 2011 (*Builtsight_Ontwikkelingen in het gevelmateriaal*[224]).

The total consumption of construction bricks per year showed a critical decrease after the economic downturn in 2008 (Annex 6.65). Available data does not discern between housing and non-housing nor new housing construction and housing renovations, but there are indications that the housing segment is a relevant recipient for construction bricks (*Vereniging Koninklijke Nederlandse Bouwkeramiek*, 2004-2014) and brick façade (Annex 6.66).

Yearly consumption of ceramic roof tiles by new housing construction is not available. Roof tiles had a market share of around 70% in sloped roofs in 2013 (*Vereniging Koninklijke Nederlandse Bouwkeramiek*, 2014). Cement and Beton Centrum however indicated that in 2007, the market share of concrete products applied in housing sloped roofs was 53% and 39% for ceramic products (see Annex 6.72). With the information above, it can be concluded that façade bricks is a common product in the housing sector despite recent decline reflecting from the economic downturn.

222 "*Even when considering that the larger part of the clays is unsuitable for firing, and about one quarter is situated below built-up lands or nature preserves, clay is not a scarce resource in the Netherlands and supplies should present no problem in the near future*" (Van der Meulen et al, 2007).

223 http://www.knb-keramiek.nl/themas/baksteen/veel-gestelde-vragen/kengetallen-baksteenindustrie/

224 E-mail from Arie Mooiman KBN *Keramiek* (*Vereningen Koninklijke Nederlandse Bouwkeramieke*)

§ 6.8.3 Cement and concrete

In Chapter 5, it was identified that concrete building products are not often commercialized for reuse. Nonetheless being cement a widely diffused material in construction, consumption trends of concrete based products is used here as a reference for comparison with other product types.

From 1946 until 1970 it was a period stimulated by modernization in the construction sector in the Netherlands and introduction new construction methods based on concrete (Bot, 2009). High demand for housing and reconstruction of infrastructures during the two-post wars led to a shortage and price increase of building materials, finding cement as a suitable substitute. In this period the cement consumption more than doubled explained by the introduction of concrete. The first concrete mortar plant was established, and after 1960s cast construction was introduced and consumption of concrete products began to rise in the Netherlands. Gradually, wood floors and foundations largely disappeared from the market and were replaced by concrete elements such as floor slabs and concrete foundation piles. After 1970, concrete consumption per capita is more substantial explained by the introduction of the *Gietbouw* (poured concrete) (Hostra et al., 2006).

Information about cement and concrete consumption are more available and in longer time spans compared with other material types studied in this chapter. As previously discussed (Annex 6.67), the increase in new added houses in the period between 1945 and 1973 corresponds with increase in cement consumption. After 1988, yearly new added homes decreases continuously until 2015 while cement consumption decreases after 2008 reaching the lowest consumption rate since 1964. Whereas the decreasing consumption of cement is apparently associated with the number of new added houses in stock, as renovation becomes a relevant activity in the stock in use it could also influence the cement consumption by optimizing existent building structures.

Approximately 50 to 55% of the cement consumption in the Netherlands is processed by the concrete mortar industry for poured concrete on construction sites. An estimated 35 to 40% of cement is used for the concrete products industry as precast concrete products (The Global Cement Report, 2005[225]; Cement & Beton Centrum[226]).

225 http://www.cemnet.com/publications/global-cement-report

226 http://www.cementenbeton.nl/marktinformatie/cementmarkt

Information about the proportion of concrete consumption in housing construction is segmented. Between 1970 through 1982 more than 50% of concrete has been used in the housing segment[227] (Hostra et al., 2006).

Hostra et al., (2006) estimated a concentration of 100 tons of stony faction materials (not only concrete) per house built before 1900, 125 tons per house built between 1900 and 1950, and 175 to 215 tons per house built after 1950. They also estimated a gradual increase up to 250 tons per house until 2025. The evolution of concentrations of stony faction materials in the housing stock was discussed in Chapter 4 (Technological factors) and earlier in this chapter in Section 6.5 (Construction year). More detailed information about how stony based materials[228] are applied in housing construction have been collected from different documents, and available for short periods of time.

During the 1980s, concrete lost market share to limestone blocks. In the 1990s there was a return of concrete consumption with a noticeable participation of *Gietbow*[229]. Since 1999 poured concrete mix application gradually shifted from low-rise to high-rise indicating the relation between an increase in housing height and type of application (Annex 6.68). The most common application of concrete mix in the form of foundations and upper floors in the years (Annex 6.69), and mainly in low-rise buildings, while upper floors and walls are the largest application of concrete-mix in high-rise buildings (Annex 6.70).

Different types of flooring systems were more frequently consumed for ground and upper floor in 2007 in the Netherlands (Annex 6.71). Similarly, the market share of different roof systems applied in housing construction in 2007 (Annex 6.72). Different from previous information (Section 6.8.2) that indicated a 70% consumption of ceramic tiles for slope roofs in new housing in 2014), Cement and Beton Centrum[230] indicated 53% share for concrete products in sloped roofs. Additionally, the overall market for pitched roof products decreased explained by the increased number of multi-family constructions more commonly characterized by flat roofs (*Bouwkennis*, 2012).

227 Estimated 35% applied in utility building, 6% in waster and infrastructure works and 5% in roads during the same period (Hofstra et al., 2006).

228 Sand lime bricks, Gypsum (application not specified) were not taken into account in this section.

229 E-mail from Wim Kramer (Cement and Beton Centrum)

230 E-mail from Wim Kramer (Cement and Beton Centrum)

On the other hand, there are indications of the dominance of ceramic products for façade application in housing construction in 2007 (Annex 6.73). For wall construction, ceramic products had a small share of 5% in 2007 (Annex 6.74) while cellular concrete and gypsum products were the most common material types for internal walls and lime silica for housing separation walls.

In summary, in low-rise and high-rise building typologies, the larger share of concrete mix application is on upper floors. Wide slab system remains a popular method in housing construction. Poured concrete and lime- silica for wall application have been very competitive with increasing prevalence of the last one. Partition walls are currently mainly dominated by cellular concrete and with significant participation of gypsum panels (Annex 6.74). For outer leaf wall application, ceramic-based products in the building segment seemed predominant when compared with other types of materials (Annex 6.73). For roof cover, data differed according to the reference year showing a competitive market share between ceramic and concrete roof tiles.

The information gathered in this section indicated the consumption of cement and dissipation of concrete applications in the housing market compared to other material types. The more recent characterization of typical product application for house construction clarifies the increase concentration of stony based products in structural applications that are currently not valuable in the market of reused products. It also indicated how building typology influences choices for constructive systems and products. Overall dwellings became more stony intense constructions, substituting other traditional materials like ceramics and wood particularly in building structure applications (walls, flooring, and foundations). This trend has a negative impact on the market of product reuse, as there is no current demand for used structural concrete products.

§ 6.8.4 Steel (and other metals)

Structural steel in the Netherlands is applied in its majority in industrial buildings (factories and warehouses) and generally in other non-residential constructions (offices)[231]. Most common products such as hot rolled products such as HE, IPE and corner profiles are imported from Germany, Luxembourg, and Great Britain. Cold-formed products such as C and U profiles are produced in the Netherlands[232].

In the Netherlands, the market share of steel structures in multi-story buildings decreases according to the height of buildings[233]. The decrease of steel usage in four and five floors building typology (Annex 6.75) is a result of competitive prices from prefabricated concrete (*Grote elementen*) and tunnel (*Gietbouw*) constructive systems after the rising costs of steel since 2004[234]. In multi-store buildings, the consumption of steel grew from 17% in 1990 to 46% in 2007 being later affected by the economic downturn (*Bouwenmetstaal*, 2010) (Annex 6.76).

For applications like window and doorframes, aluminum showed a small percentage share when initially applied in single-family social housing segment in 1974 and steel in 1954 (Thijssen, 1999).

It is estimated that currently new house construction in the Netherlands, consumes an average of 1500 kg of steel per semi-detached house and 250 kg per terraced and multi-store buildings housing types[235]. Steel has also been used in renovation projects for rooftop extensions (light gauge cold-formed steel), but no quantitative data are available[236]. Since 2000 there has been an increase in steel consumption in multi-floor residential buildings (hot-rolled steel), reflecting the overall increase in steel consumption in housing.

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231 E-mail from Mic Barendz, *Bouw met Staa*l.

232 E-mail from Mic Barendz, *Bouw met Staal*

233 *Since 2003 the market shares in buildings with 4 and 5 and 6 or more stories started increasing fast. In recent years the market shares of 4, 5, 6 and more stories are dropping. The decrease of the "overall" market share is largely due to the decrease of market shares of the categories "4 and 5 storeys" and "6 storeys and more" and the building types (free-standing) "office buildings" and office space connected to industrial buildings. The categories "2 storeys" and "3 storeys" are slightly decreasing (Annex 6.76). The buildings types "education", "other" (a.o. care, government, parking) are stable. The market share of "retail" is rising.* (*Bouw met staal _* e-mail Mic Barendz).

234 E-mail from Mic Barendz, *Bouw met Staal*.

235 E-mail from Mic Barendz, *Bouw met Staal*.

236 E-mail from Mic Barendz, *Bouw met Staal*.

New housing added per year and consumption of steel by the housing sector are apparently related until 2011 (Annex 6.77). Despite the increase consumption until 2010, the highest market share in multi-family housing construction is still represented by concrete[237].

The housing segment has small participation in the overall steel consumption compared to concrete for structural applications, wood for windows, doors and façade openings. Consumption of steel in housing construction showed to be connected to both building height and construction costs.

§ 6.8.5 Plastics

Under this category, different types of polymers were considered. In 1950's companies as BASF initiated production and commercialization of polystyrene in Germany (Bot, 2009). Large-scale production of EPR in the Netherlands came in the late 60's (Styrex). Around the same period, appeared wood frame windows covered with PVC (polyvinyl chloride), which was later replaced entirely by PVC or combined with steel (Bot, 2009). According to Sevenster (by the time this investigation was made)[238], there are not consistent figures about plastic consumption for construction in the Netherlands.

Approximately 350.000 tons of plastics were consumed in 2002 to manufacture products for the construction sector in the Netherlands (Apricod, 2012), 370.000 tons in 2005 and 380.000 tons in 2011 (Sevenster[239]). These figures do not differentiate the consumption sector between housing, utility, and infrastructure. In 2011 applications were subdivided as follows (Sevenster[240]):

- Ca. 80.000 tons insulation,
- Ca. 80.000 tons pipes and fittings
- Ca. 70.000 tons flooring

237 In some cases, houses a complete steel structure, this can be a hot-rolled skeleton from HE and IPE profiles or steel frame construction of a skeleton of cold rolled C-or U-profiles. The same applies to steel as roof or wall material, but in very small scale (Interview with *Bouw met staal*, 2012).

238 E-mail from Arjen Sevenster _The European Council of Vinyl Manufacturers (ECVM) and VinylPlus.

239 E-mail from Arjen Sevenster _The European Council of Vinyl Manufacturers (ECVM) and VinylPlus.

240 E-mail from Arjen Sevenster _The European Council of Vinyl Manufacturers (ECVM) and VinylPlus.

- Ca. 35.000 tons profiles
- Ca. 20.000 tons cables
- Ca. 95.000 tons additives and others

The overall trend indicates an increase consumption of plastics by the construction sector in Europe (Apricod, 2012). The numbers mentioned above are difficult to compare with available information for 2010 PSUT, as product classifications do not coincide.

When considering the overall plastic consumption for construction (including non–housing construction), PVC is the most common polymer consumed by weight in Western Europe (53,3% in 1995 and 47% in 2002), followed by PU (9.5%), and EPS (9%) (Apricod, 2012). The common applications of PVC in construction products are pipes, windows, floor, and wall covering, profiles followed by lining, shutters, and cables (Apricod, 2012).

According to a (CBS) survey, there were limited PVC products in the housing sector in 1972, with 2% of market share in the utility sector. According to Thijssen (1990), use of PVC pipes was more frequent after 1968 among multi-family housing and between 1966 and 1980 pipes were almost exclusive from PVC (Straub, 2001).

PVC internal door-frames were not popular in the social housing sector before 1980 having the highest share made of wood 68%, 22% steel and 8% aluminum (Thijssen, 1999). PVC external windows frames were first applied in 1980, while aluminum was initially applied in external windows after 1970 (Thijssen, 1999). Part of these early applications was affected by discoloration and decaying of the plastic (Bot, 2009). External wood frames are still the most common in residential buildings, followed by plastic and aluminum frames (Annex 6.64). In the single-family social housing group, between 1946 and 1980, the majority (84%) of the houses investigated by Thijssen (1999) had external doors and windows frames made of pinewood, 12% tropical hardwood and 5% aluminum and smaller share of steel frames. There are indications that plastic frames will rise in the future (BouwKennis, 2012) following the development of high-rise residential buildings.

The concentrations of different types of polymers in the Dutch reference house differ according to applications (W/E Adviseurs, 1999 in Meijer, 2006) (Annex 6.78). The total amount of plastic per house differs from the analyses done by Gielen (1997) where the amount of plastics were estimated between 225-500 kg for the Dutch reference house in 1992 (excluding packaging). The analyses reveal that most common types of plastics are expanded polystyrene (17,6%) and PVC based products (7,45%). According to these two assessments, consumption of plastics on the housing sector increased, where EPS has the highest share of plastic used in the housing segment (despite the average high consumption of PVC in the construction sector).

Energy efficiency measures have been determinant for the diffusion of insulating products such as EPS (Annex 6.79). Insulated facades, roofs, and floors were more commonly implemented in the late 1960s, early 1970s (Thijssen, 1990; 1999). Improvements in the insulation values in housing started in 1965 and later in 1980, 1992, and 1998 followed through the coming years (Hasselaar, 2001).

Use of insulation from 2010 to 2011 increased in both new and existing buildings sector (*Agentschap Nl*, 2012). Common plastic insulation materials are EPS, XPS, PUR / PIR including "loose" insulation used as cavity filling (glass wool flakes and EPS pearls). EPS is used in the floor and roof (van Roosmalen[241]). For non-plastics, mineral wool has a high market share (Annex 6.80). There was, however, growth in sales of plastic insulation material for the insulation of the building envelope despite a decline in new construction in 2011 (Annex 6.81) (*Agentschap Nl*, 2012).

Sales of "loose" insulation material had the highest increase comparing to previous years, showing that insulation in cavity walls in existing buildings was of major importance (Annex 6.82).

The housing stock in use building was the main influence in total sales of all insulation materials together in 2010 (17 million m²) and 2011 (21,1 million m²) (*Agentschap Nl*, 2012). According to Isobouw[242], the most common polymer insulation material applied in existing buildings is EPS filling in cavity walls, sharing the market with insulated gypsum boards. Whereas in new buildings, mineral wool has the highest market share for walls followed by PUR foam, and EPS has only a small contribution of 4% to 5%.

In roofs, sandwich panels applied on traditional wood structure are a common roof constructive method today[243]. Consumption of prefabricated insulated roofs (locally called *klapdak* system) used to be applied in large-scale developments, bringing economic advantages. As soon as these large projects decreased, the industry started to shift the technology (and adapt costs) to smaller projects[244]. This type of roof system cannot be reused and replacement is more common than partial maintenance[245].

241 Email from Benedikt van Roosmalen (*Stybenex*) 2013.

242 *Isobouw* phone interview January 2013.

243 Isobouw phone interview January 2013.

244 Isobouw phone interview January 2013.

245 Interview Teun Stam and Tristan Frese (*Restoric*/*Schiff* Group).

Finally, when considering reusable plastic products from the housing stock, PVC framing and EPS insulation have been more commonly added to the housing stock in the 70's indicating that waste flows of these products will tend to increase in the future. Rigid EPS and PU are smaller fractions comparing to other types of insulation.

The increasing consumption of PVC window and doorframes has not yet surpassed the predominance of wood frames in the housing market. Other polymer applications have increased in the stock but mainly in applications in dissipative form (sprayed or pearls) or combined with other materials such as coatings or composites.

§ 6.9 Results of material consumption trends

Finally, to assess trends in material consumption to associate with supply of reusable products, the account of input material flows indicated three significant uncertainties: the short time lapse of available information, the economic crisis that affected the construction sector in 2008, and the level of aggregated data of material flows and products related to the housings sector.

The findings collected in Section 6.8 are organized for comparison and summarized in Table 6.3. When investigating consumption trends of products for new housing construction, different levels of data aggregation were combined and in different time frames. Four relevant steps were:

- Yearly resource consumption is compared with new added houses per year. Apparent domestic consumption. Time lapse_ 1996-2006.
- Material intensity in houses according to construction period. Before 1900, 1900-1950, and after 1950.
- Material consumption by economic sector (construction or housing construction). Time lapse varies mainly static.
- Product consumption (by predominant material type) by economic sector (construction or housing construction). Time lapse varies mainly static.

The combination of material accounting at the national level and product consumption for the housing sector indicated that despite lower consumption in consumption of cement, wood, and steel apparently related to decrease of yearly new added houses, the choice for specific products and applications shows a trend that started after the WWII. The description of the housing stock groups according to construction year combined with trends in product consumption led to the following findings:

- Information regarding consumption of cement and concrete products was more consistent in comparison to other types of products and materials, and revealed the dissipation of this group of products in the housing stock particularly in structural applications. After 2001, structural elements in new houses were built more frequently with poured concrete than prefabricated system, making reuse unfeasible. Concrete products also became more frequent in the stock as slabs and roof tiles. There is current no or little demand for concrete precast products in the Netherlands.

- Wood consumption has also decreased after 2011. In housing construction main applications for wooden products remain: framing and inner leaf facades, windows, and doors. Whereas the consumption of synthetic products has prospects to increase, consumer preferences towards natural materials could influence wood consumption in the future.

- Despite the general decrease of ceramic product consumption, brick façade products are still prevalent in the local housing construction culture followed by roof tiles.

- The increasing consumption of PVC window frames has not yet surpassed the predominance of wood frames in the housing market. Insulation products increased recently and will continue to rise.

- Steel is concentrated in multi-family housing applications that slightly rose in recent years in larger urban areas, the increase consumption of concrete in high-rise constructions is a defining factor in the evolution of steel stocks.

TABLE 6.3 Summary of material trends related with the housing stock.

MATERIAL TYPE	PRODUCT TYPES RELEVANT TO SUPPLY COMMERCIAL REUSE	CONSUMPTION TREND	INPUT TIME SPAN OF ANALYZED DATA	CONSUMER SECTOR OF ANALYZED DATA
Wood	Windows and doors	. General decrease of wood consumption . No apparent relation with new housing construction	Less than 5 years	Building construction
Ceramics	Façade bricks and roof tiles	. General decrease consumption of ceramic products . Clear apparent relation of construction bricks consumption and new housing construction	More than 10 years	Construction
Cement/ concrete	Not relevant supply of reusable products	. General increase of cement consumption . Clear apparent relation until 1982. After 1982 cement usage increases while housing construction per year decreases.	More than 10 years	Construction
Steel	Not relevant suppply of reusable products in single family houses. Mainly applied as structural skeleton for multi family houses.	. Decrease of steel consumption . Clear apparent relation of steel consumption and new housing construction until 2011.	Between 5 to 10 years	Housing construction
Plastics	Windows and doors	. General increase of plastics . Unclear apparent relation with new housing construction .Unclear consumption trend of reusable products	Less than 5 years	Construction

§ 6.10 Assessment

This section tests how the multiple relations identified in Chapter 4 assist an assessment for wooden building products. The assessment starts by identifying wood concentrations in the housing stock based on literature review (Annex 6.83). These concentrations are based on the types of commercially reusable wood products identified in Chapter 5 in combination with housing typologies and respective housing plans found in literature (van Nunen 2010; de Lange, 2011; van Battum, 2002; Leupen et al., 2011; Lijbers et al., 1984; Van Elk and Priemus, 1971; http://www.rotterdamwoont.nl/pages/view/1; *Novem*, 2001; *Agentschap Nl*, 2011[c]) and construction year (Annex 6.84).

As proposed in the conceptual model, available technology also influences deconstruction for harvesting products for reuse. According to experts, the average fraction of materials usually extracted from a "typical" pre-war dwelling for further reuse varies from 30% to 70% (*Restoric*, *Van Baal*, Rob Gort _*Bouwcarroussel*) [246]. The estimated recoverable percentage in this assessment is 40%. This estimation is based on the amounts of products harvested for commercial purpose. This average recover rate does not consider only the technical feasibility to deconstruct, but also the other social and economic factors influencing the commercialization implied in the proposed conceptual model.

Another condition taken into account is that this 40% fraction accounts for products to be reused in their original function, excluding cascade reuse, which would include products with inferior quality. In this context, 40% is a low estimation compared to the average harvest in practice, which includes wooden products that will be reconditioned.

For this assessment, the amount of wood from the reference houses of each housing group varied from 5,44 tons (*Vrijstaand*) to 3,44 (*Rijtjes* 46-64) excluding subsoil structure, paneling, doors (and wall rafters if present). The amount of reusable wood in this housing sample varied from 1.37 to 2.18 tons per house according to the housing type and 3.5 74.071 tons in total (Annex 6.85).

246 Interview with *Restoric*, and *van Ball* revealed from 50%, while Rob Gort estimated from 30 to 70% recoverable material fraction for reuse. Rob Gort has also produced extensive inventories of products harvested from buildings for reuse. These inventories were divided by building type and construction year and summarized in Chapter 2 item Technology.

To understand the speed materials are released from the stock, Chapter 3 discussed the challenges to estimate the lifespan of buildings to evaluate output material flows and that survivability of buildings vary according to different characteristics rather than a generalized phenomenon.

Based on the historic data, three scenarios were estimated with different withdraw rates based on three different housing stock accounting. In scenario 1 (Annex 6.86), withdraw rates are an approximation due to lack of standardization between classification systems of housing stock by construction year and typology adopted by different data sources including accounting from respective municipalities247. Due to problems in the original data248, different intervals were calculated of 6 or 10 years. When the discrepancy of data was considerable, no approximation was made.

This method emphasizes how the surviving probability of dwellings[249] can be affected by the building's physical characteristics when subdividing in different single-family typologies. The highest withdraw rates were in *Rijwoning* before 1946 and between 1946 and 1965 (and gallery flats before 1966 not included in the study case). *Vrijstaand* houses had the lowest withdraw rates.

The reference used for scenario 2 was the report *Cijfers over Wonen en Bouwen* 2013 (Annex 6.87), which also showed a similar type of data discrepancy as mentioned above. Therefore, housing withdrawing rates were estimated from more to less aggregated information. Scenario 2 resulted from an average withdrawing rate of the housing group built between before 1906 and 1970 from 0,17% to 0,19% per year.

Scenario 3 was based on data provided from ABF Research, Syswov (Annex 6.88) with no distinction among building typologies. Housing groups from 1906-1930 (0,6%), 1945-1959 (0,31%) and 1960-1970 (0,19%) showed the highest withdraw rates. The average yearly withdrawing rate of the housing group built between 1905 to 1970 is 0,25%, coinciding with data provided by VROM (Hoogers, et al., 2004) where houses from period 1930-1940 have a higher survival rate when compared to houses from 1918- 1930 and early post-war houses until 1966.

247 Interview with Kees van der Flier (TUDelft).

248 In some cases the number of pre-war houses increased after the war see Annex 6.34 (text in red).

249 Building typology also showed to influence the survival chances of building groups when connected to their location (Section 6.4).

Finally, three scenarios were based on historical withdrawing rates from 1985 through 2011 of the housing sample to estimate yearly outflow of reusable wood:

- Scenario 1: variable according to each housing group
- Scenario 2: 0,18% yearly
- Scenario 3: 0,25% yearly

It is relevant to emphasize that as previously mentioned, this estimation is based on withdrawing rates from past years and should not be considered as a long-term forecast as they will not remain constant. As this housing sample decreases in time, it will consequently affect the amount of reusable products released.

In scenario 1, using variable withdraw rates according to each housing group, the sum of total recoverable materials for reuse from all selected housing groups were: 49.015 tons of wood (see results of all housing groups and per group in Annex 6.89). Scenario 2 with an average withdraw rate of 0,18% yearly would release 6.433 tons of reusable wood per year. Scenario 3 applied 0,25% yearly withdraw resulting in annual 8.935 tons of recoverable wood for reuse.

As discussed in Chapter 5, consumption rates of new products when available are limited to a group of products and industries, or highly aggregated by material types that are transformed into manufactured products. Therefore, as a reference, the results of the three scenarios are compared with different data regarding wood consumption rates from 2008 due to the different types sources and data available for comparison (Annex 6.83):

- Probos (2008)
  Consumption of sawn wood in the Netherlands by all markets indicating 1806093 tons, from which 1.310.989 tons softwood and 495104 tons hardwood (Annex 6.90).

- Olderburger et. al. (2010, pg.27)
  - Consumption of sawn wood and paneling by the construction sector (housing and utility together) in 2008 of 2.750.000 m^3rhe or (considering a density of 1.43) 1.4 million tons.
  - Consumption of certified sawn and paneling materials by the construction sector (housing and utility together) in 2008 reaching 71% of total sawn wood and panel consumption by the sector, 1.952.500 m3rhe or 956.700 tons.

- PSUT (2010)
  - Three products listed in the PSUT from 2010 were selected, indicating the following consumption rates by the building industry:
    - Window frames 160.000 tons
    - Doors 128.000 tons
    - Carpentry 211.000 tons

Another reference is the yearly quantities of wood accounted in C&D waste flows in the Netherlands under the Euralcode code 170201. The origin of wood waste has been aggregated under the category "construction" (Bouwnijverheid) from 2002 to 2007. From 2008 to 2010 wood waste is divided into more categories (SBI 41, 42 and 43). The category in focus in this study is 43, which includes demolition of buildings (43_ Specialized construction activities, KvK[250]) (Annex 6.91).

Scenario 1 yields higher amount of recoverable wood for reuse from the housing sample in one year when compared to the other 2 scenarios, resulting in a total of 33,54% of the total sawn wood produced in the Netherlands in 2008 or 23,22% of the wood used for carpentry work by the construction sector in 2010. It also reached 5,12% of total certified sawn wood and panels consumed by the building sector in 2008. Additionally, recoverable wood from the housing sample in scenario 1 represented 8,6% of average wood waste produced by the total construction sector from 2002 to 2007 or 42% of the average waste produced from the building demolition from 2008 through 2010[251].

For scenario 2, recoverable wood from the housing sample indicated 1,13% of the average wood waste produced by the total construction and demolition activities from 2002 to 2007 and 5,5% of the average waste produced from the building demolition from 2008 through 2010. Scenario 3 (6.433 tons) resulted in 1,56% and 7,7% respectively.

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250 http://www.kvk.nl/over-de-kvk/over-het-handelsregister/wat-staat-er-in-het-handelsregister/overzicht-sbi-codes/

251 These estimations are based on generalized wood density used for conversions. One observation is the high proportion of sawn wood and panels consumed by the building sector (2.068.000 m³ rhe) when compared to consumption of saw wood and panels by the infrastructure sector (206.000 m³ rhe) in 2013 (Oldenburger, et al., 2015). Whereas waste generated from both activities the proportions are reversed; 12.840 tons of wood waste generated from buildings and 706.660 tons generated from infrastructure respectively (data from 2010, LMA). Conversion factor used: 1 m³ rhe *gezaagd naaldhout* = 0.7407 m³ *gezaagd naaldhout* = 0.4070 mt *gezaagd naaldhout* and 1 m³ rhe *gezaagd loofhout* = 0.7092 m³ *gezaagd loofhout* = 0.4959 mt *gezaagd loofhout*.

The difference between scenario 1 and scenarios 2 and 3 reveals how assessment of the output of materials is sensitive to withdraw rates, and how disaggregated data influence the estimation of these same rates. Moreover, when comparing recoverable amounts of wood per year with wood waste flows from total C&D in the Netherlands, the following aspects should be emphasized: a) that the recoverable rate is based on reuse as in original form and function; b) the housing sample included only a few applications of wood (excluding doors[252], flat roof and other applications); c) yearly wood waste flows from construction used as reference accounts waste derived from other types of flows as infrastructure and non-housing constructions and other activities including renovation and construction rather than only demolition; d) the housing sample included buildings from a specific construction period. It is not known yet the concentration of wood in new added houses neither in recently renovated ones, which could potentially indicate a higher rate for yearly reusable wood.

Moreover, through this assessment, it becomes visible that even though cascading is essential for a sustainable bio-based economy (Goverse et al., 2001; Odegard et al., 2012), policy should reconsider the challenges hampering cascade reuse through these multiple aspects. In short, the conceptual model could be extended to other material types and different housing samples, and to different geographic areas. It can also be combined with quantitative data with rates associated with each variable under the economic, social or technological theme.

252 External doors were calculated in units apart from the scenarios above. External doors were considered to be wood based, and it is unknown the share of PVC doors mainly due to renovation works in thee housing groups. According to *Novem* (*Referentiewoningen Bestaande Bouw*, *Novem*, 2001) and *Agentschap Nl*, (*Voorbeeldwoningen Onderzoeksverantwoording, Agentschap Nl*, 2011), this housing group has been characterized by having external wooden doors. Internal doors have been calculated apart from the total recoverable wood, with an average of 7,631,000 (units) internal doors.

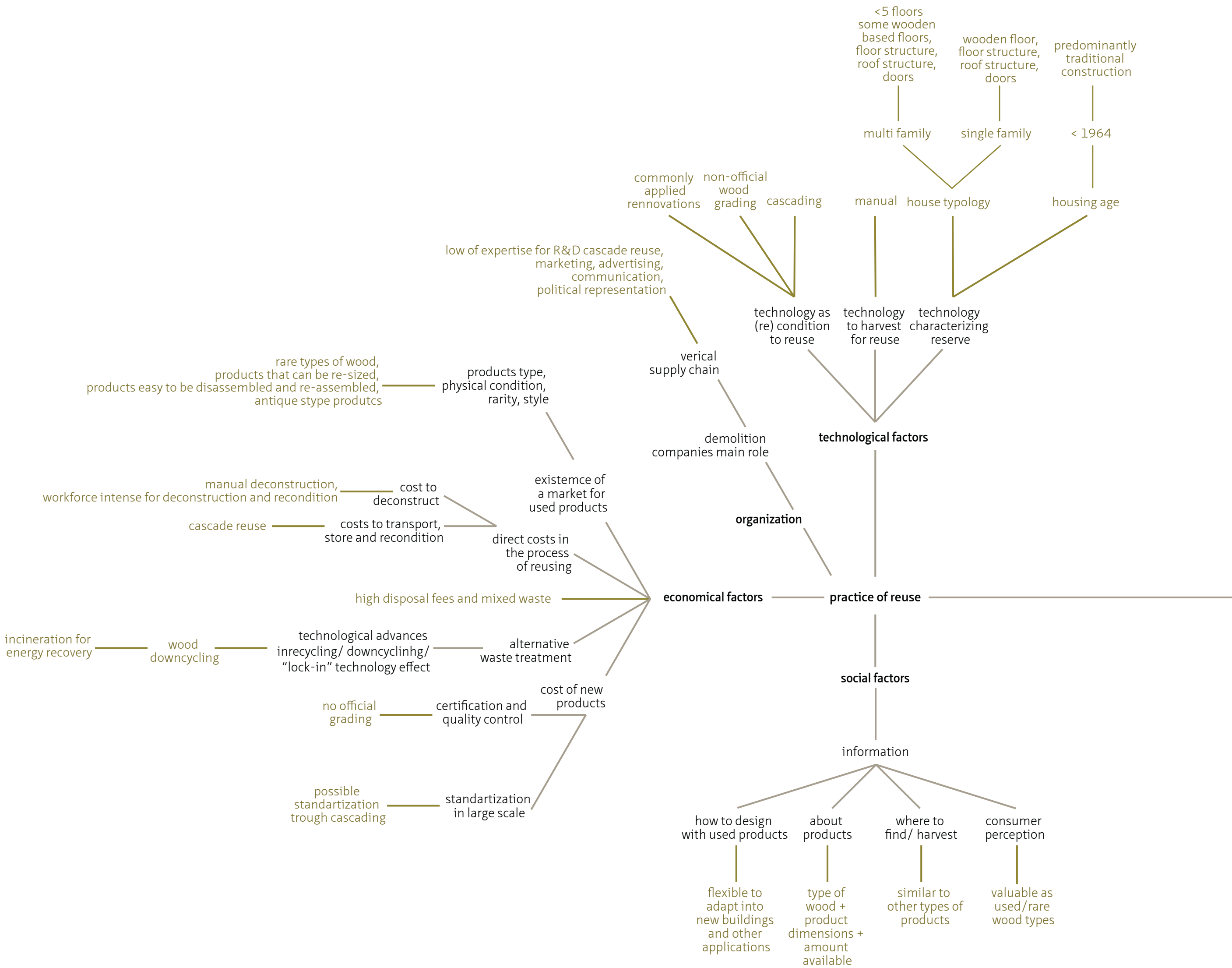
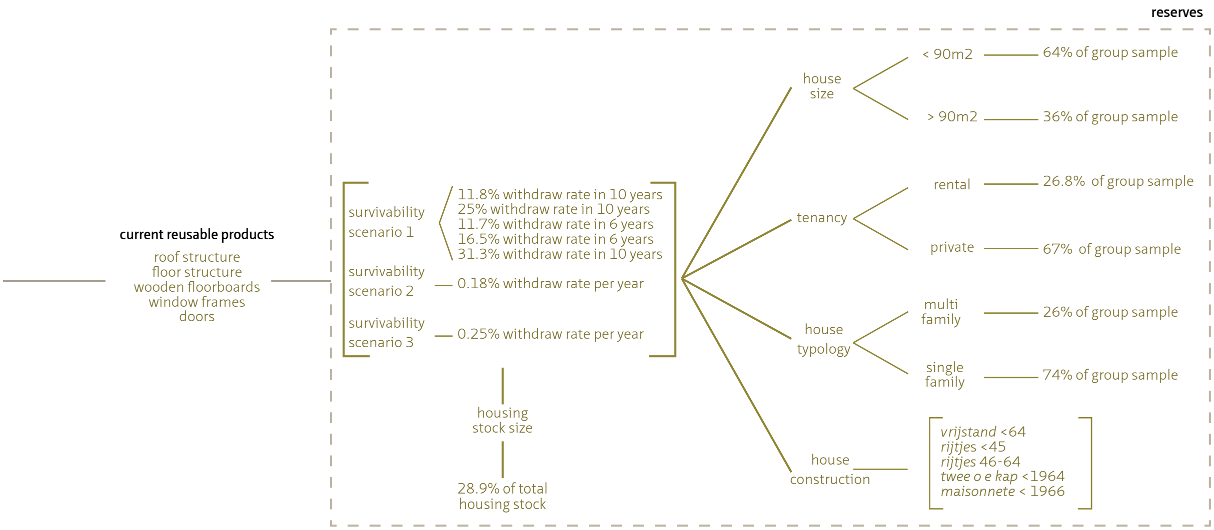


FIGURE 6.2 Reuse of wooden based products from housing stock built before 1964.


reserves
current reusable products
roof structure
floor structure
wooden floorboards
window frames
doors
survivability scenario 1
11.8% withdraw rate in 10 years
25% withdraw rate in 10 years
11.7% withdraw rate in 6 years
16.5% withdraw rate in 6 years
31.3% withdraw rate in 10 years
survivability scenario 2
0.18% withdraw rate per year
survivability scenario 3
0.25% withdraw rate per year
housing stock size
28.9% of total housing stock
house size
< 90m2
64% of group sample
> 90m2
36% of group sample
tenancy
rental
26.8% of group sample
private
67% of group sample
house typology
multi family
26% of group sample
single family
74% of group sample
house construction
vrijstand <64
rijtjes <45
rijtjes 46-64
twee o e kap <1964
maisonnete < 1966

§ 6.11 Answering Research question 4

RQ 4. How do trends in the housing stock affect reuse of building products (in the Netherlands)?

The study of the housing stock evolution identified trends that can affect the supply of products for reuse regarding the survivability and the physical composition of houses. The proposed research approach also identified how different factors relate to these changes, without implying that trends will remain constant in the future.

Housing withdraw trends in the Netherlands showed to be more stable compared to the annual number of newly added houses. Historical housing withdraws indicated to be sensitive to specific housing characteristics: rental multi-family housing in specially built between 1945 and 1965, small size houses (< 90m²) and houses built before 1930 and between 1945-1965, as well as single-family housing, such as *Rijwoning* (1946-1965). The housing stock, however, evolves and withdraw trends are susceptible to changes.

The higher withdraw rates that characterized the multifamily rental group were concentrated in housing complexes quickly built after the post-war characterized by lower construction quality. Also, results indicated that managing residential withdraws have been more feasible to occur in the rental multi-family group in the Netherlands. Therefore, as better quality construction replace the recent built post-war multi-family housing complexes, in addition to the increase of privately owned houses in the stock and the decrease of the pre-1946 housing group combined, the average survivability of the housing stock could prolong in the future. Although houses built with less than 90m² indicated to have lower survivability, it is not certain the average house size per unit will continue to increase in the future explained by the rise of single household population group including the 65 age demographic fraction. Therefore, despite the apparent increase in the average housing surface in the Netherlands, the predominant house size remains < 90m². A general increase in survivability of the housing stock could affect the supply of products released for reuse (excluding materials released from renovations). These findings indicate that other factors besides the technical age structural components motivate demolitions in the housing stock.

The housing stock continues to grow but in a slower path in recent years. Housing stock growth has been supported by continued population growth and by even faster growth in the number of households, which could offset the delay of materials released from stock induced by higher survivability.

The study of the housing stock evolution also investigated consumption trends in material types and products both historical and static consumption data using as reference the findings from Chapter 5 to evaluate the supply of products for reuse.

The harvest of ceramic and more importantly wooden products is more relevant in the market of used products, which are more typically concentrated in traditionally built houses more frequently available in the housing group built before 1945, specifically among single-family typologies. Withdraw rates from this group are still high in most regions in the country (but in a higher capacity in the West region). The decrease of traditionally built houses and the increase of stone based products will influence the supply of used wood in the future in particular from structural applications. Gallery flats built recently after the postwar have presented high withdraw rates, but with a limited recovery rate of products to be commercialized for reuse.

Regarding consumption trends, wooden products are more frequently applied in doors, windows and inner walls as studs. There is no consistent information about flooring and other types of finishing applications of wood.

Regarding plastic products, they have current limited demand in the market of used products. Currently, increase consumption of insulation products could be relevant for reuse only is applied in recoverable forms (planks and blocks).

Ceramic products are still commonly used in building facades and roof tiles, competing with concrete roof tiles in slope roof in new houses. Structural steel components are more frequently used in high-rise constructions competing with poured concrete.

As survivability of houses increase and the housing stock grows slower compared to the post war period, more attention should be given to material cycles related to renovation activities and the design and recovery of products involved in these renovations.

Finally, the analysis of the housing stock evolution combined with the study of material and product consumption revealed how changes in the housing stock as a reserve of potential reusable products could affect the supply in the future. Understanding such trends at product scale is challenging, which explains the relevance of combining different information sources and methods.

A comparative study of the evolution of groups of houses in stock that includes a classification system according to different characteristics (typology, construction age, location, tenancy), combined with improvements in the accounting system (specifying material consumption linked to manufactures and types of economic consuming sectors, in this case new housing construction), would improve the understanding of material stock evolution.

The assessment proposed to evaluate trends in the reserves of reusable wooden products puts in evidence how transformations in the evolution of the housing stock affects the supply of reusable products as the industrial system currently operates, and in combination with consumer demand.

Available information about the physical characterization of buildings (size and description of products and material types, building size) and the estimation of building lifespan were challenges found to construct more a detailed assessment for a specific group of products. Nonetheless, as data availability improves, the relevance to map and communicate the connectivity among the relations affecting the industrial system and the evolution of reserves remains critical. Visualizing these relations at product level (doors, floor boards, window frames) supports planning building capacity to recover, process and market used products in larger scale, including standardization, and specialization of activities designed for particular types of used products and enhances integration with cascade reuse and waste management.

Figure 6.3 represents how the factors investigated in this chapter related to supply of products for reuse adding to the conceptual model proposed in Chapter 2. Although in the real world these relations occur combined rather than isolated, here they are represented in binaries “increase/ decrease” or “higher/ lower” to indicate that relations change as result of the dynamics in the stock.

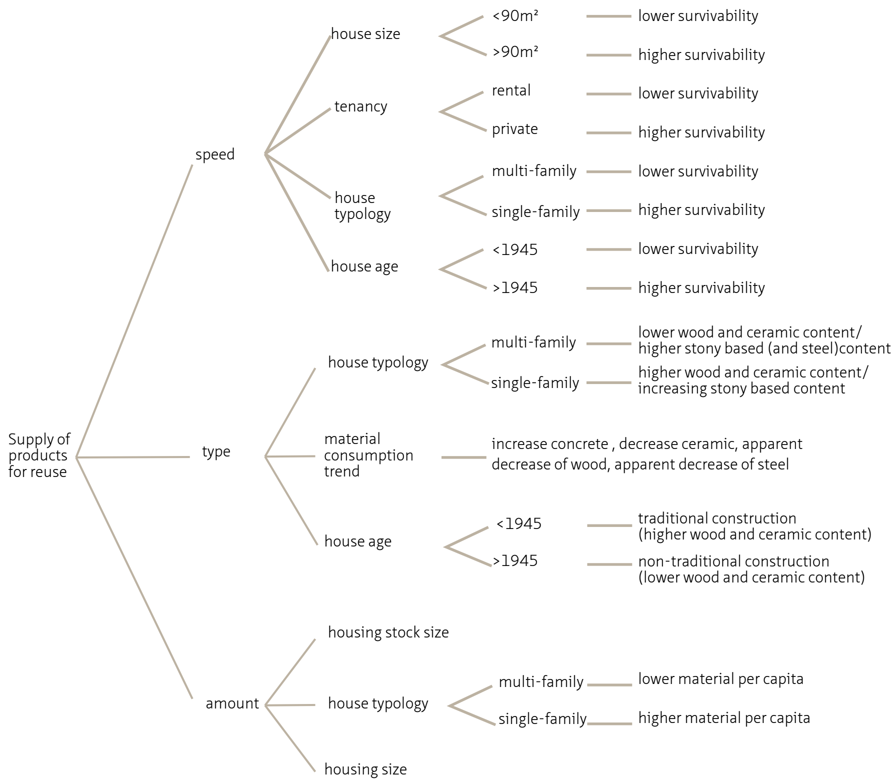


FIGURE 6.3 Diagram of relations in the housing stock evolution potentially affecting supply of product reuse in the Netherlands.

7 Presentation and discussion of results

§ 7.1 Results

Based on existing references and the results of field investigation, the conceptual model describes how the combination of different relations affects decisions to reuse building products in the Netherlands. The rhizome type of concept structure organizes and summarizes the information collected in the research process clustered by variables included in the system's view derived from the IE concept diagram introduced in Chapter 2. The relations represent different ways to influence the decision to reuse a building product and how they connect as a whole. The study started by describing the internal relations of the industrial system of reuse through the way activities are operated more contingent to the demolition industry and less as a specialized sector métier. This condition reflects on investments for R&D (technological, educational), marketing of used products, and official representation to promote increase of reuse (through targets and green certificates). From this perspective, the internal relations of the operation of reuse examined in RQ1 could influence the performance of reusing and determine paths to enhance the implementation of this practice in the Netherlands.

The RQ2 examined how external socioeconomic and technological relations influence the practice of reuse. Visualizing these relations supports how to design future strategies and systematic implementation of reuse. For instance, costs related to building deconstruction can be an economic strain to the practice that is mainly characterized by the manual workforce and hinder the competition with other cheaper forms of waste treatment. However, if technological conditions change towards constructive systems easier to deconstruct or technologies that enable quicker deconstruction of traditional and nontraditional constructive systems, it will consequently affect the economic output. The connectivity in the system proceeds by examining factors influencing demand for used products diffused through information, the educational organizations involved in the process, marketing and so forth.

Both internal and external relations regulate what products are commercially reusable. They converge to define the costs to harvest and process used products from the building stock relative to the demand for such products, to the benefits offered by different waste treatments, as well as to the cost of new products. RQ3 assessed different types of used products commonly available for commercialization in the Netherlands justified by the relations described in RQ1 and 2. Chapter 5 demonstrated that not all products are considered commercially reusable and that among different types; wood-based products are preferred. In this context, the continuity of the commercial practice of reuse is directly related to the supply and availability of reusable products (listed in RQ3), which is assessed by the study of the evolution of the housing stock discussed in RQ4. The literature review indicated that houses built before 1945 have more wood content compared to newer houses. Although the share of the pre-war housing group naturally decreases, and the study of consumption trends indicated the diffusion of cement based products in several applications in more recent houses, the model does not confirm that in the future new houses added to the stock will have less wood content in the long term. However, the study shows that certain constructive components that were wood-based in the past, have been replaced by concrete-based ones. The research methodology tracked the phenomenon of increasing accumulation of stony based products by the combination of past trends in housing withdraws, physical evolution of the housing stock, interviews with demolition companies and past material consumption trends.

The study exposed that relations on both sides of the conceptual model (from demand, processing to availability), could be adjusted with the aim to improve flows of reusable products[253]. Essentially, the model informs that by isolating specific aspects associated with the practice of reuse, a higher level of detail can be examined, but also, other combined relations shaping the system are omitted. Like any other model, this one has limitations, which comprises the analysis of some factors rather than "all" factors associated with a phenomenon (as in the real world).

When studying the industrial system of reuse, both primary and secondary data indicated that knowledge is broader regarding economic aspects enabling or constraining reuse of building products when compared to social and technological implications. The model proposed reflects this context and remains open for further development.

253 In 2003 the Ministry of Transport, Public Works and Water Management (Van der Meulen et al., 2003) announced a general increase of 15% in wood consumption mainly from the construction sector (including infrastructure). They stated that the increase in wood consumption would depend on the education of designers and the construction industry in general. This statement is an example that indicates that shifts in consumption of materials could occur in the material reserves.

In the context investigated in the Netherlands, the economic performance of reuse is affected by investments and other forms of stimuli focused on developments in waste treatment or by policy regulating waste disposal. Regulations or investments to incentivize reuse are absent in comparison to other related industries operating with the same material flow. Lack of accounting systems for reused products, quality control or technological developments that facilitate product reuse by decreasing the cost of manual workforce and time to harvest products to be reused are some aspects that indicate the absence of a formal representation and specific R&D activities designed for this "industrial" sector. Economic and policy incentives created for waste treatments as well as the dissipation of construction technologies unfeasible for reuse (as *cast in situ*) indicate the gap between goals to improve waste prevention through reuse and the actual developments in the field of sustainable resource management.

Regarding the technical implications of reusing products that could pose risks to the performance of existing or new constructions, cascade reuse could be a potential alternative and complementary activity in the existing practice of reuse. By giving used products new functions that demand inferior technical performance, while retrieving economic profits, cascading offers potentials to prevent a more extensive range of products to integrate waste streams. However, this process also requires a revision of the definition of reuse and correspondent policy implications.

Regarding social aspects, availability, accessibility and quality of information were identified to be relevant when influencing the performance of reuse. Potential users and "waste" owners fundamentally lack knowledge on how to reuse, where to find used products and what are the benefits of reusing. The practice of reuse currently functions as an appendix of the demolition industry, bringing benefits as well as disadvantages. Some of the disadvantages are the limited formalization and specialization of activities focused on reuse as a particular industry, being also a condition found in other European countries[254]. Information as forms of communication among stakeholders is a weak condition in the practice, more specifically regarding what is communicated (availability of products, location, technical description) and how it is communicated (user-friendly websites, complete and updated inventories, showroom and other generic marketing tools available in conventional markets of new products). One relevant finding was the role of e-commerce in the commercialization of used products. Although the volume of transactions has not been measured, commerce among individuals is available, accessible and competes with specialized physical stores.

254 "*At present the Second-Hand market is hardly perceived as a sector of its own*" (Arold and Koring, 2008, pg. 6).

For the study of material reserves, historical data of the composition of the housing stock showed that building typology, tenancy, and construction year of houses influence housing survivability. The proposed research approach did not evaluate the predominance of each factor but investigated how they associate with the evolution of housing stock. Buildings are products of their time, reflecting characteristics that will lead to early or later obsolescence as well as types of products that are more or less "in tune" with the commercial demand for used products. The construction year and typology of buildings relate to aesthetics, construction quality, building technologies, and amounts of products that influence the supply of products for reuse.

The study identified that as the quality of constructions improved from the early post-war period, it is estimated that the survivability of the housing stock increases. Also, although houses smaller than 90m² has lower survivability, they are still a predominant average house size in the Netherlands, which reflects the increase of single households. In the next decades increase in the 65 years old population group indicates that the housing stock will increase in the number of houses and the material per capita, offsetting the increased housing survivability.

Most single-family typologies in the Netherlands are private homes except *Rijwoningen* from 1946 to 1991, and most multi-family typologies are rentals. Withdraws of multi-family rental houses built in recent post-war in the Netherlands is high compared to other housing groups, and they are predominant in the West part of the country. As the input of single-family houses and private houses increase, it could influence an increase in the survivability of the housing stock, delaying material output. In the Netherlands, multi-family houses have a lower share of wood and ceramic-based products compared to pre-war constructions particular single-family houses. Therefore, an increase in multi-family housing share in the stock could also influence the supply of products for reuse.

In summary, the trends in the housing stock relevant to the practice of reuse as defined by the left side of the conceptual model (Figure 7.1) are:

A General increase of consumption of building materials per capita in particular stony based products;
B Continued predominance of single-family houses, especially terraced, which could positively influence the application of material types to be harvested for reuse as wood;
C General increase of survivability of the housing stock implying in delays of housing withdraws, but possibly be offset by the increase in the housing stock and increase of house surface per unit;
D Increase application of stony based products in particular *cast in-situ* concrete implying a reduction of reusable structural components.

Withdraws and new construction in the Netherlands correspond to approximately 0.2% and 2% per year respectively of the total stock. Information obtained from interviews and quantitative data indicate that material streams derived from other activities as housing renovation is a relevant source of reusable products or waste and should be included in future studies focused on waste prevention strategies, especially in mature economies as in the Netherlands.

Finally, the conceptual model represents how critical social, technological and economic factors influence the demand, the processes, and the supply mechanism of building products for reuse in the Netherlands. Whereas the center part of the conceptual model expresses the performance of the practice of reuse indicated by quantities, speed and types of products harvested for reuse; the left and right sides of the conceptual model indicate different paths to influence or change its core.

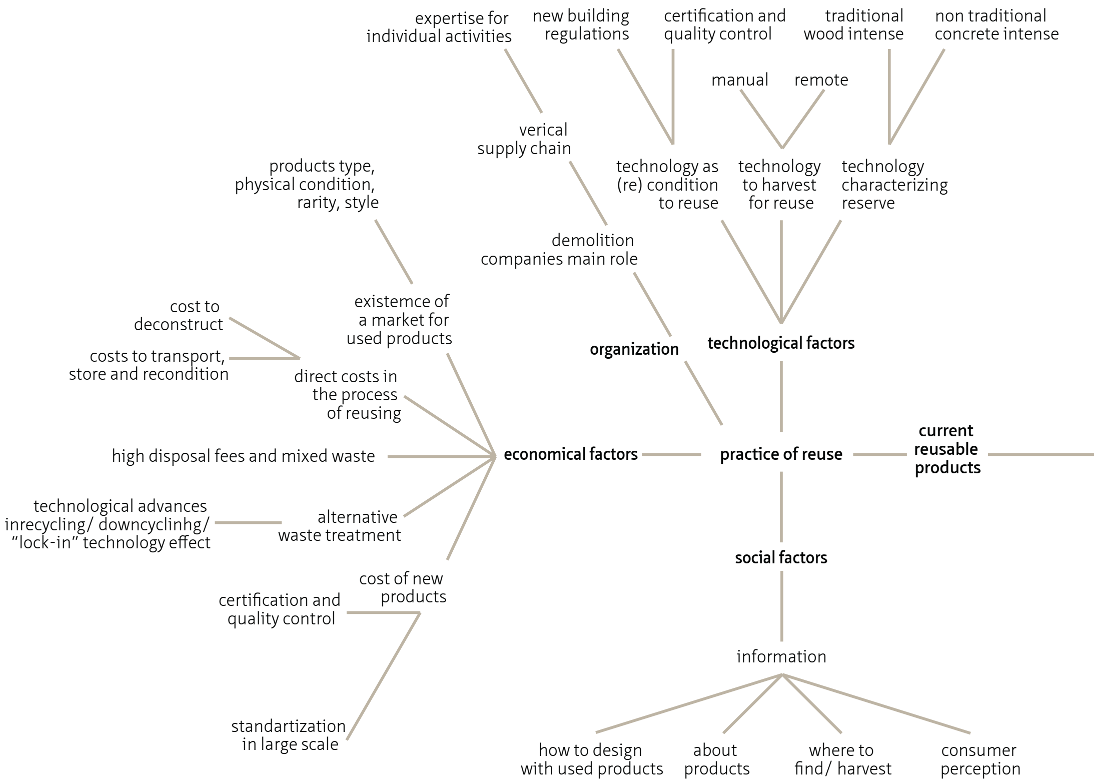
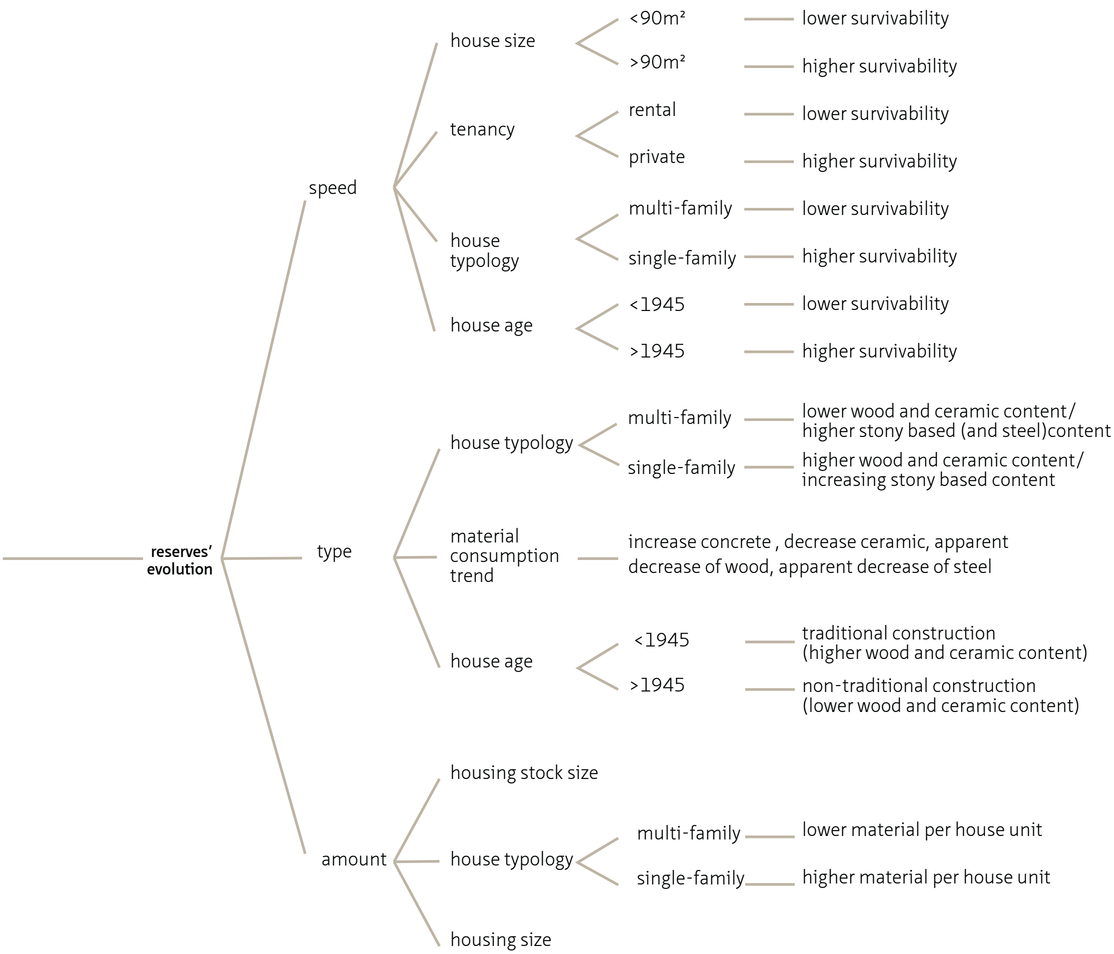


FIGURE 7.1 Conceptual model for building product reuse in the Netherlands.


reserves' evolution
speed
house size
<90m²
lower survivability
>90m²
higher survivability
tenancy
rental
lower survivability
private
higher survivability
house typology
multi-family
lower survivability
single-family
higher survivability
house age
<1945
lower survivability
>1945
higher survivability
type
house typology
multi-family
lower wood and ceramic content/ higher stony based (and steel)content
single-family
higher wood and ceramic content/ increasing stony based content
material consumption trend
increase concrete , decrease ceramic, apparent decrease of wood, apparent decrease of steel
house age
<1945
traditional construction (higher wood and ceramic content)
>1945
non-traditional construction (lower wood and ceramic content)
amount
housing stock size
house typology
multi-family
lower material per house unit
single-family
higher material per house unit
housing size

§ 7.2 Research objectives

RO1: To identify main characteristics of the supply chain of building products in the Netherlands, including critical social, technological and economic factors that characterize and define it.

Adopting the IE concept as a foundation, this research investigated how different relations affect building product reuse in the Netherlands from a system's perspective. Chapter 4 examined the current practice of building product reuse in the Netherlands through four main clusters: organizational, social technological and economical, demonstrating how these relations affect what is harvested for commercial reuse. The investigation of the activities and actors involved in the commercialization of used building products in the Netherlands focused predominantly on interviews with practitioners and experts. Through their narrative, the description of economic, social and technological processes that justify the harvest of products from the building stock was constructed and compared to existing references. These relations explain how products are harvested and listed in Chapter 5. From this perspective, the study juxtaposes what products are commercially reusable with the network of relations that determine why they are commercially reusable.

RO2: To identify how changes in the building stock can affect the practice of reusing products.

The housing stock as reserves affects the supply of reusable products in amount, speed and type or composition these products area accumulated and released from buildings. Although this is common sense information, the research described how some factors could influence these three aspects as examined in Chapter 6 (housing typology, housing size, construction year, location and tenancy). Some of these factors affect the survivability of buildings, the concentration, and characterization of types and amounts of materials and products, and consequently decrease the supply of reusable products (using as reference the inventory of products in Chapter 5).

RO3: To develop a dynamic representation (conceptual model) of how waste prevention through reuse could evolve through time.

The list of products identified in Chapter 5 ("current *commercially* reusable products" in Figure 7.1) is a benchmark to evaluate the performance of the practice of reuse, which is the lever between the evolution of the reserves and the evolution of the industrial system influenced by dynamic internal and external forces. From this perspective, the larger the range and the amount of products are reused, the higher is the performance of the industry of the reuse. The map representing these relations in Figure 7.1 indicates where the vulnerabilities in the system are. To improve the diversion of flows of products released from the building stock from waste streams depends on calibrating these vulnerabilities to adapt to these dynamic factors.

§ 7.3 Transferability

The IE concept is the derivation from which this study evolved, and it is considered here a constant from which variables were added according to the object of study. The conceptual model constructed, therefore, is a representation of the industrial ecology of building product reuse. Through this perspective, the closer the model is to the derivation structure, the more generic it is, and the more extensive the ramifications evolve from the core, the more specific it becomes. In other words, the study of wood-based products demonstrates how the findings in this research can be further applied, evolving to different levels of specificity, extended to different time frames, product types, or geographic boundary. The result of this research proposes the generic representation of building product reuse in the Netherlands is structured as follow in Figure 7.2.

- Organizational:
  - It has been discussed how the formalization or improvement of a practice relates to new or improved specialization of activities.
- Economic:
  - Disposal fees are a reference for alternative disposal.
  - Competitive markets regarding new products (and primary resources).
  - Competitive markets regarding different forms of material treatment (or waste treatment).
  - New business models that take into account the three previous economic aspects and operation aspects (logistic and processing.)
- Social:
  - Information is the element that associates with education either for the specialization of activities mentioned or for development of products that will integrate the waste prevention system or yet to dissipate the benefits of waste prevention.
  - Information also associates with perception and accessibility of reusable products.

- Technology:
  - Technology is considered in three time periods, associated with existing and evolving material stocks, to harvest these stocks and process them into a new life.
- Reserves:
  - Reserves can change through time in content, and the time they remain in stock before being released.

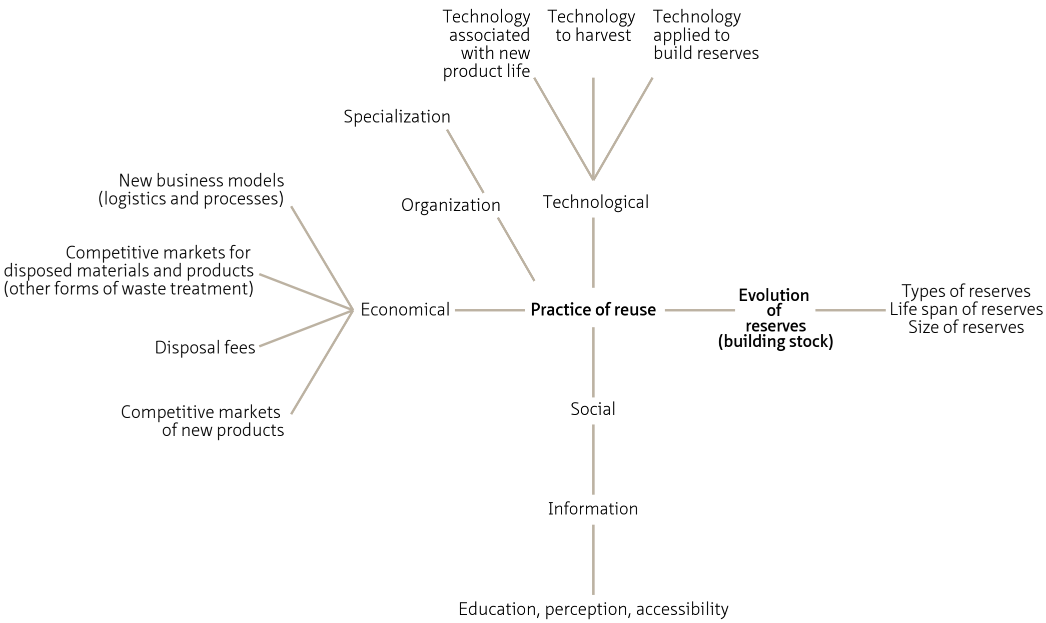


FIGURE 7.2 Generalized conceptual model for waste prevention.

Chapter 5 demonstrated how the conceptual model could be adapted to elucidate specificities of the reuse of wood- based building products. This exercise also reflected on what is constant in a complex dynamic system, and what is transferable from the knowledge here generated that can go beyond time and specificity. The study case of wood-based products indicated the potentials to integrate measurable information in the proposed model to convey potential targets of types of materials and products to be harvested for reuse. According to Bakas et al. (2011) this is a challenge in waste prevention due to lack of data. It also communicates different paths to improve flows of reusable products to support how to design policy mechanisms having into account the economic, social and technological aspects combined with the aim to improve the performance of reusing.

§ 7.4 Reflecting on research method and validity

The systemic approach proposed by the theory of Industrial Ecology established the basis for the research design, and it was adapted to represent how different relations in the real world influence the practice of reuse in the Netherlands. The conceptual model proposed is a simplification of reality structured by the pre-established national geographic boundary, three multidisciplinary clusters associated with the industrial system of reuse (economic, social and technological) and the assessment of material reserves grounded on the study of the housing stock evolution.

The clustered structure adopted from the IE theory helps to understand relations by themes, facilitating planning of specific strategies rooted to a respective "subject" within the systems' scope. The approach, therefore, aimed to emphasize the different aspects influencing the commercial function of reuse, constructing relations based on data grounded on empirical evidence involving stakeholders, experts, and extending the work developed in the existing literature.

Concerning the appropriateness of the selected tools and techniques relative to data availability, research time, and research goals, Chapters 1 and 2 indicated why and how existing tools applied in IE studies had to be revised to investigate the practice of reuse and what points to being tested. According to Lifset and Graedel (2002), the field of Industrial Ecology allows flexibility in the combination of approaches and tools as part of the constructive discourse. Different concepts explored in IE studies are included in this research to map how multidisciplinary relations influence the commercial viability of building product reuse in practice in the Netherlands.

Whereas the methodology applied for the study of reserves adapted past references of dynamic stocks modeling and material flow analysis, the tools applied to study the economic, socio and technological relations that influence reusing required a combination of information generated in previous studies. The timeline of data applied in the two methods were distinct.

The study of the industrial system (represented on the left side of the conceptual model) did not pre-establish a rigorous timeline, but it focused on knowledge available in literature and interviewed practitioners, which most references dated as early as 2000. Among all sources investigated, including those from different countries, the informality of reuse as a practice causes difficulty of data accessibility. The investigation departed by identifying activities in the supply chain and key stakeholders involved. The reference literature guided the content of semi-structured interviews with experts describing their experience in practice in the Netherlands. The reuse of building products in practice in the Netherlands is less formalized than industrial activities in waste management, and it is more compact in consequence of the limited technical processes involved and the participation of few stakeholders predominantly centralized by the role of demolition companies performing several activities in the chain. These characteristics are represented as influential to the organization of the industry.

The study focused on the development of a framework to support actionable knowledge aimed to assist a broad community of stakeholders including policymakers and the interface with potential consumers of used products. As demolition companies centralize the decision-making and management of flows of products to be reused, the results of this study correspond in large to this user group.

The response to the surveyed sample of companies commercializing used products was limited. From eighty-one questionnaires submitted to demolition companies and specialized retailers of used products, eight agreed to respond to questions during interviews. Experts and retailers of used products in other countries represented another group of interviewees. According to Tristan Frese (*Schiff*) and Van Erne (former head of *Stichting Millieunet*), *Oude bouwmaterialen*, *Komu* b.v, *Bouwcarrossel* and *Schiff* were the most relevant references in the commercialization of use products in the Netherlands. *Komu* b.v., however, ceased its commercial activities during the time interviews were made for this research. *Bouwcarrossel* was no longer active but agreed to participate in interviews and provided with an inventory of 450 building deconstruction cases for product reuse in the Netherlands including quantitative data and description of products. Other companies previously listed as retailers of used building products in the *Stichting Millieunet* inventory, were no longer active or had their activities reduced during the economic crisis in 2008. Nonetheless, the interviewed companies are considered representative according to how they are recognized by other companies in the same field, the time they have been operating in practice and the capacity of retail stock. Interviews were conducted more than once with the same interviewee and results were crossed among different companies, with information derived from specialists inside and outside the Netherlands, and existing literature.

Interviews with experts in design with used products (Rotor, Basurama, SuperUse Studios, Liz Ogbu), specialized business in the commercialization of used products (Jan van Ijken, Rob Gort) and existing literature provided information regarding the social interface with used products. Once again, existing literature was used as a guide to construct the content of interviews with the practitioners and specialists. The social interface is described through the expert's perspective, whereas the owner of reusable products and end consumers were not included in the research process.

Aspects of price, aesthetic condition, competition with similar new products, challenges to purchasing products with no warranties or lack of standardization are some of the factors that influence the decision to consume used products. Some of the information provided by the literature and specialists, was instead associated with economic and technological aspects. Beyond these factors, the aspects raised by the interviewed practitioners and specialists were oriented to what and how information is exchanged with potential users. Forms of dissemination like educational systems have been described in previous studies. Except for green certificates associated with public demolition tenders, the decision to reuse from the product owner's perspective is not clear based on the information collected in this research and little information is available in the literature.

To identify what products are considered commercially feasible for reuse in the Netherlands, primary data derived from visits to demolition companies and specialized retailers, research on specific websites and existing literature, mainly from outside the Netherlands was used as a reference to answer RQ 3. Additionally, existing surveys provided by experts regarding what products are harvested for their commercial operation were also assessed. The inventory of commercially reusable products is the result of comparative analysis of the four types of data sources. However, understanding the narrative that explains how products are considered commercially viable is relevant, because it reiterates the relations discussed in Chapter 3 clustered in the economic, social and technological categories.

Finally, the study of the industrial system is a compilation of information collected through interviews with practitioners, web sites, and specialists with the guidance of parallel literature review to contextualize previous results in the case of the Netherlands and compare results.

Regarding the study of reserves, there hasn't been an analysis of building stocks dynamics oriented to assess the supply of building products for reuse in the Netherlands. Available tools conventionally focused on assessing the availability of natural resources to process them into new products, to improve vulnerability of supply chains or to evaluate waste treatment capacity.

During the research process, it was found that available data was too aggregated to identify consumption trends, accumulation, and release of building products concerning the economic sector in focus (housing construction). The housing stock was divided into smaller clusters according to construction year and typology and analyzed through time. The timeline used to identify housing stock changes was dictated by data availability in respect to constructions built within 1900 to 2014. Although housing stock accounting is available since 1900, descriptive information characterizing the stock is more scarce. For the study of consumption trends of materials and products the timeline varied. Historical information is available for cement consumption (1930-2011) and ceramic products (1992- 2014), less available for steel (1990- 2009) and very limited for the consumption of wood (2003-2011 but aggregated). The main challenge in the study of product consumption is the level of aggregation of existing data and difficulty to associate consumption of types of products with new housing construction. In this regard, diverse sources of information describing construction technologies and diffusion of building products were relevant to estimate the evolution of the evolution of the housing stock according to product composition.

Data provided by PSUTs, by official organs, organizations and manufacturers were inconsistent and therefore used as a complementary source of information. The Dutch national accounting system holds data to formulate metabolism diagrams with much higher accuracy than presented in published reports, but this data was not available for public use at the time this research was done. Through the course of this study, when comparing periodical reports from private organizations and information derived from interviews with CBS members, there are indications that material flow accounting in the Netherlands improves towards a higher level of details, connectivity among existing data and transparency[255].

It was also challenging to infer the evolution of the housing stock when comparing new added houses per year with production rates of specific building products, annual material consumption at the national level, and consumption rates of respective products in the Netherlands. Earlier data of materials and products flows classified by

255 Chapter 2 discussed the account of waste flows showed to be less relevant for the goal of this study than the study of the technological evolution in housing construction also because they were so aggregated and changed classification through the last 15 years that it was difficult to track a substantial trend. Moreover, accounting of waste flows showed to be inconsistent due to the recent data available and changes in the accounting system that has been improving towards more detailed information by material types and origin, making comparison challenging among different years. Constant changes in classifying materials and sources of waste reflect this ongoing process to improve data assessment that could bring benefits for EOL strategies that including reuse as showed in this study. Tracking waste flows (as suggested in this research) by counting at the source through optimizing on site inventories from demolition companies brings potentials to improve understanding of waste flows by quantity of waste, type of material, building age and typology, and possibly by product type.

the categories housing, non-housing buildings, and infrastructure or by the activities (new construction, withdraws) are often not equally standardized according to sources (interviews at CBS and *Agentschap Nl*).

The challenges to formulate consumption trends based on secondary data of different material flows associated with the complexity to connect with different types of products and activities in housing sector were evident, which answer the first point tested by the proposed methodology[256]. Whereas assessing a smaller sample of materials and products could bring more specific information about each particular consumption trend, the focus of this study was to emphasize how material accumulation evolves in the stock and relates to the processes of product reuse.

In the lack of consistent data regarding consumption trends of building products, existing descriptive analysis of typical housing units combined with data regarding market shares of products consumed in new housing construction and the energy efficient reports assessing the house stock in use were relevant to narrow the information gap between material and product consumption and the housing sector. Additionally, although the information available to determine the consumption trends of some products and materials was inconsistent, information regarding other materials competing for the same application was relevant. For instance, data regarding consumption and application of concrete based products in housing construction was critical to understanding the diffusion of stony products in the housing stock, decreasing the concentration of wood, ceramics, and steel.

Comparing clusters of houses in stock through time was also a critical method to understand housing obsolescence. Different secondary data sources were crossed to compare and verify yearly added and withdrawing rates according to groups of houses. Whereas yearly new added houses and withdraws data is available for more than a hundred years, characteristics as size or typology are more recent and become more consistent in the last twenty years. Additionally, as classifications changed through time according to sources, some approximations were made, for instance, different classifications of housing typologies and construction year. Studying the housing evolution through these classifications revealed more information about the survivability process than generalized lifespan rates. Therefore it is expected that governmental agencies continue periodic assessments of the housing stock according to different housing categories, that the classification system remains more or less

256 “*The characterization of material throughput in the accounting phase that can best associate to the analysis of product reuse*”.

constant for periodic comparison, and that they include more information regarding buildings' physical characteristics.

Other references available in literature focused on the technical description of constructive systems in the Netherlands were also used to verify how the housing stock physically progressed through time. In short, the housing stock in this study is a collection of subcategories associated with different features deviated from the pre-established group of factors, which according to literature review could influence the stock dynamics by influencing housing survivability.

Through this approach, it was identified that most withdraws in the last thirty-one years happened with buildings aging hundred years and fifty years old and that there are distinct stock dynamics between regions, building typologies, housing size, construction period and demographics. This finding shows that the second point to be tested in the methodology[257] improve the understanding of obsolescence in the housing stock.

In the future, as the supply of natural resources decrease or are more controlled, recovering resources from existing built stock will become more valuable (Graedel and Howard-Grenville, 2005), justifying more explicit and transparent accounting system of materials and products and better tracking of their stocks to envision a more integrated way to manage them through waste prevention.

Some important considerations to be made are the time of data collection in this study that coincided with the economic crisis in 2008. Some trend disruptions were visualized on new annual housing construction, withdraws and, during interviews with demolition companies indicating a drop in demolition activities.

Also, some of the responders from demolition companies indicated that the economic crisis influenced their decision to diversify their core business by including reuse; others indicated an increase in sales of used products caused by clients looking for cheaper alternatives to new products. Another consideration is regarding time intervals of available data. Time intervals associated with consumption of materials, products, housing withdraws, and new added houses, as well as the classification of the housing stock associated with the pre-determined factors, did not coincide to determine uniform comparative basis. Longer time spans are preferred to determine consistent system behavior and trends.

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257 *"The study of a less generalized (compared to generalized life expectancy) end of life process for residential buildings".*

Rather than proposing long-term scenarios or predictions in the system's behavior, the study investigates the metabolic process of product reuse that is based on a combination of factors. Some of these factors could change through time, ultimately translating into economic feasibility affecting the final decision to reuse. Although the conceptual model does not represent the multiple nonlinear correlations among factors in the system, some of these interrelations are described in the study. For instance, the cost to deconstruct buildings to harvest products for reuse affects the harvest of products for reuse, and therefore if technologies improve this condition, which is mainly characterized by manual work, it will affect the economic output of the process. The evaluation and representation of all interrelations as feedback loops would be too extensive and potentially too complex both as a visual representation and as the extent of the data included in the study to verify causality.

Each relation represented in the model is constructed by primary and available secondary data. Primary data collected to assess the economic and technological relations characterizing the practice of reuse in the Netherlands could improve with additional survey responses, more specifically companies commercializing used products. It is debatable, however, that a more extensive sample of companies could generate results that are more robust or alter the structure identified in this research. The information provided by Dutch companies reinforced findings from other assessments made in other parts of Europe and the United States, indicating past and recent challenges in the operationalization of reusing building product.

In the same way, increasing the number of interviewed groups to explore aspects regarding the social interface in the consumption of used products could reveal more information about the system presented. However, the interviews emphasized more specifically practitioners, experts, and available literature, and time available for research is the physical constraint imposed to chose the system boundary in focus.

Considering the characterization of the housing stock on a national scale, primary data derived from a smaller sample of houses would be too extensive for this study. The study relied on a combination of data sources that included historical studies of technology diffusion and studies of reference houses both historical analysis and updated sources in the housing stock in the Netherlands.

The study of trends in the dynamic stock limited to the analysis of historical data comparing yearly-added houses and withdraws associated with factors referred in previous studies suggesting to be relevant for the study of construction material flows and stocks.

The information collected during semi-structured interviews revealed information that was not available in literature and information not quantified in previous studies, showing that qualitative investigation can add knowledge to more traditional quantitative approaches. Some of this information relates to the influence of manufacturers of new products in marketing and consumption trends; how investments in technological development in waste treatment are connected to industrial conglomerates in contrast to the absence of corporation interest representing reuse, and volatile prices of raw materials are some examples.

Moreover, the bottom-up approach also generated unexpected findings. These unexpected outcomes are anticipated in the IE systems perspective (Lifset and Graedel (2002), and were identified to be relevant in practice, as the case of cascade reuse, which is broadly applied in practice and adapts to social, technological and economic forces affecting reuse particularly evident in the case of wooden products. Another unexpected finding is the transformation of existing commercial activities through e-commerce and the unknown capacity of products being reused through trade among individuals. These additional findings although were not in evidence, reinforced the results of this study simplified in the conceptual model, and it acknowledges that dynamics within the system are also a result of factors external to the system's boundary. The conceptual model captures a condition that affects the results in the central part of the conceptual model, and that according to changes in these conditions; strategies could be designed aiming improvements in the future.

The research process converged data provided from real-world practice and literature into clusters proposed by the IE concept as a way to organize and reduce information. By indicating how different factors influence the performance of reuse as a waste prevention strategy, the research is complete. However, as showed in previous paragraphs, the conceptual model can be further developed in complexity as well as in specificity as demonstrated in Chapter 6.

It is also relevant to discuss how to improve the integration of quantitative data concerning the internal and external relations of the industrial system (and socio-economic and technological) for specific assessments (like the one proposed for reusable wood-based products), with the aim to advance the understanding not only regarding the availability of reusable products through the evolution of reserves, but also the demand for these products.

Time and data availability influenced investigation techniques. On the one hand, extending time frame for field research could produce stronger evidence of trends in the system or would help to build relationships with interviewed companies and organizations. On the other hand, reducing the system's boundary would affect the research goal to produce an overview of the context of reuse in the Netherlands.

The risk involved in the deduction process in this research could be a consequence of the exclusion of specific relations or variables existent in the real-world, and less on the misrepresentation of the variables assessed in the study. Whereas more information could introduce other critical aspects regarding reuse and increase complexity in the model, it is questionable that it would affect the connectivity of the system's parts or invalidate the structure proposed by the conceptual model.

For Sterman (2002, pg. 521) "*all models are wrong and cannot be validated*..." because the restraint is the actual limiting nature of models. Nonetheless, the confidence of a model can be build through multiple dimensions (Radzicki and Tauheed, 2009), by indicating usefulness of the model, "*on the ongoing comparison of the model against all data of all types, and on the continual iteration between experiments with the virtual world of the model and experiments in the real world*" (Sterman, 2002, pg. 521). All these steps were included in the research process for data collection and as part of the on- going verification process, but the model remains open for future evaluations and applications in the field of waste prevention as discussed in Chapter 2.

Finally, the metabolic process of reuse building products in the Netherlands is influenced by decisions restrained by the four types of factors: technology, social, economic and reserves as proposed by the IE concept. These clusters are a simplification of how these factors act combined rather than isolated.

The conceptual model proposed, is a map that can evolve as knowledge increases in the field and adapted to represent other levels of the complexities affecting the streams of materials deviated from waste treatment.

§ 7.5 Conclusion and answering the MRQ.

MRQ. What are the perspectives for reuse of building products from the housing stock, given contextual factors that influence the process chain and reserves?

This study proposes a representation of how different relations influence the process of waste prevention in the Netherlands, facilitating or restricting the commercial reuse of building products. The visualization of relevant linkages across the system contributes to the collective understanding of the system itself, necessary to construct more robust connections among stakeholders for existing or new supply chain models.

The qualitative approach departed from clustering information in categories is an adaptation of fundamental components of the Industrial Ecology theory. The research proceeded by examining how social, economic, technological relations, and the accessibility of reusable products conditioned by dynamics in the housing stock influence what is commercially suitable for reuse, and identified what constraints exist within this process. This holistic approach generates an overview centralized by the role of the practitioner.

Consequently, strategies to improve waste prevention through reuse could be limited if consider isolated factors of the process chain. Within the system boundary depicted in this study, different aspects simultaneously influence the commercial reuse of building products in the Netherlands. From this perspective, future policy design and plans to improve the commercial practice should consider the following aspects: i) knowledge improvement of the evolution of material reserves; ii) increase the specialization of activities in different stages of the reuse process; iii) technological innovation to increase harvest of reusable products; iv) educational and other forms of knowledge dissemination that regard what, how, why and where to find reusable products whereas sustaining the environmental benefits of reusing. These aspects should also elucidate ways to increase competitiveness with new products and different forms of waste treatment.

Ultimately, the representation of results found in this research allows the viewer to understand the process of building product reuse and some of the motivations that conditions this process. The framework proposed in this study is a way to facilitate decision making by practitioners and policymakers, to visualize the connectedness among different aspects of building construction, deconstruction and processes to reuse building products in the Netherlands. Ultimately, the framework offers different paths to generate additional evaluation or action with the aim to adapt this waste prevention strategy to changing conditions and improve reuse in time.

TOC

§ 7.6 Recommendations for future studies

- To develop feedback loops within the system introduced (Academics).

- To create methods to evaluate the levels of predominance among different variables influencing the system described in this study with the goal to prioritize future action plans (Academics, Governmental agencies).

- To improve information regarding the role and influence of waste- owner in waste prevention. It is relevant to communicate building owners or "waste" owners about the benefits of reusing. Additionally, whereas building owners sort products at source for reuse spontaneously (to sell them at *Marktplaats*), it is critical to provide means to offer technical guidance on what and how to reuse, where to exchange these products, and to develop other forms of incentives to support them. (Practitioner: deconstruction companies specialized in the harvest of reusable buildings products, retailers of used building products and demolition companies).

- To test the proposed conceptual model to different types of reserves including other housing groups, infrastructure, institutional, and commercial buildings. Another relevant aspect is to study materials and products' flows generated by renovation activities rather than building demolition (Academics, Governmental agencies, Demolition companies).

- To expand knowledge of materials and products cycles in the industrial ecology and sustainable metabolism of cities. There is a predominant focus on energy efficiency in buildings compared to material "efficiency" and material stocks, while studies focused on assessing building products are even rarer. Tracking product stocks could potentially help to plan (e.g., take-back chains) better integration with manufacturers (Academics, Governmental agencies).

- To develop action plans focused on more specific types of materials or products while maintaining the holistic view constructed in this research with the goal to achieve systemic production. The case of wooden products demonstrated here could support the design of new production chains to match more efficient processing and user assessment (Academics, Governmental agencies, Practitioners).

- Future studies could test different strategies to elaborate the social factors identified in this research. One of them is to explore marketing tools that could improve public perception, shopping experience, and consequently value and demand for used products. The second one is part of the on-going process to develop networks and database to increase connective between supply and demand. The past experiments mentioned in this research are references that could be explored with different levels of specificities regarding types of products, geographic area, and types of stakeholders involved (designers, architects, manufacturers), as an alternative to the already existing *Marktplaats*, as well as adapted to the evolving efforts to implement a CE (Academics, Practitioners).

§ 7.7 Policy recommendations

It is important to emphasize that policy was not the original intended subject of analysis in this research. The aim was to exam the self-organizing system within a free market context. However, although "policy" is not explicitly represented in the conceptual model, it is an influential instrument, for instance imposing limited landfill or disposal fees. These examples show that even when establishing minimum targets, it can resonate in the EOL phase of products. It is critical to identify what old or new policy measures obstruct or incentivizes the development of reuse as discussed in this study as the incentives that support other forms of waste treatment rather than prevention.

Through the course of this work, it was witnessed the transformation of guidelines into policy implementation and the dissemination of the concept of Circular Economy in the Netherlands resulting in different recent experiments. The New Horizon[258] initiative (in the Netherlands) as an example, surged as a platform committed to improving C&D waste management through creating and stimulating processes to divert materials and products harvested from demolition and renovation from traditional downcycling. Its approach connects a group of stakeholders that goes beyond the industries of demolition and reuse, including investors, manufacturers, experts, and designers. This heterogeneous platform exemplifies the multidisciplinary aspects of the system discussed in this study necessary to systemically explore the deeper levels of specialization the various possibilities to divert materials flows from waste. The expansion of initiatives like this one as well as other study cases connect new players and construct possible new supply chains (processes, and demand) to increase the

258 http://newhorizon.nl

mass and types of products for reuse and cascade reuse that are economically feasible, and more accessible.

Once again, policy is a catalyst for these new developments as it is demonstrated by how these recent initiatives are reviving the knowledge generated fifteen or more years ago (Duffy, 1990; Brand, 1995; Crowther,1999; Kibert and Chini, 2000; Te Dorsthorst et al., 2000; Kristinsson et al., 2000; Habraken, 2003; Durmisevic, 2006). Researches and the practice of reuse of building products in the Netherlands remained relatively stagnated reflected by the lack of literature, incentives, regulations and formal accounting of reused products until the implementation of the more recent Circular Economy focused policies. To support future development and implementation of reuse of building products in the Netherlands, this study recommends the following actions:

– To increase data transparency and connectivity particularly regarding material flows and stock evolution as well as product consumption associated with economic sector.

– To include assessment of physical description and material content both descriptive and quantitative in periodic studies of reference houses in the Netherlands, (currently, these reposts are mainly focused on energy efficiency) to evaluate material stock evolution more consistently and improve knowledge in housing survivability.

– Inventories made by demolition companies at source should be more rigorously formalized, controlled and available for consultation to help material monitoring. These inventories are critical to improving waste flows accounting that today are still highly aggregated by type of material and source. Additionally, these inventories could also help to establish targets by percentage of products reusable per building or to formalize accounting system for the used product, which today is absent from the overall resource accounting. This type of monitoring could improve monitoring of waste generation as well as waste prevention both quantitatively and qualitatively proven to be a challenge not only in the Netherlands but also in elsewhere in Europe.

– Beyond definitions, past government support in the form of subsidies for waste treatment conflicts with the goals of the waste hierarchy towards prevention through reuse and cascade reuse. Moreover, government tendencies to enable market forces to regulate waste management position the reuse industry with a less formalized structure in a less competitive state. Establishing targets, or minimum percentage of materials to be reused, increasing the time for harvesting reusable products from demolition sites, as well as helping to establish quality certification systems for used products are some of the mechanisms to support waste prevention through reuse.

- There is an unclear and heterogeneous definition of the term “reuse” affecting how regulations are or could be designed more efficiently to support and improve existent activities in practice. . This condition is reflected on what is considered waste and non-waste, what is accounted as recycled or reused and finally how material flows are treated. The definition of reuse as suggested by the Circular Economy (Ellen MacArthur Foundation) was the most accurate to represent what has been found in practice in the Netherlands, offering a higher level of flexibility including upstream and downstream processes to prevent waste according to the type of product and material and supporting different business models. “Reuse”, “preparing for reuse” as defined by the WFD 2008 are not separated activities in practice, and it would be challenging to monitor and regulate both of them apart.

- To support the formation of multidisciplinary platforms directly related in the construction industry to set dialogue, experiments, data exchange and tests new of supply chains.

Annex 1 Chapter 1

ANNEX 1.1 **Global CO_2 missions and material consumption***

GLOBAL CO2 EMISSIONS	INDUSTRIAL CARBON EMISSIONS	INDUSTRIAL SECTOR	APPLICATION
35% Industry	45% Others		
31% Buildings	25% Steel	56% Construction	65% Superstructure 35% Non- structure 10% Substructure
27% Transport	19% Cement	100% Construction	53% Concrete mix for housing 31% Utility building 3% Water infrastructure 5% Road
7% Others	4% Paper		
	4% Plastic		
	3% Aluminum	24% Construction	37% Roofing 27% Windows 15% Curtain walls

** Based on data from WellMet, 2012 and CementenBeton Centrum, 2012*

ANNEX 1.2 **Summary on the experiences on technology of material recycling practices (Tam and Tam, 2006)**

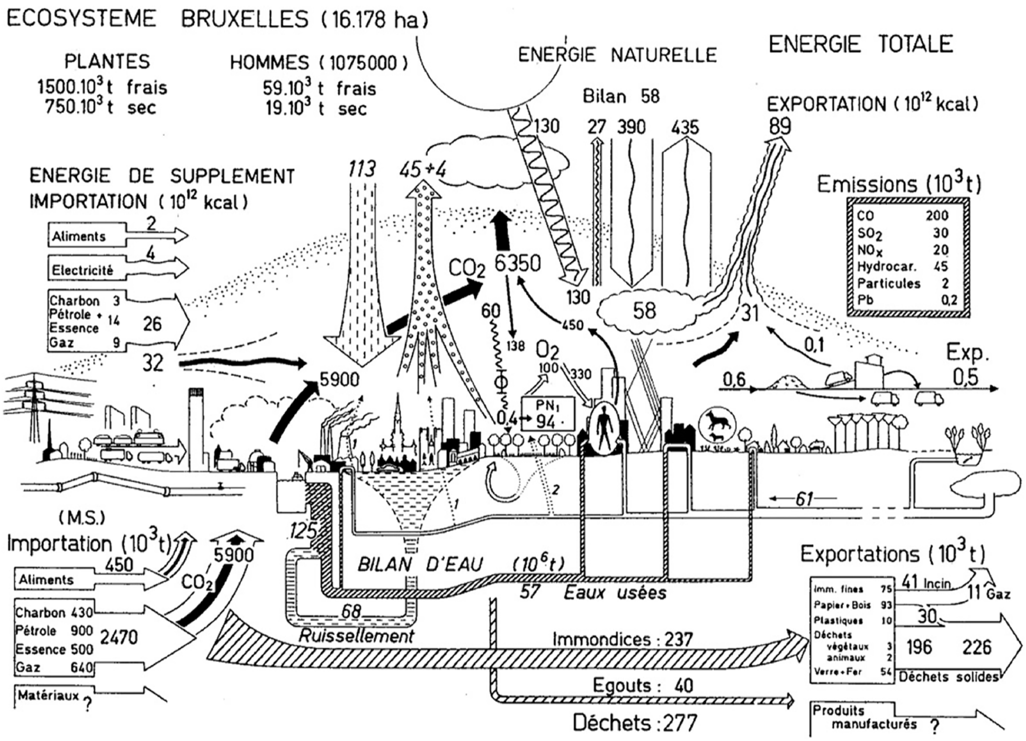
C&D MATERIALS	RECYCLING TECHNOLOGY	RECYCLED PRODUCT
Asphalt	Cold recycling Hear generation Minnesota process Parallel drum process Elongated drum Microwave asphalt recycling system Finfalt Surface regeneration	Recycled asphalt Asphalt aggregate
Brick	Burn to ash Crush into aggregate	Slime burnt ash Filling material hardcore
Concrete	Crush into aggregate	Recycled aggregate Cement replacement (replace cement by fine portion of demolished concrete) Protection of levee Backfilling Filler
Ferrous metal	Melt Reuse directly	Recycled steel scrap
Glass	Reuse directly Grind to powder Polishing Crush into aggregate Burn to ash	Recycled window unit Glass fibre Filling material Tile Paving block Asphalt Recycled aggregate Man-made soil
Masonry	Crush into aggregate Heat to 900 °C	Thermal insulating concrete Traditional clay brick Sodium silicate brick
Non-ferrous metal	Melt	Recycled metal
Paper and cardboard	Purification	Recycled paper
Plastics	Convert to powder by cryogenic milling Clipping Crush into aggregate Burn to ash	Panel Recycled plastic Plastic lumber Recycled aggregate Landfill drainage Asphalt Man-made soil
Timber	Reuse directly Cut into aggregate Blast furnace deoxidization Gasification or pyrolysis Chipping Moulding by pressurizing timber chip under steam and water	Whole timber Furniture and kitchen utensils Lightweight recycled aggregate Source of energy Chemical production Wood-based panel Plastic lumber Geofibre Insulation board

ANNEX 1.3 **Example of sustainable design strategies that include the concern of resource consumption and waste production**

CONCEPT	REQUIREMENTS FOR IMPLEMENTING THE CONCEPT
Ecodesign: a promising approach to sustainable production and consumption. United Nations Environment Programme, Paris, France. (J. C. Brezet; C. G. van Hemel)	Analysis: How does the product actually fulfill social needs? Production and Supply of Materials and Components: What problems can arise in the production and supply of materials and components? In-House Production: What problems can arise in the production process in your own company? Distribution: What problems arise in the distribution of the product to the customer? Utilization: What problems arise when using, operating, servicing and repairing the product? Recovery and disposal: What problems can arise in the recovery and disposal of the product
Biomimicry: mimic nature (J. Benyus)	Runs in sunlight Uses only the energy it needs Fits form to function Recycles everything Rewards cooperation Diversity Local expertise Curbs excesses from within Taps the power of limits
The Golden Rules for Ecodesign (S. Bringezu)	Potential impacts to the environment should be considered on a life cycle basis or from cradle to grave The intensity of use of processes, products and services should be maximized The intensity of resource use (materials, energy and land) should be minimized Hazardous substances should be eliminated Resource input should be shifted towards renewables
The Natural Step (K. H. Robèrt)	Reduce concentrations of substances extracted from the earth's crust (reducing exploration of scarce minerals Use efficiently Reduce use of fossil fuel Use substances less unnatural for more natural and easier to break in nature Rely on well managed ecosystems pursuing productive and efficient use of land Use of substitution and dematerialization Reduce substances produced by society Reduce harvesting or other forms of ecosystem manipulation

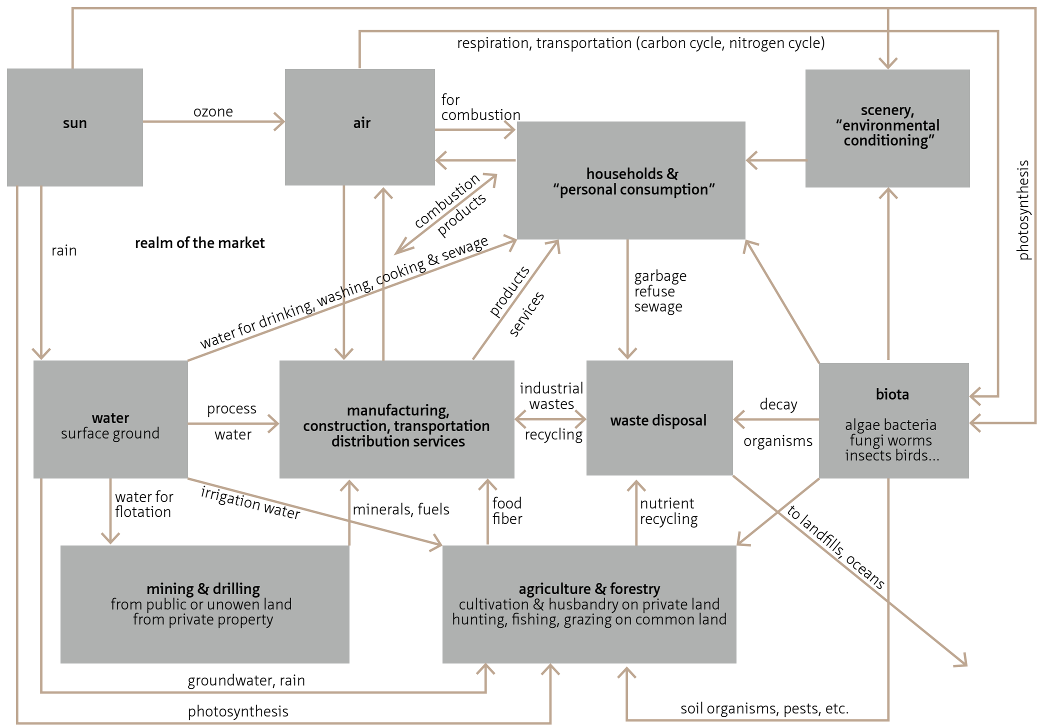
Annex 2 Chapter 2

ANNEX 2.1 Scheme of urban metabolism ("*The urban metabolism of Brussels, Belgium in the early 1970s.*" Duvigneaud and Denayeyer- De Smet, 1977)



TOC

ANNEX 2.2 **Scheme of industrial metabolism ("*What is industrial metabolism?*" _ Ayres, R. U. in Allenby, Braden R., and Deanna J. Richards, eds. The greening of industrial ecosystems. National Academies, 1994.)**



ANNEX 2.3 **Type of data source and knowledge focus**

Waste management	Retailers	Demolition companies	Associations	Experts	Academics	Manufacturers and related organizations
.Waste selection parameters focused on reuse.	• Economic, technological and social parameters to reuse • Amounts of materials harvested for reuse	• Economic, technological and social parameters to reuse	• Number of business, • Existent incentives for reuse • Amounts of materials harvested for reuse	• Potentials and barriers • Comparative retailer mechanism to the Netherlands • Designers specialist of used products	• Building technology	• Consumption trends

ANNEX 2.4 **Data source for RQ 1, 2, 3**

TYPE OF REFERENCE	CONTACT PERSON	ORGANIZATION	DATE/ CONTACT
Experts (USA/ SP)	Pablo Rey	Basurama	pablo@basurama.org November, 2015
Experts (USA)	Liz Ogbu	Public Architecture	liz@lizogbu.com March, 2013
	Mary E. Williams	Construction and Demolition Recycling Specialist Department of the Environment City and County of San Francisco.	mary.williams@sfgov.org September, 2012
Demolition companies (NL)	Hans Oranje	Oranje Demontage	ho@oranje-bv.nl December, 2012 November, 2012 July, 2012
Demolition companies (NL)	John van Herk	MiSa Advies (VERAS)	johnvanherk@misa-advies.nl October, July, 2012
Demolition companies (NL)	Fred Veer	Van Ball	F.A.Veer@tudelft.nl 2012, 2013
Demolition companies (NL)	Walter Gubbels	Gubbels Wegenbouw en Sloopwerken bv	w.gubbels@gubbels.nl November, 2012
Government agency (NL)	Anja van Lieshout	Rijksinstituut voor Volksgezondheid en Milieu (RIVM)	anja.van.lieshout@rivm.nl December, 2012
Government agency (NL)	Karín I. Fraai	Gemeente Rotterdam Slim SLope	ki.fraai@Rotterdam.nl July, 2012
Waste management organizations (NL)	Olaf van Hunnik	Materialen, Mobiliteit en Klimaat Rijkswaterstaat Leefomgeving	olaf.vanhunnik@rwsleefomgeving.nl May, 2013
Government agency (EU)	Özgür SAKI	Project Manager, Waste Prevention and Management European Environment Agency	Ozgur.Saki@eea.europa.eu
Government agency (USA)	Meri Soll Program Manager	Stop Waste (USA)	MSOLL@stopwaste.org March, 2013
Experts (SE/EU)	Johanna Fredén	IRCOW	johanna.freden@ivl.se September, 2012
Experts (UK)	Jonathan Essex	Bioregional	essex@bioregional.com September, 2010
Experts (NL)	Frans de Haas	De Haas en Partners	frans@dehaasenpartners.nl
Experts (EU)	Stephane Arditi	European Environmental Bureau	stephane.arditi@eeb.org November, 2011

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ANNEX 2.4 **Data source for RQ 1, 2, 3**

TYPE OF REFERENCE	CONTACT PERSON	ORGANIZATION	DATE/ CONTACT
Experts (NL)	Lisanne Dölle	Verdraaidgoed	lisanne@verdraaidgoed.nl December, 2012
Experts (USA)	Charlie O'Geen	Charlie O'Geen	cjogeen@gmail.com
Experts/ Retailer (NL)	Rob Gort	Bouwkringloop/ Bouwcar-rossel	bouwkringloop@kpnmail.nl April, 2013 March, 2013 December, 2012
Experts/ Retailer (BE)	Lionel Billiet	Rotor	billiet.lionel@gmail.com 2013, 2014, 2016
Experts/ Retailer (NL)	Jan Swinkels	Wonderwall Studios	info@wonderwallstudios.com October, 2012
Expert (NO)	Anne Sigrid Nordby	Asplanviak	AnneSigrid.Nordby@asplan-viak.no September, 2013
Experts/ Retailer (USA)	Nathan Benjamin	Planetreuse Marketplace	nbenjamin@planetreuse.com April, 2013
Retailer (USA)	Ted Reiff	The ReUse People of America, Inc. (US)	tedreiff@thereusepeople.org March, 2013
Retailer (USA)	Shannon Goodman	Lifecycle Building Center	shannon@lifecyclebuilding-center.org October, 2012
Retailer (USA)	Justin Green	Build It Green!NYC	justin@bignyc.org
Retailer (NL)	Michel van Slingerland	Hornbach	Michel.vanSlingerland@hornbach.com December, 2012
Academic (NL)	Kristel Hermans	Technical University of Eind-hoven/ Trek-in	kristelhermans@hotmail.com January 21, 2016
Academic (NL)	Dr. ir. Leo Gommans	TUDelft	L.J.J.H.M.Gommans@tudelft.nl December, 2012
Academic (NL)	Irene Jonkers	Nyenrode Business Univer-siteit Center for Sustainability Researcher	I.Jonkers@nyenrode.nl December, 2012
Academic (NL)	Tim van der Grinten	Technical University of Eind-hoven/ Trek-in	tvdg.arch@gmail.com January, 2016
Academic (NL)	Ton Kowalczyk	(former TUDelft)	ton.kowalczyk@architectu-uratelier.nl May, 2012
Academic (USA)	Charles J. Kibert	University of Florida	ckibert@ufl.edu April, 2013 (and during DC conference)

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ANNEX 2.4 **Data source for RQ 1, 2, 3**

TYPE OF REFERENCE	CONTACT PERSON	ORGANIZATION	DATE/ CONTACT
Academic (D)	Claus Asam	Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR)	Claus.Asam@BBR.Bund.de January, 2013
Demolition companies/ Expert (NL)	Cor.J.L.M. Luijten	Slim Slope	cjlm.luijten@Rotterdam.nl July, 2012
Demolition companies/ Expert (NL)	Robert Barclay	Van Liemp/ 2Life-Art	robert@2life-art.nl December, 2012
Experts (NL)	Duzan Doepel	Doepel Strijkers Architects	dommele@sublean.nl July, 2009
Experts (NL)	Erik van Erne	Stichting Milliuenet	erik@wolfram-publications.com info@stichtingmilieunet.nl November, 2012
Waste management (NL)	Arnold Rolsma	LMA - Agentschap NL	arnold.rolsma@rwsleefom-geving.nl May, 2013
Waste management (NL)	Maarten Goorhuis	NVRD	Goorhuis@nvrd.nl October, 2012
Waste management (NL)	Sarah.Ottaway	Sita	Sarah.Ottaway@sita.co.uk January, 2013
Waste management (NL)	Edwin Schokker	Vereniging Afvalbedrijven	schokker@verenigingafval-bedrijven.nl September, 2012
Waste management (NL)	Max de Vries	BRBS Recycling Branchevereniging Breken en Sorteren	info@brbs.nl June, 2011
Waste management (NL)	Otto Friebel	Van Gansewinkel	otto.friebel@vangansewinkel.com October, 2011
Waste management (NL)	Mark de Boer	Recycling	Mark@recycling.nl June, 2011
Waste management (NL)	Ivo Haenen	WASTE advisers on urban environment and development	ihaenen@waste.nl June, 2011
Waste management (NL)	Geert Cuperus	F.I.R./ BRBS Recycling Branchevereniging Breken en Sorteren	info@brbs.nl March, 2009

ANNEX 2.5 **Data source for RQ 4**

	REFERENCE	ORGANIZATION	CONTACT/ DATE
Manufacturers and related organizations (NL)	Wim Kramer	Cemenetenbeton	Material input and production manufacture
Manufacturers and related organizations (NL)	Arie Mooiman	Koninklijke Nederlandse Bouwkeramiek	mooiman@knb-keramiek.nl October, 2012
Manufacturers and related organizations (NL)	Maurice van Dijk	BouwKennis B.V.	vandijk@bouwkennis.nl January 2013
Manufacturers and related organizations (NL)	Mic Barendsz	Bouwenmetstaal	Mic@bouwenmetstaal.nl September, November, 2012
Manufacturers and related organizations (NL)	Andreas Kellert	ICDuBo	a.kellert@icdubo.nl October, 2011
Manufacturers and related organizations (NL)	Bob Commandeur	CBM	commandeur@cbm.nl October, 2012
Manufacturers and related organizations (NL)	Olav Pouw	Centrum Hout	O.Pouw@centrum-hout.nl October, 2012
Manufacturers and related organizations (NL)	Martine Meijering	Gips Recycling Nederland BV	mmeijering@gipsrecycling.nl December, 2012
Manufacturers and related organizations (NL)	Dubbers, Sjon	Nederlandse-Branche-Vereni-ging-Gips (NBVG)	j.dubbers@upcmail.nl January, 2013
Manufacturers and related organizations (NL)	Remko Zuidema	Slimbouwen	r.zuidema@slimbouwen.nl April, 2013 June, 2012
Manufacturers and related organizations (EU)	Arjen Sevenster	The European Council of Vinyl Manufacturers (ECVM)	arjen.sevenster@plasticseu-rope.org> October, 2012
Manufacturers and related organizations (EU)	Estée de Boer	Nederlandse Isolatie Industrie (NII)	N.IsolatieIndustrieNII@ ecofys.com info@nii.nl October, 2012
Manufacturers and related organizations (NL)	Gerald Bakker	Eternit	Gerald.Bakker@eternit.nl September, 2012
Manufacturers and related organizations (BE/EU)	Jeroen Vermeij	EUROFER	J.Vermeij@eurofer.be September, 2012
Manufacturers and related organizations (NL)	Piet Meinen	De Houtinformatielijn Cen-trum Hout	HoutInformatie@cen-trum-hout.nl October, 2012
Manufacturers and related organizations (NL)	Egbert Zeef	Production and EQSHP Manager Siniat BV	egbert.zeef@siniat.com January, 2013
Manufacturers and related organizations (NL)	Frans G.M. van Swam	Buildsight	vanswam@buildsight.nl, January, 2013
Manufacturers and related organizations (NL)	Maurice van Dijk	Bouwkennis	vandijk@bouwkennis.nl January, 2013

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ANNEX 2.5 Data source for RQ 4

	REFERENCE	ORGANIZATION	CONTACT/ DATE
Manufacturers and related organizations (NL)	Jan Oldenburger	Probos	jan.oldenburger@probos.nl August 04, 2013
Manufacturers and related organizations (DK)	Anita Rasmussen	Danish Technological Institu-teConcrete Centre (concrete production)	anc@teknologisk.dk November, 2012
Manufacturers and related organizations (NL)	Ubbo Ubbens	MRF - Metaal Recycling Federatie p/a LEJEUNE Association Management	ubbo.ubbens@fme.nl August, 2012
Manufacturers and related organizations (NL)	Robert van Notten	Stichting Duurzaam Verpak-kingsglas	robert.vannotten@duur-zaamglas.nl August, 29, 2012
Manufacturers and related organizations (NL)	Judith van Dijk	Vlakglas Recycling Nederland	algemeen@ipdubo.nl August, 2012
Manufacturers and related organizations (NL)	Kramer, Wim (Den Bosch) NLD	Cementbeton	wimkramer@cementenbet-on.nl November, 2012
Manufacturers and related organizations (NL)	Benedikt van Roosmalen MBA Directeur	Stybenex	bvanroosmalen@stybenex.nl January, 2013
Manufacturers and related organizations (NL)	Berry van Oosterhout Consultant Consumer Choices	GfK Retail and Technology Benelux B.V.	berry.van.oosterhout@gfk.com December, 2012
Manufacturers and related organizations (NL)	Bert Kattenbroek	nbvt	B.Kattenbroek@nbvt.nl November, 2012
Manufacturers and related organizations (EU)	Jeroen Vermeij	EUROFER	J.Vermeij@eurofer.be September, 2012
Manufacturers and related organizations (NL)	Piet Meinen	De Houtinformatielijn Cen-trum Hout	HoutInformatie@cen-trum-hout.nl October, 2012
Manufacturers and related organizations (NL)	Hans Koning	Metaal Recycling Federatie	August 31, 2012 hkoning@mrf.nl
Manufacturers and related organizations (NL)	Vera Tomberg Office Manager	FSC	v.tomberg@fsc.nl December , 2012
Experts (NL)	Remco Spiering Cindy Vissering	Stichting Bouwreserach (SBR)	R.Spiering@sbr.nl October 24, 2012 C.Vissering@sbr.nl September, 2012
Experts (NL)	Rob de Wildt	RIGO	Rob.de.Wildt@rigo.nl October, Novemeber, 2012
Experts (USA)	Rob Englert	D-Build	renglert@d-build.org July, 2011

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ANNEX 2.5 **Data source for RQ 4**

	REFERENCE	ORGANIZATION	CONTACT/ DATE
Experts (NL)	Daniel Tulp	W/E Adviseur	December, 2012 tulp@w-e.nl
Experts (NL)	Geurt Donze	W/E Adviseur	December 05, 2012 donze@w-e.nl
Experts/ Academic (NL)	Haico van Nunen	Bouwhulp/ Technical University of Eindhoven	h.v.nunen@bouwhulp.nl December 17, 2012
Experts (NL)	Frans Hooykaas	Stichting Rotterdam Woont	f.hooykaas@gmail.com September, 2012
Experts (NL)	Piet Bot	Open Lucht Museum	P.Bot@openluchtmuseum.nl August, 2012
Experts (NL)	Hans den Otter	SYSWOV	Hans.denOtter@abf.nl December, 2012
Experts (NL)	Hans den Otter	Abf Research	Hans.denOtter@abf.nl December, 2012
Experts (A)	Dr. Stefan Giljum	SERI	stefan.giljum@seri.at June, 2011
Experts (NL)	Arnoud Feijen	TNO	mail@arnoudfeijen.nl December, 2012
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Experts (EU)	Tobias Loga Nikolaus Diefenbach Britta Stein	Tabula project http://episcope.eu/iee-project/tabula/	t.loga@iwu.de n.diefenbach@iwu.de b.stein@iwu.de August 01, 2012
Experts (USA)	Sam Hamrick	Reportlinker.com.	news@reportlinker.com May 27, 2009
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Academic (USA)	dr. Daniel Ibañez	Harvard GSD	dibanez@gsd.harvard.edu August, 2015

>>>

ANNEX 2.5 **Data source for RQ 4**

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Academic (NL)	Hu, Mingming	Leiden University/TUDelft	Hu@cml.leidenuniv.nl July 11, 2012
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Academic (NL)	Frank Koopman	TUDelft	f.w.a.koopman@tudelft.nl November 01, 2012
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Academic (NL)	Hielkje Zijlstra	TU Delft	H.Zijlstra@tudelft.nl August 08, 2012

>>>

ANNEX 2.5 **Data source for RQ 4**

	REFERENCE	ORGANIZATION	CONTACT/ DATE
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Government agency (NL)	dr. Roel Delahaye	CBS	r.delahaye@cbs.nl 2015, 2013
Government agency (NL)	dr. Cees P. Baldé,	CBS	c.balde@cbs.nl May 18, 2013
Government agency (NL)	Arnold Rolsma	LMA	arnold.rolsma@rwsleefom-geving.nl May 13, 2013
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Government agency (NL)	Meerbeek, Anja	Planbureau voor de Leefom-geving	Anja.Meerbeek@pbl.nl September 21, 2012
Government agency (NL)	Bieler, Jim	Agentschap NL	jim.bieler@agentschapnl.nl September 20, 2012

Annex 3 Chapter 3

ANNEX 3.1 **Houses (according to tenancy and type of building) that have had passed through some kind work in the previous year (in %)***

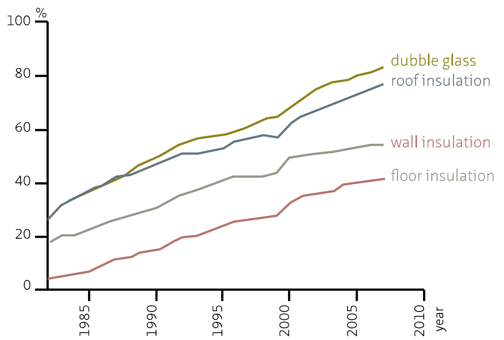
	PRIVATE OWNED		SOCIAL RENTAL		PRIVATE RENTAL			
					Institutional investment		Private investment	
	S	M	S	M	S	M	S	M
Insulation/ Energy saving	19.8	12.6	12.2	7.9	11.2	8.3	10.9	10.6
Maintenance	55.2	43.3	40.4	32.7	46.5	34.5	41.6	33.7
Structural repair	23.7	20.8	17.3	13.3	19.4	13.1	20.4	18.9
New facilities	18.7	12.3	8.2	5.1	8.8	5.3	8.1	5.8
Aesthetic improvements	18.6	14.2	7.9	5.0	7.7	5.9	9.8	6.4
Communal	-	32.5	-	21.0	-	23.6	-	20.7

** (WBO 2002 in Meijer and Thomsen, 2006).*

ANNEX 3.2 **Energy and sound regulations[1] influencing material accumulation in buildings.**

Regarding changes of material accumulation, insulation system is a category in the housing segment that has progressively increased. More emphasis has been made on energy saving than sound or fire insulation (Feijen, 2003; Senternovem, Gort et al., 2007; Itard et al., 2008; Koppert, 2012). As in Annex 3.1, shows ho insulation works distinctions of renovation works occurred more often in private owned houses compared to rentals. Despite the oscillations in the new housing construction market, new energy efficiency measures applied for buildings, boosted the market for insulating materials, which is expected to increase both in the new and existing stock in the coming years (Koppert, 2012) (Figure A).
Currently, dwellings built before 1965 will be in general poorly insulated. This group represents 38,8% of the whole stock and has an average rate of 2,71 energy index, the worst in the housing stock. The second group that also requires some improvements dates from 1965-1974 with an average energy index of 2,28 representing 19,1% of the stock (Agentschap Nl, 2011). It is expected that the waste production caused by these measures will be seen in the future. Parallel to this consumption trend, adequate waste treatment should be allocated, which could include reuse.

Figure A. Comparative application of insulation measures in the housing stock between 1982 to 2007 Senternovem, EnergieNed, www.compendiumvoordeleefomgeving.nl)



1 Regulations about sound and fire insulation in houses increased the consumption trend of concrete based materials substituting wood flooring and pillar foundations that coincided with high demand of low cost housing during the post war as previously explained (Intron and Rigo, 2006). "In the coming years, government policy will increasingly focus on energy-saving measures, with the objective of reducing CO2 emissions, making responsible use of materials and improving the internal conditions of housing for occupants". (Itard et al., 2008). "The goal is to set up an estimation method for the environmental costs and investments Dutch households make for home improvement regarding to energy efficiency and the environment" (Koppert, 2012).

Annex 4 Chapter 4

ANNEX 4.1 **Traditional housing construction systems in the Netherlands**

Airey
At times, this system is considered as "*stapelbouw*", and in other cases it is classified as "*licht montagebouw*". This system was applied in the Netherlands in single-family housing, maisonettes, *portiek* and *galerij* projects, mostly around 1960. The walls of Airey dwellings consist of small, prefabricated reinforced concrete columns or in other cases steel skeletons. Against this skeleton, reinforced concrete facade panels are fixed with bolts. The facade is insulated with Styrofoam 2 cm imposed in a steel edge beam in the wall. Floors are made of steel lattice girders that are fixed on a steel edge beam on the wall, and on top the floor is covered with wooden boards. The roof is often traditionally made of wooden beams, covered with wooden boards and roofing tiles.
Muwi
Muwi has also been applied in *portiek*, *galerij* and single-family houses. From all post war construction methods this was the most successful one. It is a *stapelbouw* system where the structural walls are of hollow light-concrete blocks filled with concrete. Originally the facades were internally covered with insulation panels and outside finishing was made with clay bricks. Non-structural walls were made of 1 floor height prefabricated elements. It is then a combination of *stapelbouw*, *grote elementen* and traditional construction. Floors were made of prefabricated elements applied on a concrete beam grid.

ANNEX 4.2 **Non- traditional housing construction systems in the Netherlands:**

Gietbouw also called "the new Traditional".
Korellbeton was the most dissipated system with the largest share of production built before 1962. It is a monolith system with a load-bearing wall made of poured concrete in situ and rigidly connected horizontally to the floors. Floors are also made of concrete panels. Internally, the wall is treated with waterproof plaster.
Today this system is largely applied and known as the Tunnel-Form Structure. Non- structural walls could be erected with gypsum blocks, aerated concrete blocks or still assembled panels. The external facades are finished either with brickwork of plaster. It is a good construction system for *galerij* housing but very few *portiek* was built. Only 6% of the *portiek* built with non-traditional systems was built with *gietbouw* (van Battum, 2002). Tunnel-Form construction remains the dominant method of production for structures in housing in the Netherlands. The reuse of such structures is not yet economically viable, as technologies that are able to cut concrete slabs are far too expensive to make it a standard procedure. Nonetheless, other parts in the building are still subject to evaluation for further reuse. Welschen and RBM are other well-known "*gietbouw*" systems, but also in the monolith category.
Montagebouw
The main characteristics in this method are walls and floors industrially fabricated in large size components and later assembled together at the construction site with help of a crane. Load bearing walls are composed of ceiling height elements of concrete. The joints can be connected either by wet or dry system. Facades are of pre-fabricated concrete elements, or prefabricate wood structure; different materials are applied from the outside (van Elk and Priemus,1971). Cavity wall system with internal prefab concrete elements and outside finished with diverse materials, or traditional cavity walls, are also found combined in this system. Non-structural walls are made of concrete panels or blocks. Floors are made of concrete elements with or without cavities.
Smit II. Structural walls are composed of concrete elements and facades are combined between concrete panels with external wood elements together with brickwork. The floor, as well as the roof, is made of wood. Non-structural walls are made of concrete panels. This system was mainly applied for single housing units (van Elk and Priemus, 1971).

>>>

ANNEX 4.2 **Non- traditional housing construction systems in the Netherlands:**

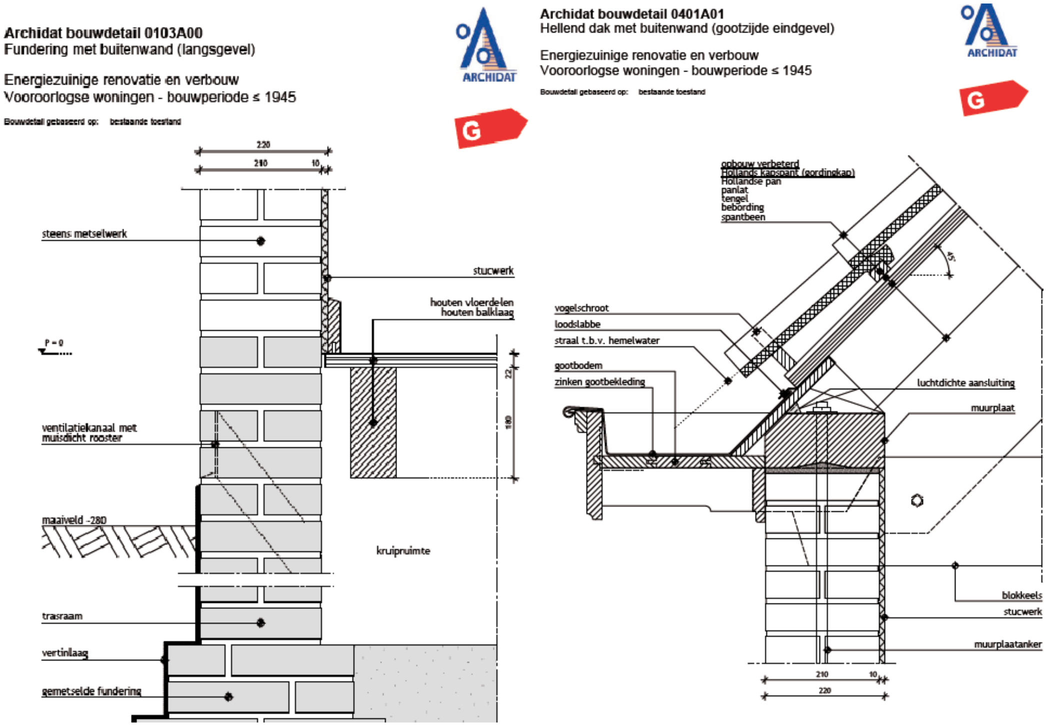
>>> Montagebouw

BMB. *Baksteen montage bouw*. Structural walls are of concrete elements. The outside facade is composed of mechanically applied brickwork elements (a mold covered with bricks and then covered in concrete). The inside panel is of grained concrete. For the non-structural components, lightweight autoclaved elements are used. Floors are prefabricated of reinforced concrete.

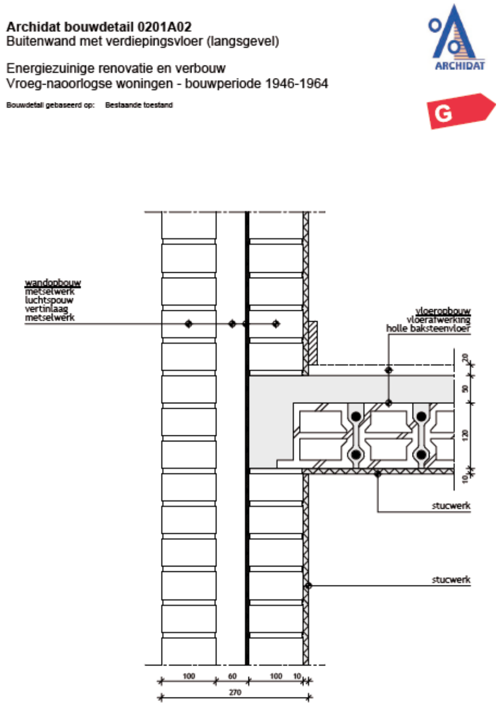
Rottinghuis. Walls are made of concrete ceiling height elements. Outside layer treated with brickwork, the cavity walls were not insulated. Floors were initially of ribbed structure with wood on top, later it changed for flat panels.

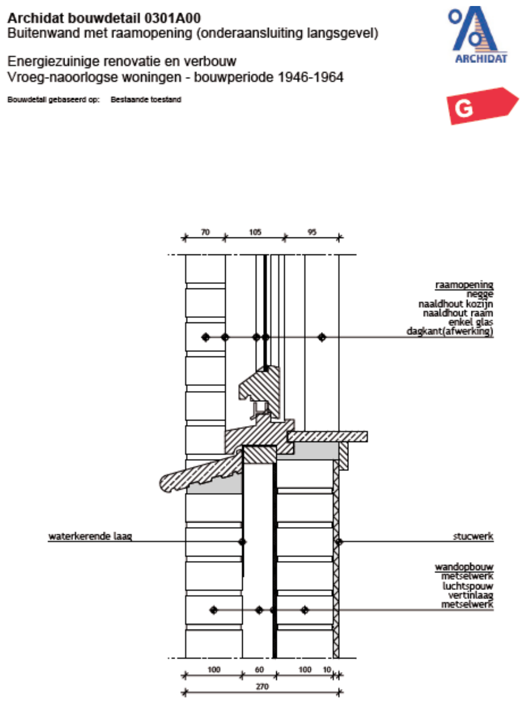
*Dura- Coigne*t. Usually found in mid height buildings between *portiek* and *galerij*. Walls and floors are of reinforced concrete. Non-structural walls are prefabricated panels. The facade elements are filled sandwich construction. Also the floors are prefab elements. Wood frames are casted in the concrete element.

ANNEX 4.3 **Constructive detail typical houses built before 1945 housing construction systems in the Netherlands**

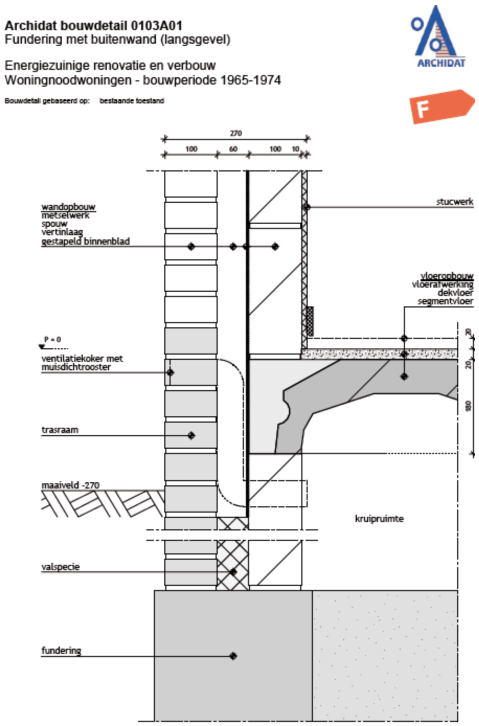


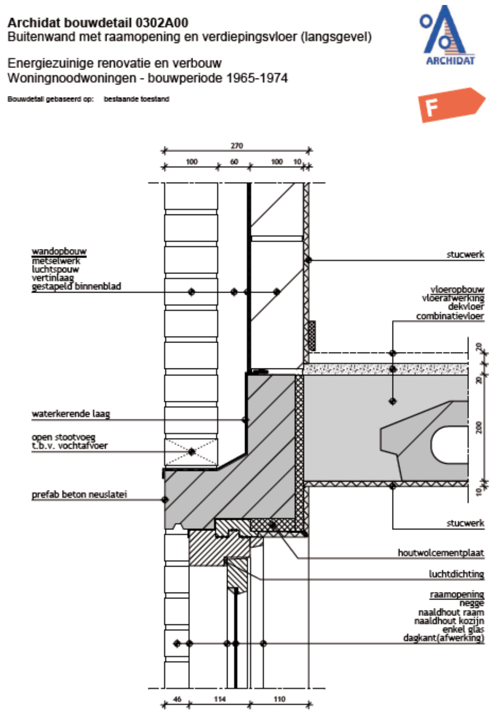
(Source: Fundering met buitenwand (langsgevel). Energiezuinige renovatie en verbouw Vooroorlogse woningen - bouwperiode ≤ 1945 pag 21 and Hellend dak met buitenwand (gootzijde eindgevel). Energiezuinige renovatie en verbouw Vooroorlogse woningen bouwperiode ≤ 1945 Page 22. Archidat, 2012.)



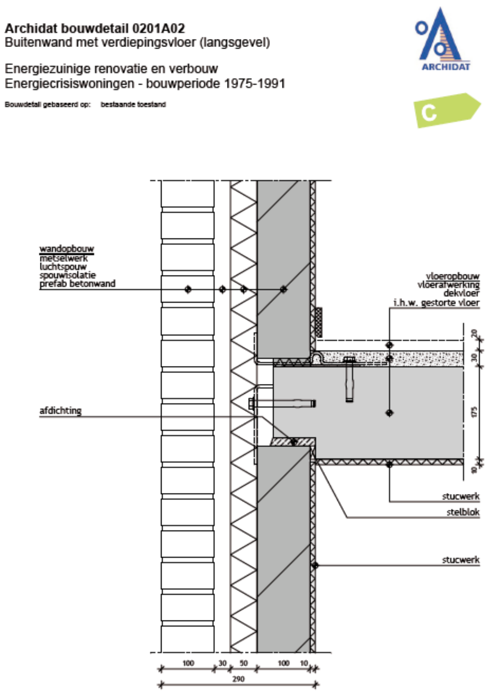


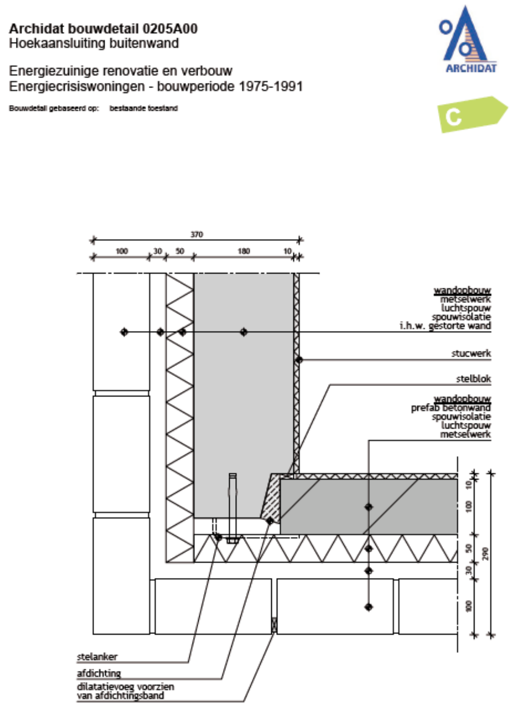
(Source: Archidat, 2012 pg. 28 and 30.)





(Source Archidat 2012 page 36 and 38.)





(Source: Archidat, 2012 page 44 and 46.)

LETTER

Research _ Building product reuse
Professor Han Brezet
Professor Arjan van Timmeren
Researcher Loriane Icibaci

In this research:
We are currently analyzing the dynamics of supply and demand of building materials in the housing construction system in the Netherlands.

Why?
In the future we will try to recover more and more materials from our cities and use them more efficiently. As such we will have to improve the way to design buildings, to develop building components, to improve material waste management and innovate at the material science level.

How:
We are analyzing building material consumption trends since 1900 to see how the biggest changes occurred and what were the immediate reasons related to these changes. Understanding the way we consume materials is extremely important to manage waste streams in short and long term future, both in quantitative and qualitative aspects.
The housing built stock today shows how we have been consuming materials and what were the factors that influenced these changes through time such as: demographics, consumer habits, policy, economics, technology and culture. Such trends will dictate demolition and renovation trends as they facts that are directly connected. With this questionnaire we want to have a clearer image of the existing material composition today in the housing stock in the Netherlands. The result will be compared to the demographics, economic and other factors listed above.

Future:
Material innovation is growing fast towards more environmental products. This will also change the way we will build and also deconstruct/ demolish.
Both environmental and economic forces will push companies to investigate more collaborative/ integrated solutions with fewer losses. In the era of Urban Mining, value of materials will increase and new "Symbiotic" opportunities should be explored.

You:
The relevance of this study for demolition companies is to access database that will help you to prepare future capacity. How much waste will be released and when? What are the material use trends for housing construction? In regard to policy, stepping up in the waste ladder _ from landfill to waste prevention _ is still the main goal. Technology and strategic integrated management will lead to new opportunities not yet fully explored.
We kindly ask you to dedicate a few minutes from your time to respond this questionnaire, which most of the questions are originated from standard demolition inventories that companies. The questionnaire is divided in 6 parts. The goal is detect bottlenecks for the future and how to improve building material management.
*The term REUSE here is part of the investigation originated from the EU Waste Framework Directive from 2008, where reuse should be reviewed in 2013 from all European member estates.

>>>

STEP 1: Choose at least five building groups from the combinations bellow to fill out questionnaire*:

1 Vrijstand

AB. Vrijstand woning (<1964)

C. Vrijstand woning (1965-1974)

D. Vrjstaandwoning 1975-1991

E. Vrjstaandwoning 1992-2005

** ex: 2 C= Vrijstand woning 1965-1974*

>>>

STEP 1: Choose at least five building groups from the combinations bellow to fill out questionnaire:

2. Twee onder 1 kap

AB. Twee onder 1 kap (<1964)

C. Twee onder 1 kap 1965-1974

D. Twee onder 1 kap 1975-1991

E. Twee onder 1 kap 1992-2005

> > >

ANNEX 4.7 **Questionnaire**

STEP 1: Choose at least five building groups from the combinations bellow to fill out questionnaire:

3. Rijwoning

A. Rijwoning (<1945)


B. Rijwoning (1946-1964)


C. Rijwoning (1965-1974)


D. Rijwoning (1975-1991)


E. Rijwoning (1992-2005)


>>>

STEP 1: Choose at least five building groups from the combinations bellow to fill out questionnaire:

4. Maisonnettewoning

AB. Maisonnettewoning (<1964)

C. Maisonnettewoning 1965-1974

D. Maisonnettewoning 1975-1991

E. Maisonnettewoning 1992-2005

>>>

STEP 1: Choose at least five building groups from the combinations bellow to fill out questionnaire:

5. Galerijwoning

AB. Galerijwoning (<1964)

C. Galerijwoning 1965-1974

D. Galerijwoning 1975-1991

E. Galerijwoning 1992-2005

>>>

TOC

STEP 1: Choose at least five building groups from the combinations bellow to fill out questionnaire:

6. Portiekwoning

A Portiekwoning (<1945)

6B. Portiekwoning (1946-1964)

6C. Portiekwoning (1965-1974)

6D. Portiekwoning (1975-1991)

6.E Portiekwoning (1992-2005)

>>>

TOC

STEP 1: Choose at least five building groups from the combinations bellow to fill out questionnaire:

7. Flatwoning

AB Flatwoning <1964

C Flatwoning 1965-1974

D Flatwoning (1975-1991)

E Flatwoning (1992-2005)

Images source: Agentschap Nl 2011

>>>

STEP 2: Questionnaire

1. Building

1.1

GROUP: ______________________________ BUILDING TYPE: ____

1.2

Building size to be demolished ___________________________________m2

(Floor area of all floors from the entire building_ including and common areas as garage, storage...)

Size of ONE unit house or apartment ______________________________m2

2. External envelope

2.1

External wall material____

Total amount to be demolished ___________(specify unit: kg or m2 or m3)

Internal wall material ____

Total amount to be demolished ___________(specify unit: kg or m2 or m3)

Insulation material ____

Total amount to be demolished ___________(specify unit: kg or m2 or m3)

Single wall facade?

☐ Yes ☐ No

Which material? ____

2.2

Could some of these components be deconstructed and REUSED? (please choose one option)

Which components? ____

☐ YES, EASY to deconstruct and POSSIBLE to REUSE components

☐ YES, but NOT SO EASY to deconstruct and SOME materials are possible to REUSE

☐ NOTHING could be REUSED. TOO DIFFICULT to deconstruct.

How much from the external envelope can be deconstructed for REUSE? _______________________________________

Ex. 10% of façade bricks; and 15% of bricks from internal wall and 70% of rock wool insulation could be recovered for reuse (in % of each total component group or in kg).

2.3

What do you do with these materials today after deconstruction? ____

2.4

If it is possible to REUSE some products, please estimate:

_______Men/ ________hour/ ________ m^2 or _______kg of building material type _________________________________

Ex. 1 men/ 2h/ 5m2 = 970kg of brick façade.

>>>

TOC

STEP 2: Questionnaire

3. Structure

3.1
Building structure material ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)

3.2
Could some of these components be deconstructed and REUSED? (please choose one option)
Which components? ____
☐ YES, EASY to deconstruct and POSSIBLE to REUSE components
☐ YES, but NOT SO EASY to deconstruct and SOME materials are possible to REUSE
☐ NOTHING could be REUSED. TOO DIFFICULT to deconstruct.
How much from the building structure can be deconstructed for REUSE? ____
Ex. 130% clay bricks 5% of concrete pre cast lintels from wall openings (in % of each total component group or in kg).

3.3
What do you do with this type of structural material today after deconstruction? ______________________________________

3.4
If it is possible to reuse some products, please estimate:
_______Men/ ________hour/ ________ m^2 or ________kg of building material type ______________________________

4. Floor

4.1
Which materials are used for the ground flooring construction system?
FloorStructurematerial____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)
Floor Finishing material ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)
Floor Insulation material ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)
Please describe floor construction system from upper floors ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)

4.2
Could some of these components be deconstructed and REUSED? (please choose one option)
Which components? ____
☐ YES, EASY to deconstruct and POSSIBLE to REUSE
☐ YES, but NOT SO EASY to deconstruct and SOME materials are possible to REUSE
☐ NOTHING could be REUSED. TOO DIFFICULT to deconstruct.
How much from the ground floor can be deconstructed for reuse? ____
Ex. 40% of wood from floor structure; 0% lose fill insulation; 80% from wood floor boards covering (in % of each total component group or in kg).
How much from the top floors can be deconstructed for reuse? ____
Ex. 40% of wood from floor structure; 70% from wood floor boards covering; 0% ceramic tiles (in % of each total component group or in kg).

4.3
What do you do with this type of floor system today after deconstruction? ____

4.4
If it is possible to reuse some products, please estimate:
_______Men/ ________hour/ ________ m^2 or ________kg of building material type ______________________________

>>>

STEP 2: Questionnaire

5. Roof

5.1
Which materials are used for the roof construction system?
Roof Structure____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)
Roof Cover ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)
Roof Insulation ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)

5.2
Could some of these components be deconstructed and REUSED? (please choose one option)
Which components? ____
☐ YES, EASY to deconstruct and POSSIBLE to REUSE
☐ YES, but NOT SO EASY to deconstruct and SOME materials are possible to be REUSED
☐ NOTHING could be REUSED. TOO DIFFICULT to deconstruct.
How much from the roof system can be deconstructed for reuse? ____
Ex. 40% of wood from roof structure; and 90% of roof tiles; 15% rigid insulation (in % of each total component group or in kg).

5.3
What do you do with this type of roof system today after deconstruction?

____

5.4
If it is possible to reuse some products, please estimate:
_______Men/ ________hour/ ________ m^2 or ________kg of building material type ________________________________

6. Internal walls

6.1
Which materials are used for the internal walls?
Type I ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)
Type II ____
Total amount to be demolished ___________(specify unit: kg or m^2 or m^3)
Others____

6.2
Could some of these components be recovered for REUSE, including wall studs if applicable? (Choose one option bellow)
Which components? ____
☐ YES, EASY to deconstruct and POSSIBLE to REUSE
☐ YES, but NOT SO EASY to deconstruct and SOME materials are possible to be REUSED
☐ NOTHING could be REUSED. TOO DIFFICULT to deconstruct.
How much from the internal walls can be deconstructed for REUSE? ____
Ex. 60% of wood from wall studs; and 10% of wall tiles; 10% Drywall panels (in % of each total component group or in kg).

6.3
What do you do with this type of wall components today after deconstruction? _______________________________________

6.4
If it is possible to reuse some products, please estimate:
_______Men/ ________hour/ ________ m^2 or ________kg of building material type ________________________________

>>>

STEP 2: Questionnaire

7. Doors and windows

7.1
What material are the windows, doors and frames from the facades_ _
Total amount to be demolished _ _ _ _ _ _ _ _ _ _ _(specify unit: kg or m^2 or m^3 or door in units)
Which glass type is used? (Please circle one or more options)
Single Double
Total amount to be demolished _ _ _ _ _ _ _ _ _ _ _(specify unit: kg or m^2 or m^3)

7.2
Could some of these components be deconstructed and REUSED? (please choose one option)
☐ YES, EASY to deconstruct and POSSIBLE to REUSE
☐ YES, but NOT SO EASY to deconstruct and SOME materials are possible to be REUSED
☐ NOTHING could be REUSED. TOO DIFFICULT to deconstruct.
Which components? _
How much from these windows, doors and frames can be deconstructed for REUSE? _
Ex. 10% of Vinyl frames; and 90% of wood windows; 100% wood doors (in % of each total component group or in kg).

7.3
What do you do with these materials today after deconstruction? _

7.4
If it is possible to reuse some products, please estimate:
_ _ _ _ _ _ _Men/ _ _ _ _ _ _ _ _hour/ _ _ _ _ _ _ _ _ m^2 or _ _ _ _ _ _ _ _kg of building material type _
General questions about reuse:
8. Most of concrete components are not disassembled, so they are demolished and mixed with other stony Bow and Sloop Afval. Could some pre cast concrete elements be deconstructed with certain facility in the projects you listed above. Could you name them?
Ex. Pre cast concrete staircases.../Concrete balustrade...etc.
9. Do you try to recover materials to resell them for reused material dealers and second hand products retailers?

>>>

STEP 3: Summary material inventory								
Building Group								
Type of material	What was in this building?		Amount of material recovered for reuse[1]		Level of difficulty to recover for REUSE			Destiny_ From construction site to... [3]
	Application	Mark a cross	% [2]	kg	High	Medium	Low	
Brick	Facade							
	Building Structure							
	Other use_ Specify:							
Wood (timber)	External Kozijn (doors and windows							
	Internal Kozijn (doors and windows							
	Building structure							
	Floor structure							
	Roof structure							
	Floor covering							
	Wood stud (framing for internal walls)							
	Other use_ Specify:							
Other wood products	Plywood_ Specify product:							
	Chipboard_ Specify product:							
Steel (and other metals)	Building structure							
	External doors and windows (kozijn)							
	Steel/ metal stud (framing for internal walls)							
	Aluminum frames (kozijn)							
	Other use_ Specify:							
Plastic	Windows and doors							
	Piping							
	Wall covering							
	Floor covering							
	Polystyrene insulation (insulation boards)							
	Other use_ Specify:							

>>>

STEP 3: Summary material inventory								
Building Group								
Type of material	What was in this building?		Amount of material recovered for reuse[1]		Level of difficulty to recover for REUSE			Destiny_ From construction site to... [3]
	Application	Mark a cross	% [2]	kg	High	Medium	Low	
Ceramic	Roof tiles							
	Wall/ floor tiles							
	Bathroom fixtures							
	Other use_ Specify:							
Concrete	Roof tile							
	Any other pre cast product (specify):							
Glass	Single							
	Double							
Gypsum	Drywall panels							
Linoleum								

1 Example: Reuse means that the component can be used again in a new project without recycling.
2 Example: 70% of the total façade
3 Example: Scrap metal facility

ANNEX 4.8 **Average disassembly result of 450 average homes demolition excluding structure (Bouwcarrousel bv, Rob Gort, 2005)**

COMPONENTS RECLAIMED	AMOUNT AVAILABLE PER HOUSE (UNITS)	SUITABLE FOR REUSE (%)
wc met stortbak, valpijp, manchet	1	50
wastafel met kraan en sifon (excl. valpijp)	1.5	80
spiegel	1	40
planchet (vzv geen plastic)	0.2	40
fontein met sifon (excl. valpijp)	0.5	80
fonteinkraan (uitgegaan is van op was-bakje gemonteerde kraan)	0.5	90
douchekop en slang	1	40
douchekraan	1	90
glijstang of ophangoog	0.7	50
zeepbakje (vzv geen plastic)	0.3	60
wasmachinekraan	1	80
gaskraan	1	75
kastplanken van inbouwkasten, voorzover uit triplex of massief hout of mdf	3	60
cv-ketel of gashaard of geiser bouwjaar 1996 of nieuwer	0.5	50
bijbehorende rookgasafvoer, muurdoor-voer	1	50
drukvat	0.5	60
keukenblok onderkastjes	3.5	50
aanrechtblad	1	50
keukenkraan (uitgegaan is van op het blad gemonteerde kraan)	1	90
bovenkastje keuken	3	50
frontjes van keukenkastjes (indien com-plete kastjes of blokken ongeschikt zijn voor hergebruik)	6	20
binnendeur paneel of opdek of board	12	25
achterdeur, hout	1	40
binnendeurkozijn, massief hout	12	10
rolhorren bij ramen of deuren	0.5	30
vensterbanken, voorzover massief hout of werzalit (en geen asbest eronder)	0.5	70
jaloezien vzv metaal of hout	0.5	70
wasmachineschakelaar	1	80
wcd's en lichtschakelaars, opbouw	18	25
trekschakelaars voor verlichting	2	75
lichtarmaturen voorzover in goede staat	1	60

>>>

ANNEX 4.8 **Average disassembly result of 450 average homes demolition excluding structure (Bouwcarrousel bv, Rob Gort, 2005)**

COMPONENTS RECLAIMED	AMOUNT AVAILABLE PER HOUSE (UNITS)	SUITABLE FOR REUSE (%)
buitenarmaturen (gang, centraal trap-penhuis)	0.75	80
centrale toegangsdeuren (per etage en op bg)	0.1	70
voordeur	1	70
deur van berging in kelder en/of op balkon of in thuin	1.5	30
openslaand raam met beslag	4	60
renovatiekozijn (kunststof)	0.6	50
losse ruiten dubbel glas voorzover intact (als kozijn incompleet)	0.3	90
trapleuning	1.2	50
radiator plus knop	7	50
groepenkast	1	70
deurbelinstallatie	1	50
houten vloerdelen in m2	10	60
houten balkjes (uit binnenwandjes e.d.) in m	4	50

ANNEX 4.9 **Inventory of reusable material from a gallery flat complex in the Netherlands***

PRODUCTS	AMOUNT AVAILABLE PER HOUSE (UNITS)	AVERAGE FOR REUSE (%)
Aanrechtblad, rvs, diverse lengtes	1	50%
Radiator plus knop, dverse afmetingen en diktes	7	50%
Binnendeur, papier-of handboard, afmetingen vaak 78X 201 cm, inclusief slot maar vaak zonder hendels en sleutels	6	40%
Binnendeur, houten panelen, afmetingen 78X 201 cm, inclusief slot maar vaak zonder hendels en sleutels	3	60%
Voordeur, multiplex of naaldhout, vaak met ruitje, 82-94 cm breed en 200-216 cm hoog	1	70%
Keukenblok, kastjes en laden van Bruynzeel, 60cm diep, 90cm hoog, 150-200cm breed	1	50%
Keukenkastje (boven) van spaanplaat, vaak Bruynzeel, 32cm diep, 50cm breed, 58cm hoog	3	40%
Pui/raam, enkel/ dubbel glas, kozijn PVC of hout	10m3	50%
Wc-pot, meestaal Sphinx standard, wit keramiek, zonder storbak	1	50%
Wastafel, meestaal Sphinx standard, wit keramiek, met kraan en sifon	1.5	60%

** Adapted from Bouwcarroussel, No- Flat Future, VROM, Utrecht, 2007.*

ANNEX 4.10 **Reference of cascade reuse cases. Study cases that support findings described in Business model 3***

These cases are depicted to emphasize two major innovative aspects: highly integrated production chain and serial production. Alternatively from Patel (2010), who has calculated financial benefits in the case of commercialization of reused structural steel for the low end, these cases focus on product development based on initial low cost retrieved components from demolition and deconstruction that later targets the high-end market. Here the integration of the chain not only minimizes financial losses but distributes profits and benefits along the same chain, strengthening the structure to reinvest in technology, skills, marketing, storage, transportation and workforce[1]. Most importantly, investments can go back to deconstruction, where more materials can be harvested. Patel (2010) also recognizes that the integration of the chain is a condition for the model to compensate the costs in each step. During the interviews there was no consensus on which steps of the chain have the highest potential for losses between transportation and workforce. Nonetheless, the challenge of remanufacturing products in the Netherlands was economically interesting enough that companies have evolved in this segment despite the economic downturn.

Serial production demands understanding of flows of materials and components able feed continuous manufacture. Although seasonal[2], flows of reused components can also be partially replaced by new ones when necessary. Continuous production also decreases the need for storage and related costs[3]. Continuity in the market of reused building components is a challenge hampering commercial growth and consequently an incentive to deconstruct and reuse (Hurley et al., 2002). Serial (re)manufacture presents an alternative in this context as demonstrated in the subsequent cases.

Remanufacture (as illustrated in the cases 'a", "b" and "c") does not solely rely on the DIY market for retail of reused building components. Remanufacture offers finished products to be offered to general consumers just as the traditional "off-the-shelf". Even components that had no, or negative, value for reclaim, can be given a value through creative thinking[4]. Hence, more materials could be deconstructed and "transformed" for consumption.

>>>

ANNEX 4.10 **Reference of cascade reuse cases. Study cases that support findings described in Business model 3***

a. Trek-in cabin

van der Grinten

The cabin comprises an average of 80% reused material including: wood facade, "I" frames in the walls, wall studs, doors transformed as internal wall panels, EPS and mineral wool insulation, wood used for internal finishing, flooring and furniture and electric sockets (FIGURES 3 and 4). When in shortage of reused components, new materials, or other reused components with similar technical performance, were also applied. However, unavailability of reused components was not a barrier for the Trek-in experiment. This cabin project is in its second phase of development where costs and time for construction (200 hours less) are being minimized. Tim van der Grinter, as one of the students from the team that brought the Trek-in cabin design together, considered that the construction process could be reduced to 150 hours less when the full-industrialized scale is in place. In his analyses, costs related to workforce and transportation are the most important to be controlled. Material costs are average one third cheaper than new ones. Comparing to a standard industrial manufacturing of a new product where each component is provided by a different supplier; here the supplier is the demolition company that collects materials from different sources.

In this experiment design proves to be able to add value to the final product justifying deconstruction and production steps including logistics and profits. In a competitive market as the building demolition sector in the Netherlands, it is not uncommon that companies look for adapting their activities, as well as combining demolition and sorting or demolition and/or recycling. In this case the new step is product development and retail.

>>>

b. Stavne

University of Science and Technology, Trondheim, Norway and the GAIA group

Stavne is a building component designed with reclaimed wood. It was developed by the University of Science and Technology, Trondheim, Norway together with the GAIA group (Nordby at al., 2009). The product brings several benefits such as environmental improvements through optimizing local waste streams, flexible constructability and is a user-friendly building component inspired by local construction systems. Wood waste flow in Norway is important and is mainly cost free, however a major barrier in the project was the cost of labor (a general burden in Europe) to manufacture Stavne[5], making it difficult to compete with new constructive systems in the same category. In this case, adding value was limited to the point that it did not justify investments needed for (re) manufacture. Hence, not all types of products designed and (re) manufactured from reused components will allow flexibility for cost adjustments necessary to be marketable.

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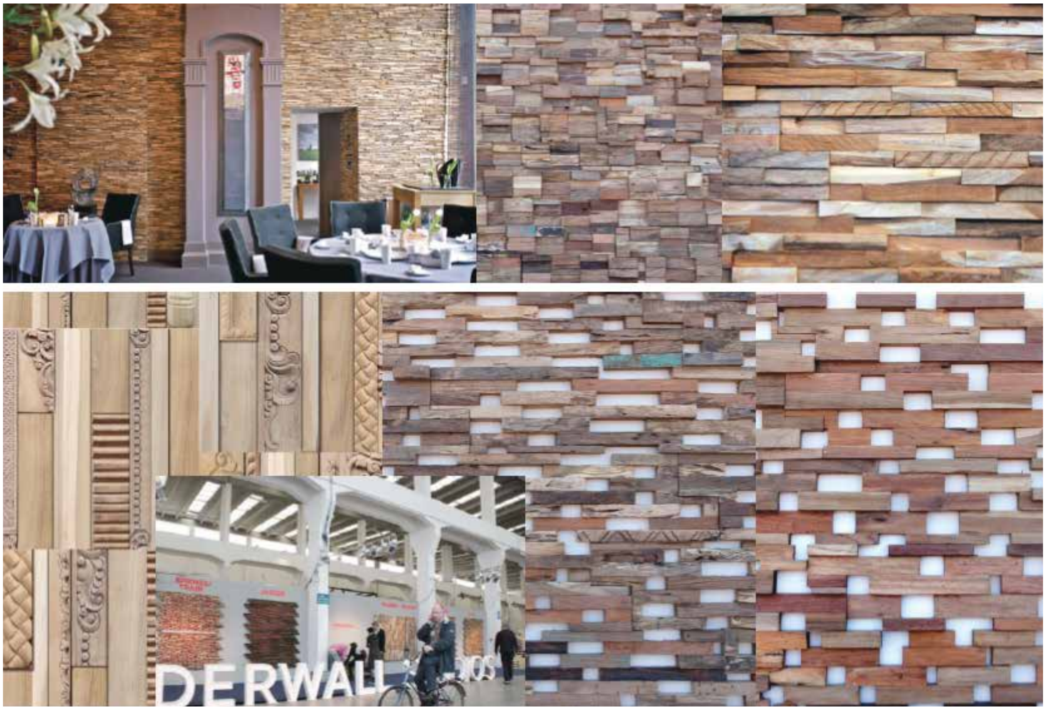
TOC

c. Wonderwall



www.wonderwallstudios.com

Wonderwall has been a successful project in the Netherlands[6]. As with Trek-in, this is another experiment to provide design solutions able to integrate reused components into a serial production of a new product, in this case wall finishing panels. Although the components were not directly derived from demolition waste, Wonderwall emerged in the construction market with the goal to deviate wasted wood from incineration in Indonesia. Even though the production requires intense manual labor (in Indonesia), the product focused on the high-end market with export activities to several countries. Similar examples of this approach were found in the United States where reused wood is a common waste stream from buildings[7]. Shami (2008) identifies that remanufacture is a relevant way for adding value to wood where the final quality of the product supports the means to deconstruct and final profit margins.

>>>

d. Restoric, Oude bouwmaterialen

Jan van Ijken *Oude Bouwmaterialen, Emmnes*

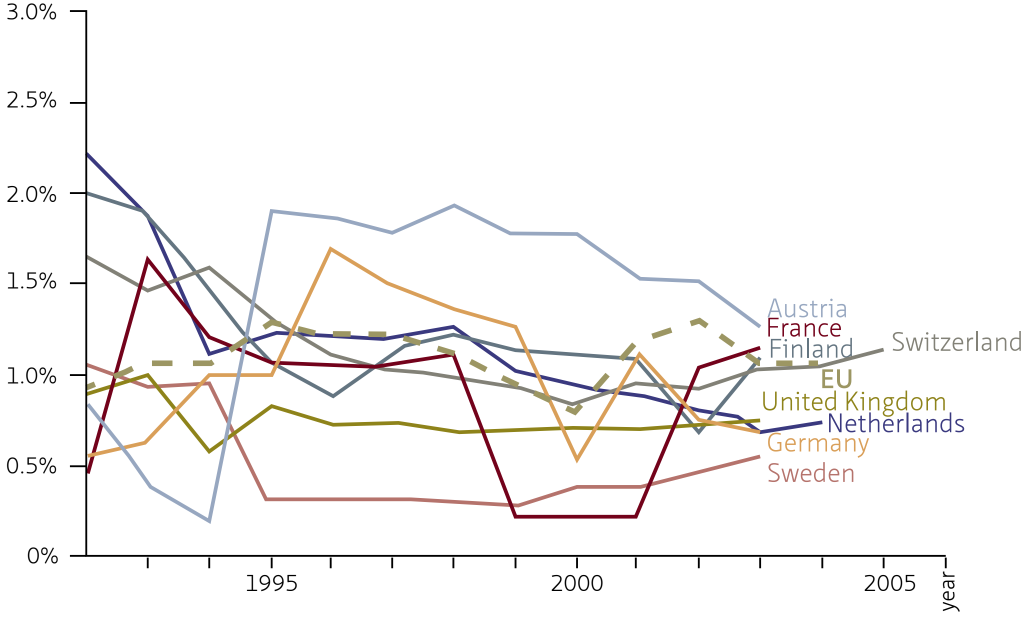
Schijf Group, Amsterdam

Oude bouwmaterialen is a stripping company that focuses on retail of products more expensive than new ones, but for a small margin. It is currently the largest operation in the Netherlands in construction reclaim components for reuse. Although it is still active in marketing multiple products, from bricks, tiles, fences, staircases, wooden structures and flooring, doors, etc., it has evolved into exploring product development with a strong design identity and an elaborated interface with users by setting up a showroom display and on-line advertisement. Most of the remanufactured products are furniture-based design.
Restoric is part of the Schijf group that includes demolition, transporting and most recently sorting of C&D waste (Figure D).
It has also long been active in reclaiming and retailing reused components. With time, this activity came to a slow decay until recently with the implementation of product development from reused building parts. These three companies (van Liempd, *Oude bouwmaterialen* and Schiff) have so far seen positive results in this type of entrepreneurship.

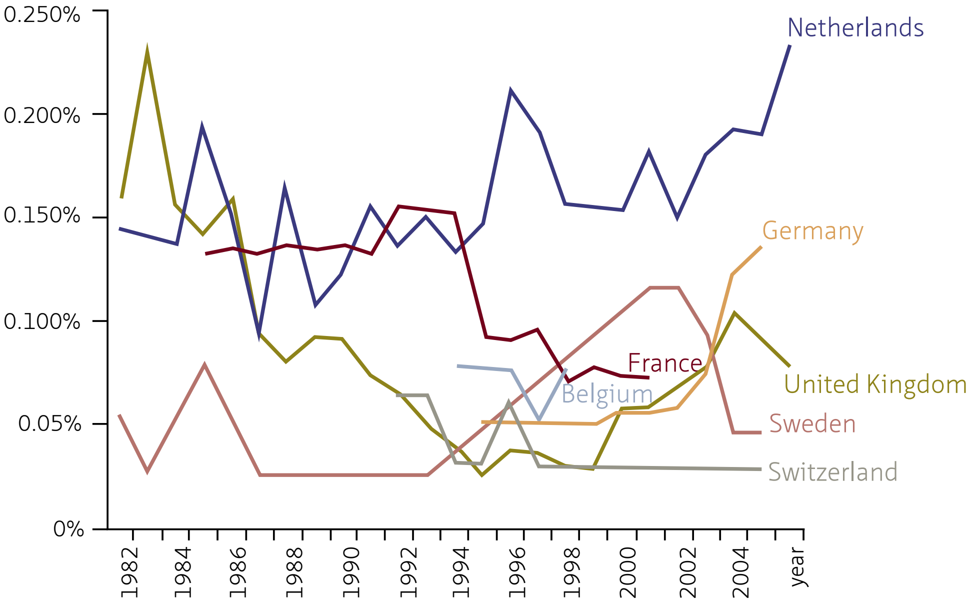
1 *Interview with Robert Barclay (van Liempd)*
2 *Interview with Tristan Frese (Restoric)*
3 *Interview with Lisanne Addink-Dölle,VerdraaidGoed!, 2012*
4 *Interview with Robert Barclay (van Liempd) talking about old electric sockets as an example.*
5 *Email from A.S. Nordby*
6 *Interview with Jan Swinkels (founder of Wonderwall)*
7 *E.g viridianwood.com/ and Kireiusa.com*

** except in the case of Stavne, the information collected was derived from interviews)*

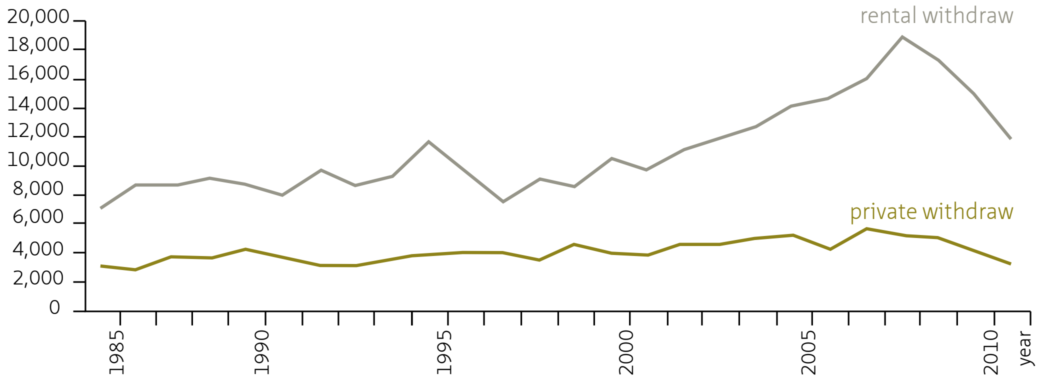
ANNEX 6.1 **Annual construction rate as % of the total housing stock (Itard et al., 2008)**



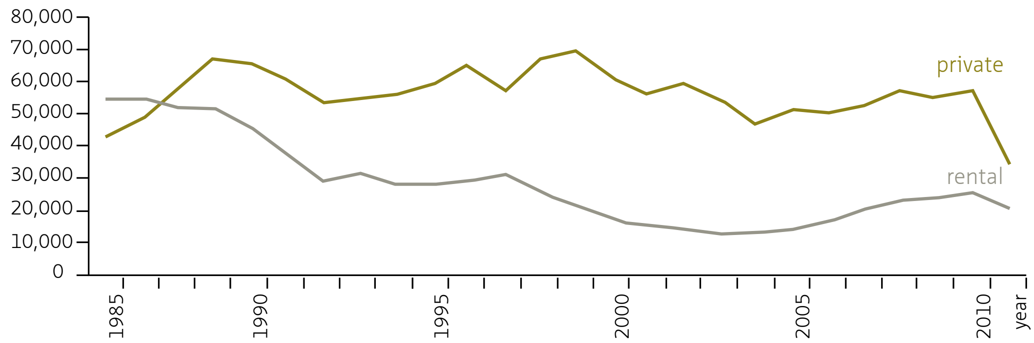
ANNEX 6.2 **Annual demolition rates as % of the housing stock (Itard, I. et al., 2008)**



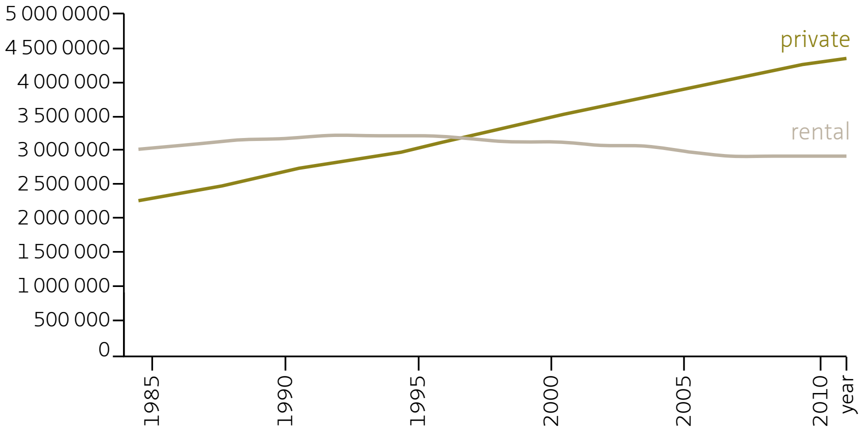
ANNEX 6.3 **Housing withdraw in the Netherlands by tenancy 1985-2009 (absolute numbers) (ABF Research, Syswov)**



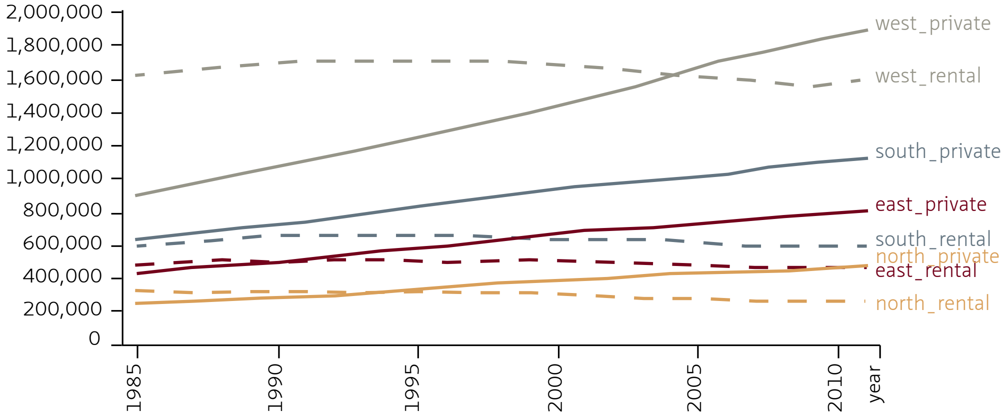
ANNEX 6.4 **Yearly new housing construction by tenancy (absolute numbers) (ABF Research, Syswov)**



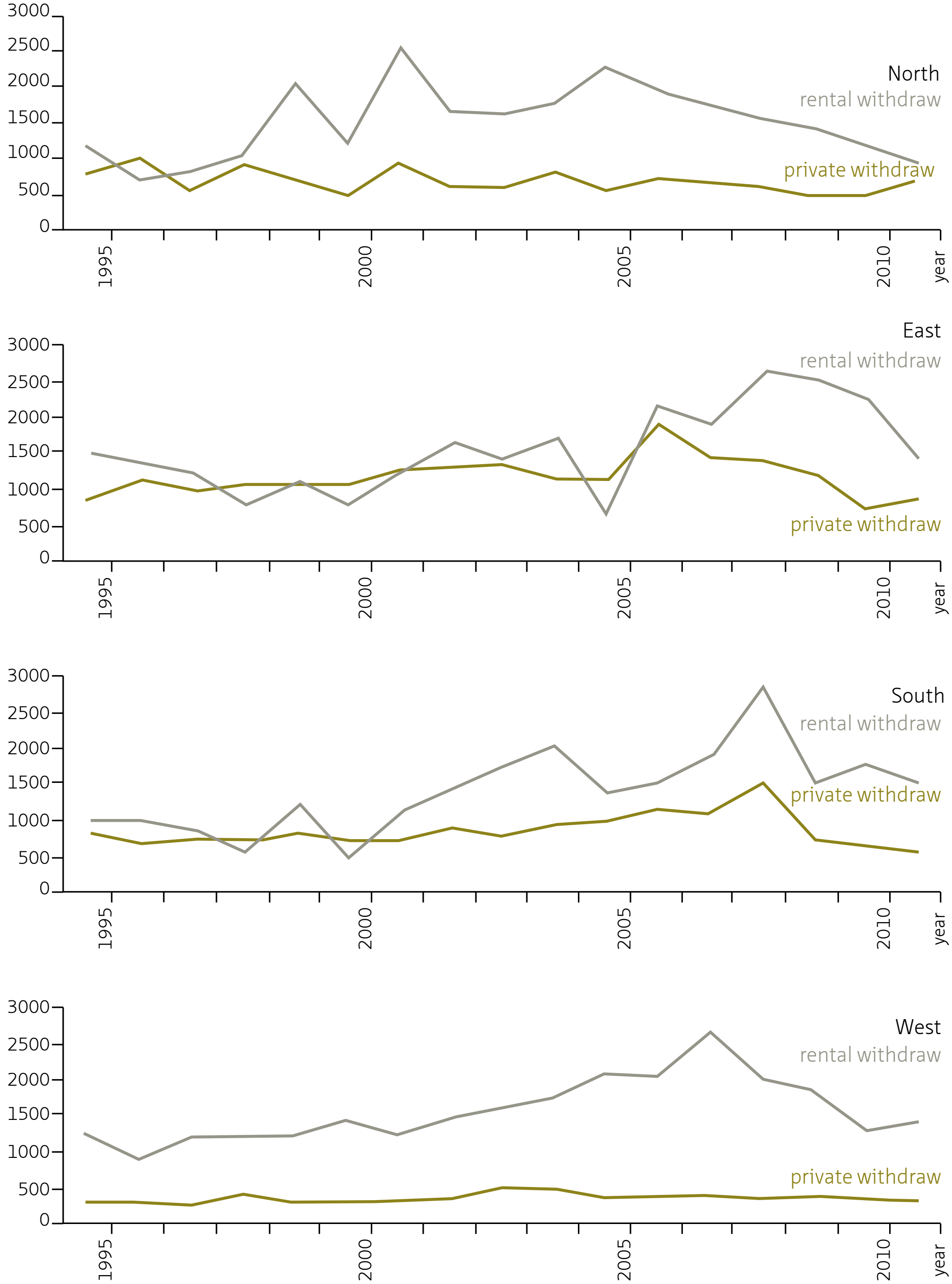
ANNEX 6.5 **Evolution of stock according to tenancy (absolute numbers) (ABF Research, Syswov)**



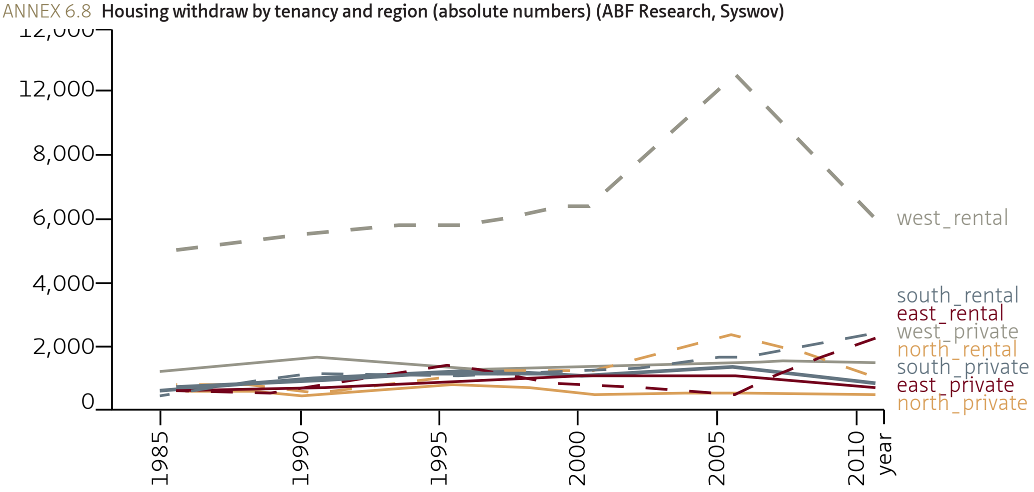
ANNEX 6.6 **Stock evolution by tenancy and region (absolute numbers) (ABF Research, Syswov)**



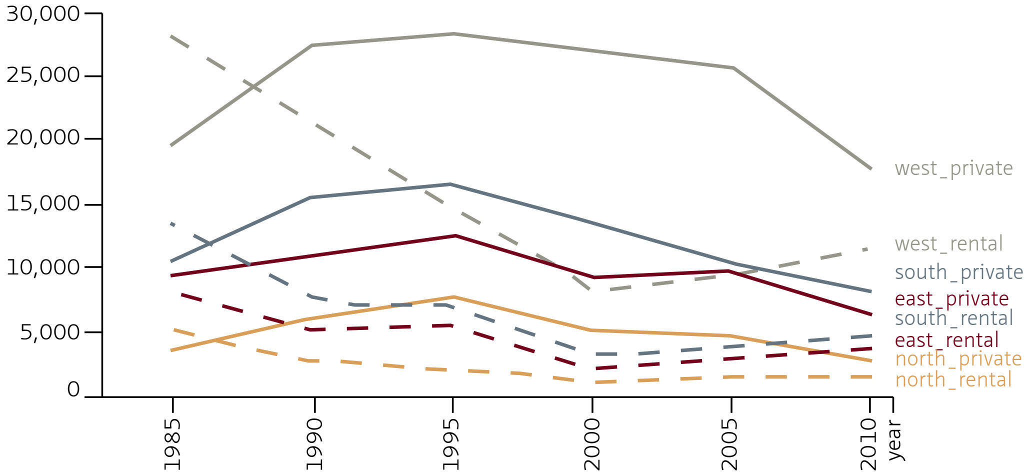
ANNEX 6.7 Withdraws by tenancy by region (CBS)



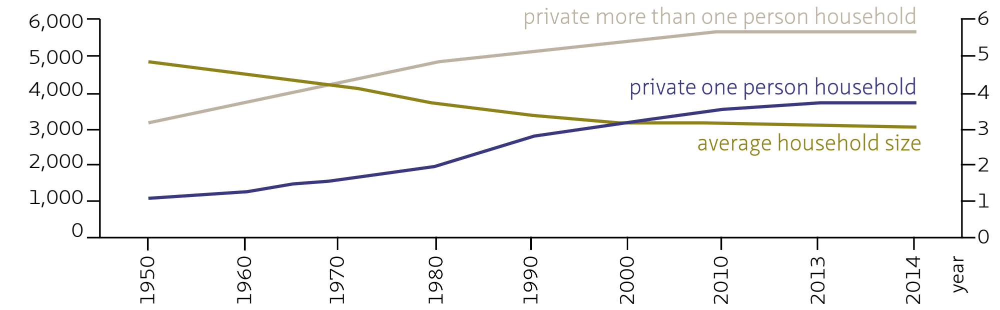
ANNEX 6.8 **Housing withdraw by tenancy and region (absolute numbers) (ABF Research, Syswov)**



ANNEX 6.9 **New added houses by tenancy and region (absolute numbers)(ABF Research, Syswov)**



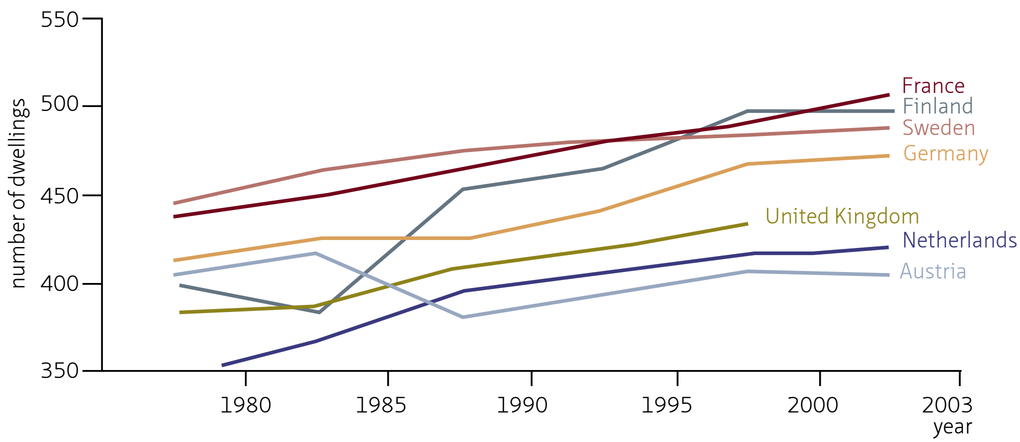
ANNEX 6.10 **Evolution of household in the Netherlands (left axis household numbers X1000, right axis number of people per household) (CBS)**



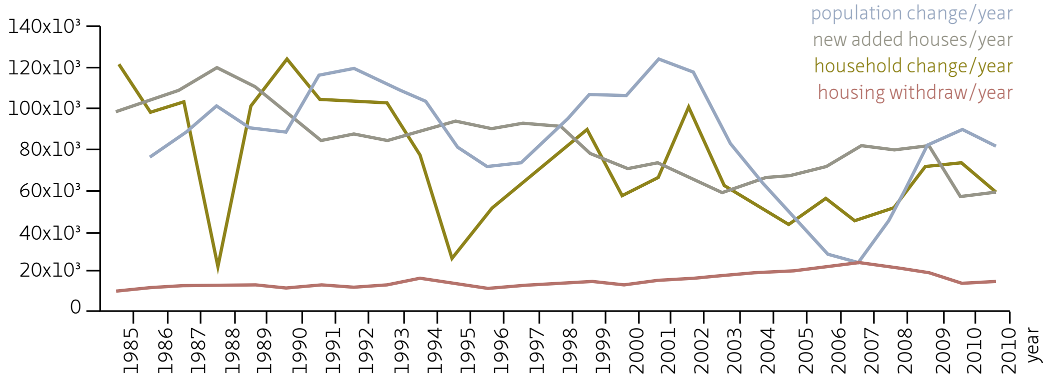
ANNEX 6.11 **Average household in private house (CBS)**

1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2011	2012	2013
3.71	3.56	3.45	3.21	2.95	2.78	2.54	2.42	2.35	2.3	2.27	2.22	2.21	2.2	2.19

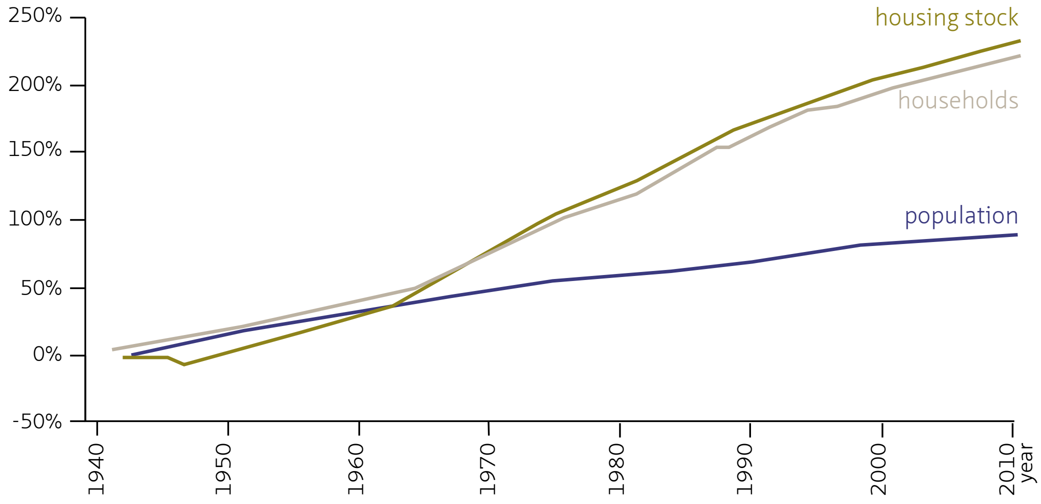
ANNEX 6.12 **Evolution of the number of dwellings per 1000 inhabitants (Itard, I. et al., 2008)**



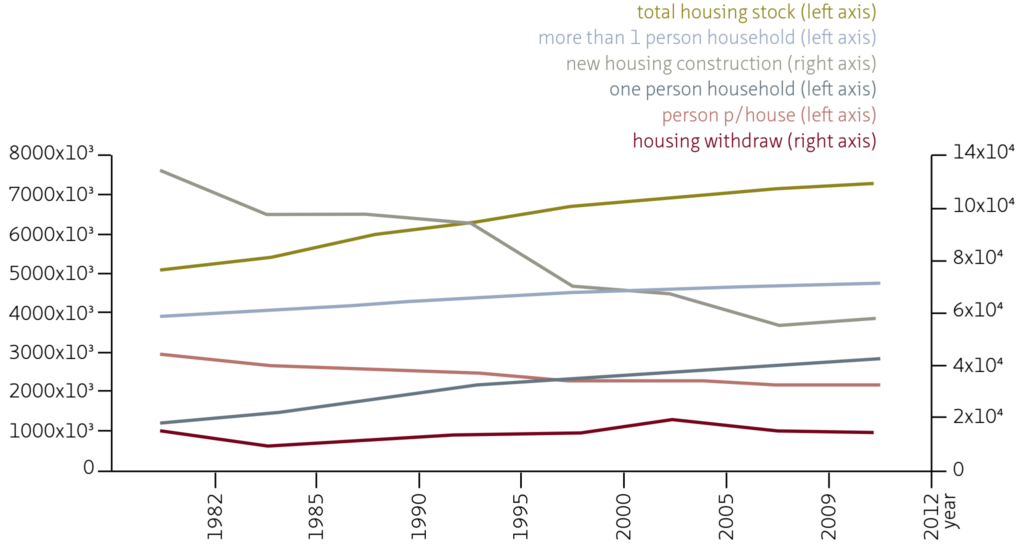
ANNEX 6.13 **Yearly housing withdraws, yearly new added houses compared with yearly population changes*, yearly household changes** (absolute numbers) (CBS)**



ANNEX 6.14 **Population, housing stock and total number of private households since 1940 in % growth (CBS)**



ANNEX 6.15 **Yearly housing stock evolution changes with household groups (CBS)**



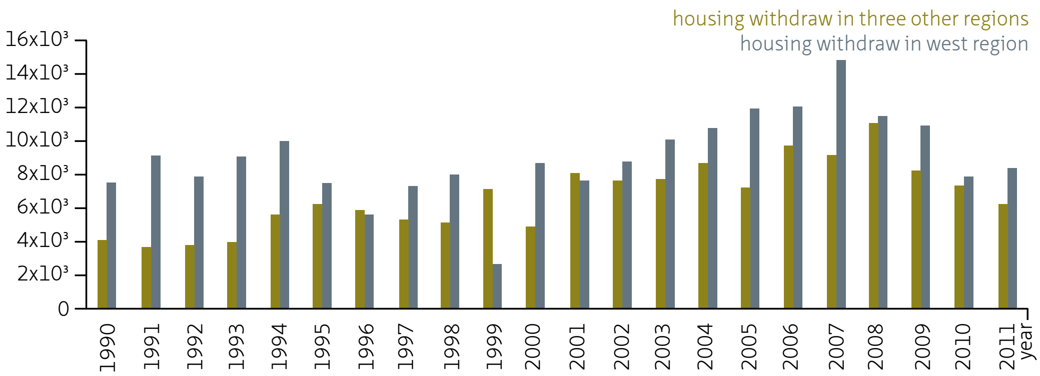
ANNEX 6.16 **Share householders according to composition in three types of areas in the country in 2010 (in %) (CBS)**

CITY			
	One person household (%)	Household without children (%)	Household with children (%)
2000	46.3	26.0	27.8
2004	46.8	25.2	28.0
2006	47.4	24.7	27.9
2008	47.6	24.7	27.7
RURAL			
	One person household (%)	Household without children (%)	Household with children (%)
2000	27.2	32.4	40.4
2004	28.4	31.9	39.7
2006	29.0	31.8	39.2
2008	29.7	31.8	38.5
OTHER AREAS			
	One person household (%)	Household without children (%)	Household with children (%)
2000	26.4	32.7	40.9
2004	27.8	32.4	39.9
2006	28.5	32.4	39.2
2008	29.2	32.6	38.3

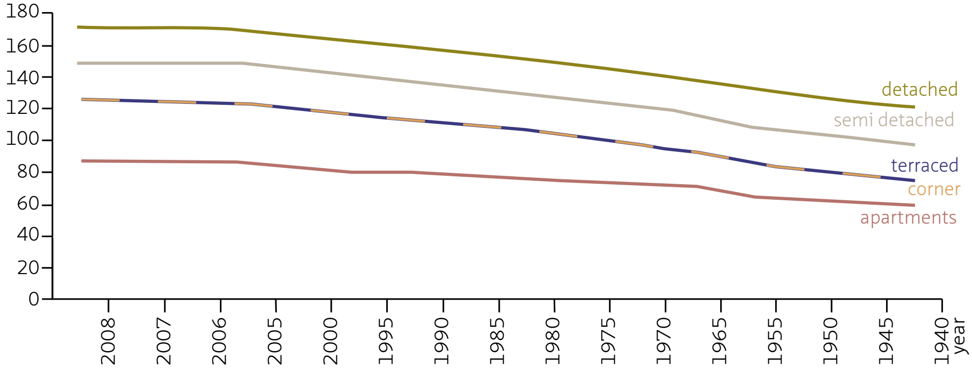
ANNEX 6.17 **Household growth compared to housing stock growth between 2000 and 2014 by region (CBS)**

REGION	Household growth 2 categories (%) (2000-2014)		Household growth total (%) (2000-2014)	Amount of households (2014)	Total housing stock growth (%)	Population growth (%) (2000-2014)
North	1 person household	25%	10%	289 604	7%	3.6%
	More than 1 person household	3%		493 819		
East	1 person household	29%	14%	509 555	11%	7.4%
	More than 1 person household	7%		1 018 076		
West	1 person household	18%	11%	1 451 971	10%	7.5%
	More than 1 person household	7%		2 218 338		
South	1 person household	33%	11%	552 722	9%	2.9%

ANNEX 6.18 **Housing withdraws in West compared to 3 other regions together (CBS)**



ANNEX 6.19 **The average used living surface in m² of Dutch households (Schoonvelde, 2010)**



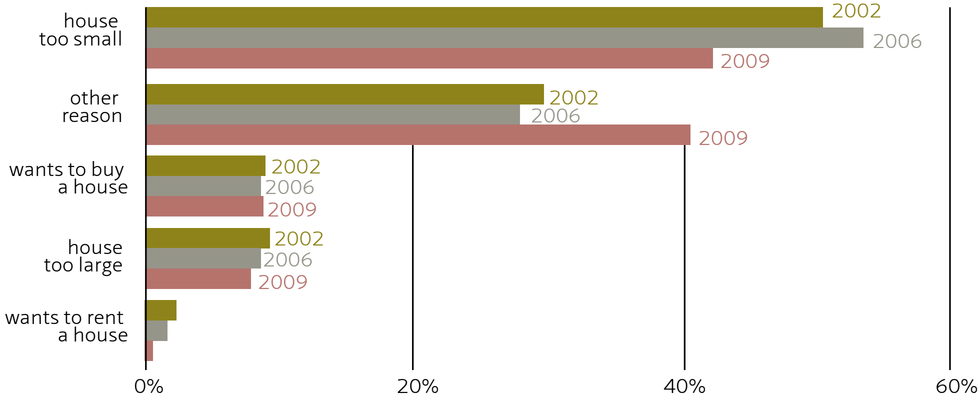
ANNEX 6.20 **Typical housing plans in the Netherlands through time (de Lange, 2011)**

YEAR	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
AGE	40	44	48	52	56	60	64	68	72	76
Plan typology										
Housing surface	40	50	60	65	75	80	90	95	100	110
Persons / house	8	7	6	5	4.5	4	3.5	3	2.5	2
Surface p/person	5	7	10	13	16	20	26	3	40	55

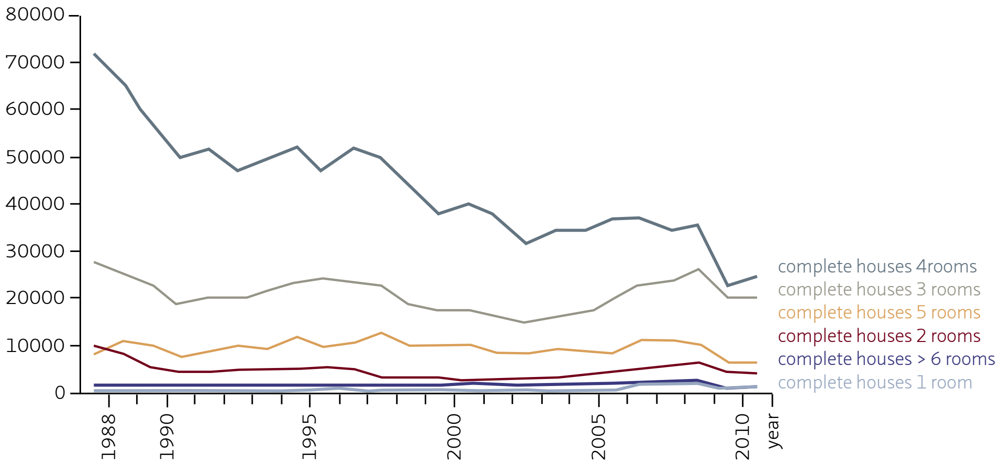
ANNEX 6.21 **Surface per house according to construction year (m²) (Rijksoverheid, 2009)**

Average square meter	<1945	1945-1959	1960-1969	1970-1979	1980-1989	1990-1999	>2000
Single family	148	121	126	140	133	153	162
Multi family	79	70	75	74	71	82	90

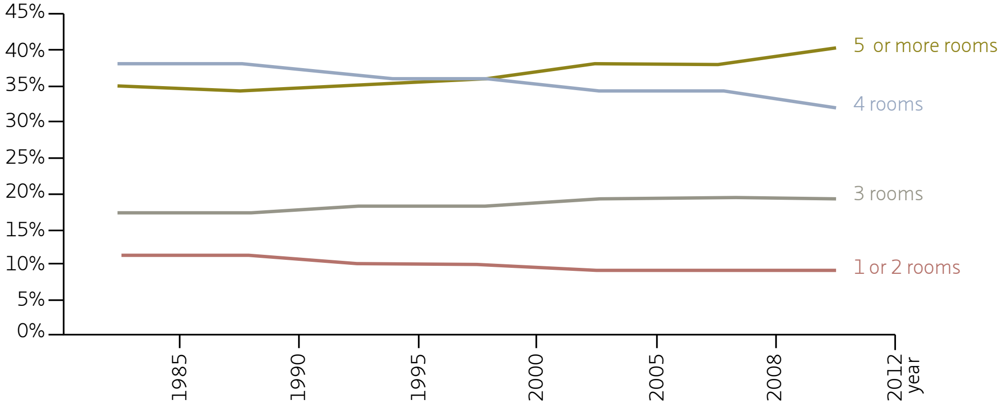
ANNEX 6.22 **Main reasons to move to another house 2002-2009 in percentage (Blijie et al., 2009)**



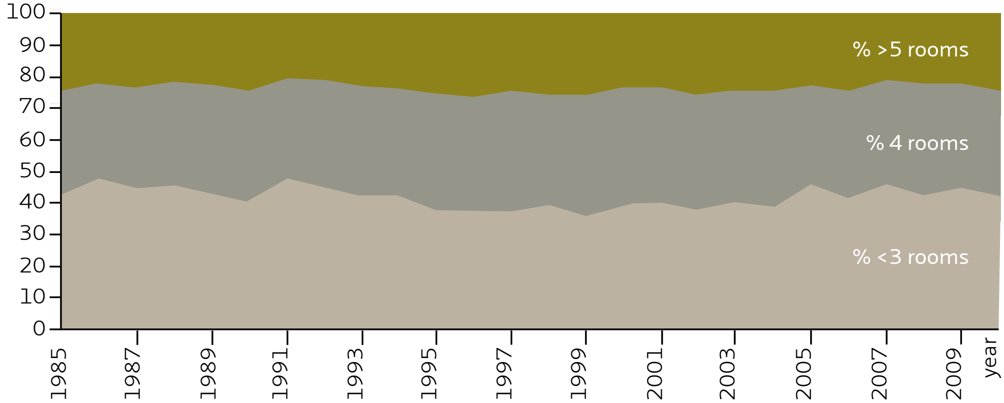
ANNEX 6.23 **New completed houses by number of rooms (CBS)**



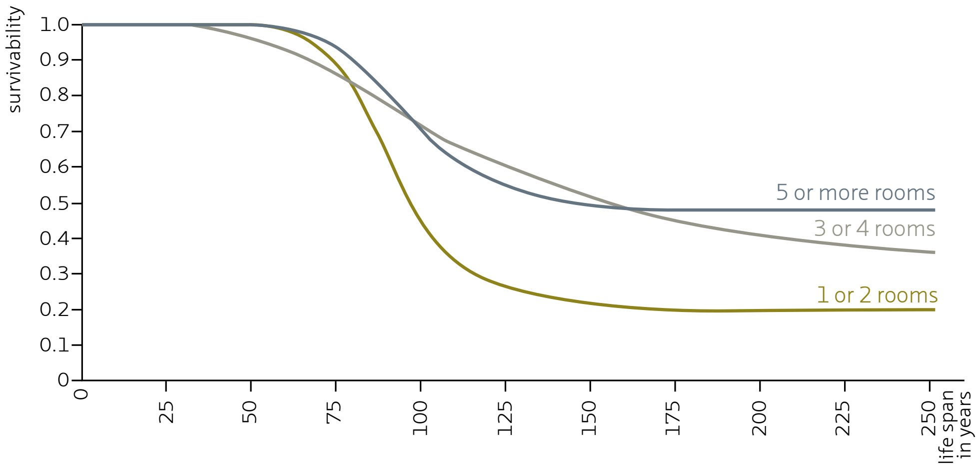
ANNEX 6.24 **Housing stock evolution by size (in %) (ABF Research, Syswov)**



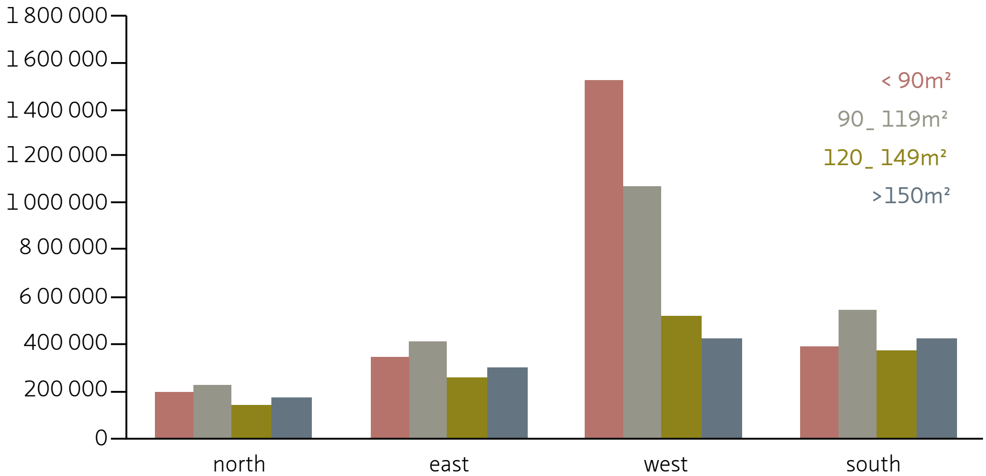
ANNEX 6.25 **Housing withdraw according to house size (in %) (ABF Research, Syswov)**



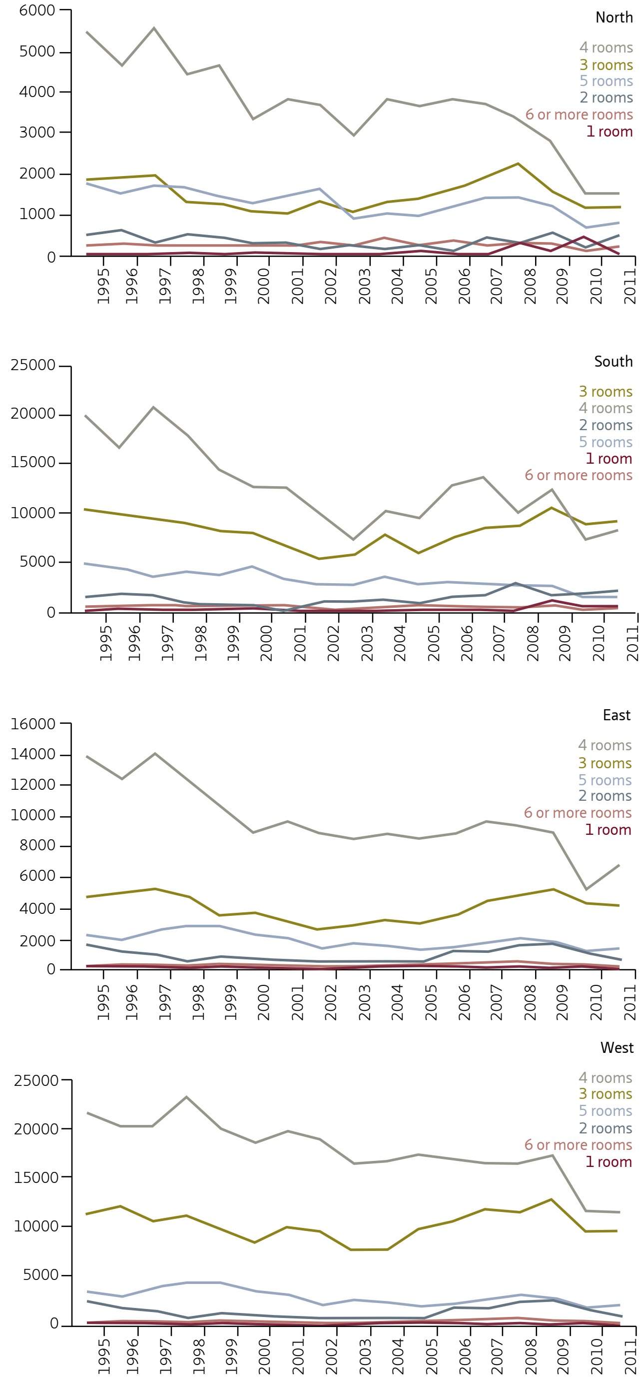
ANNEX 6.26 **Life span of buildings according to size of houses (survivability %/year) (Hoogers et al., 2004)**



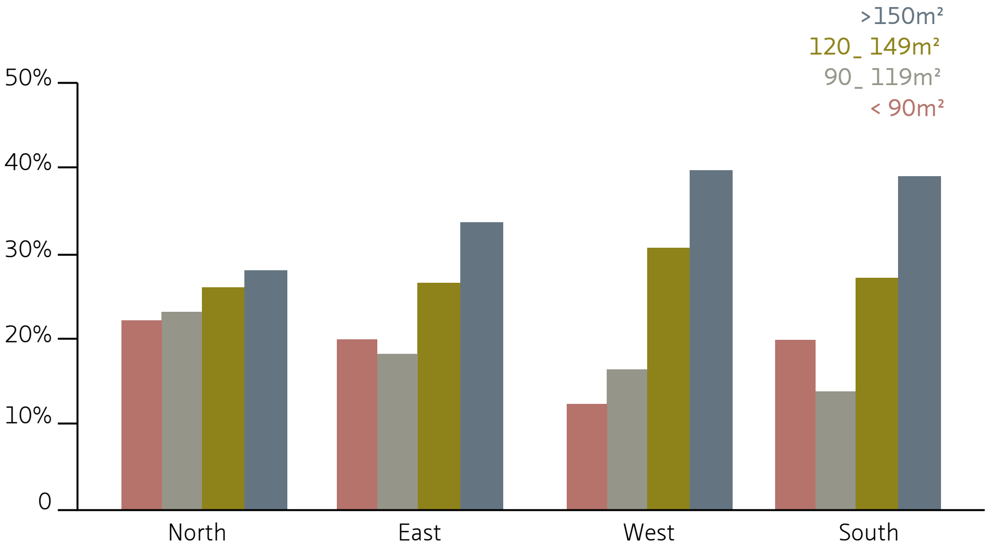
ANNEX 6.27 **Housing stock according to house surface in 2013 (m²) (ABF Research, Syswov)**



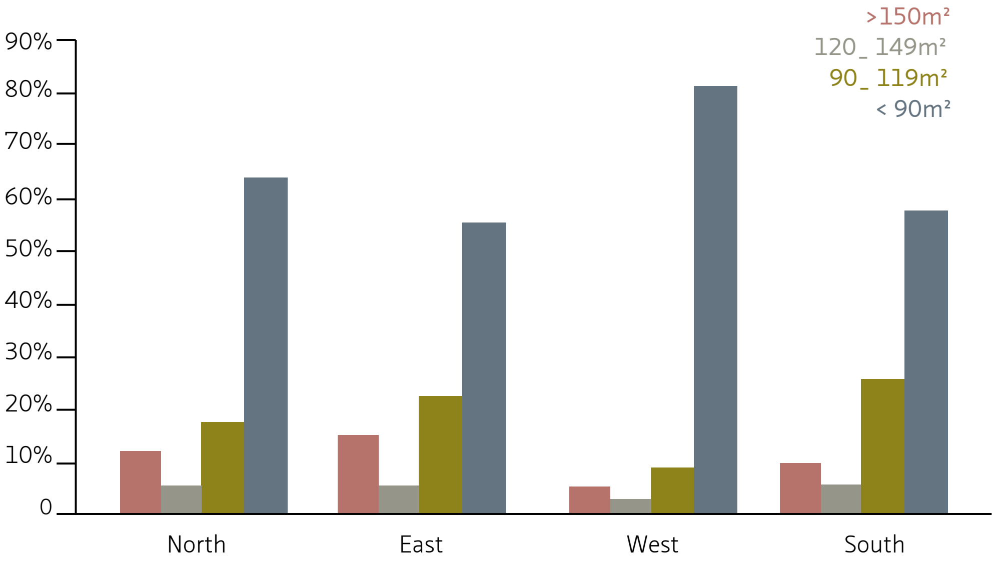
ANNEX 6.28 **Yearly new added houses by number of rooms by region (absolute numbers) (CBS)**



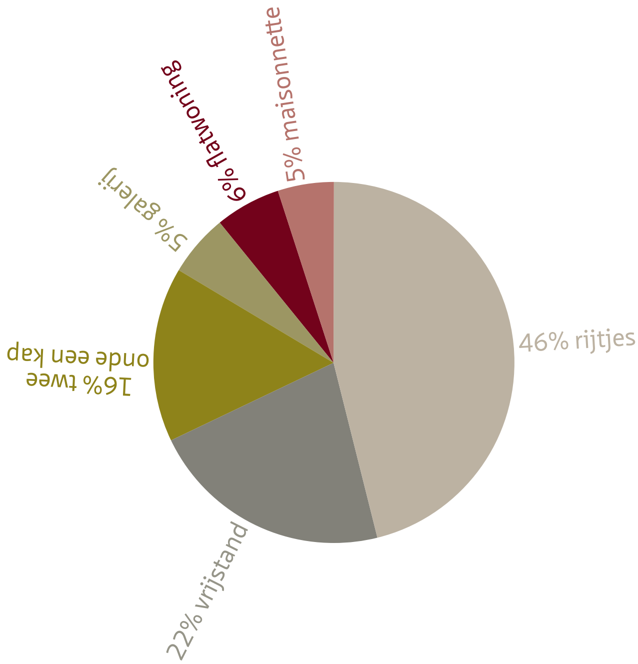
ANNEX 6.29 **New added houses according to house size and location in 2012 (in %) (ABF Research, Syswov)**



ANNEX 6.30 **Housing withdraw in % according to location and size in 2012 (in %) (ABF Research, Syswov)**



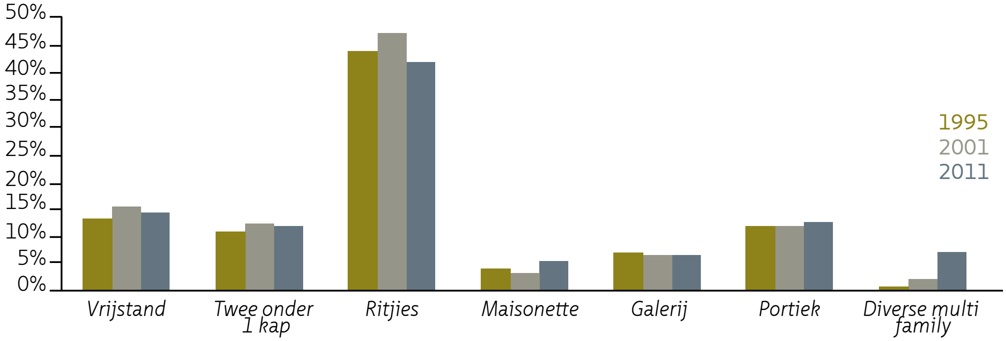
ANNEX 6.31 **Share of housing typologies in the stock (m²)(Agentschap Nl, 2011[c])**



ANNEX 6.32 **Housing stock evolution by typology (in %) (ABF Research, Syswov)**

	1985	1990	1995	2000	2005	2010	2011	2012
Stock multi-family [%]	30.3	29.7	29.3	29.1	28.9	29.1	29.2	29.3
Stock single-family [%]	69.7	70.3	70.7	70.9	71.1	70.9	70.8	70.7

ANNEX 6.33 **Share of housing typologies as ratio of total stock (in %) (Novem, 2001; Agentschap Nl, 2011[c])**



ANNEX 6.34 **Comparative data according to building typology, construction year and tenancy**

2001 [1]	2007 [2]	2011 [3]	STOCK MUTATIONS	TENURE [3]
Population:15 863 950 (CBS)	Population:16 357 992 (CBS)	Population:16 655 799 (CBS)		
Eurostat: GDP p capita 134. Real GDP growth rate 3,9%	Eurostat: GDP p capita 132. Real GDP growth rate 3,2%	Eurostat: GDP p capita 131. Real GDP growth rate 1,5%		
CBS Stock: 6.589.662 Newly built: 70.650 Withdraw:13 528	CBS Stock:6 967 046 Newly built: 80.193 Withdraw: 23.840	CBS Stock:7 217 803. Newly built: 57. 703 Withdraw: 14 467		Private Social Rental Private Rental
Vrijstand				
before 1966	before 1966	before 1964		
500.000/ 8%	513.000 8%	441.000 6,5%	11.8% withdraw rate in 10 years or average 1.18% per year.	P 91% SR 1% PR 8%
1966 -1988	1966 -1988	1965- 1991		
325.000/ 5,3%	295.000 4,3%	340.000 5,1% (1965- 1988: 286.692)	9.2%% withdraw in 6 years or 1.53% per year.	+/- P 95% +/- PR 5%
after 1988	1989-2000	1992- 2005		
137.500/ 2,2%	204.000 3,2%	178.000 2,6%	No demolition rate	P 96% PR 4%
Twee o e Kap				
before 1966	before 1966	before 1964		
380.000/ 6%	393.000/ 6%	285.000 6,5%	25% withdraw rate in 10 years or average 2.5% per year.	P 84% SR 10% PR 6%
1966 -1988	1966 -1988	1965 -1991		
280.000/ 4,5%	301.000/ 4,6%	366.000/ 5,4%	No demolition rate	+/- P 87% +/- SR 9% +/- PR 4%
post 1988	1989 -2000	1992 -2005		
104.500/1,7%	125.000/ 2%	173.000/2,6%	No demolition rate	P 95% SR 2% PR 3%
Maisonnette				
before 1966	before 1966	before 1964		
230.000/ 3,5%	203.000/ 3%	226.000/3,3%	11.7% withdraw rate in 6 years or 1.95% per year	P 29% SR 44% PR 27%
	1966-1988	1965-1991		
	94.000/ 1,4%	116.000/ 1,7%	No demolition rate	+/- P 70% +/-SR 11% +/-PR 19%
	1989-2000	1992-2005		
	19.000/ 0,3%	40.000/0,6%	No demolition rate	P 39% SR 44% PR 17%

>>>

ANNEX 6.34 **Comparative data according to building typology, construction year and tenancy**

2001 [1]	2007 [2]	2011 [3]	STOCK MUTATIONS	TENURE [3]
Rijtjes				
< 1946	< 1946	< 1945		
600.000/ 9,5%	501.000/ 7,5%	523.000/ 7,7%	16.5% withdraw rate from the stock in 6 years or 2.75% per year	P 71% SR 23% PR 6%
1946 -1965	1946 -1965	1946 -1964		
735.000/ 12%	669.000/ 10%	478.000/7%	31.3% withdraw rate from the stock in 10 years or 3.13% per year	P 40% SR 57% PR 3%
1966 -1976	1966 -1975	1965 -1974		
650.000/ 10,5%	654.000/10%	606.000/9%	No demolition rate	P 47% SR 47% PR 6%
1976 -1980	1976 -1979	1975 -1991		
230. 000/ 3,5%	165.000/ 2,5%	879.000/12,9%	4.3% withdraw rate from the stock in 6 years or 0.72% per year	P 61% SR 34% PR 5%
1980 -1988	1980 -1988			
540.000/ 8,7%	469.000/ 7%		13.1% withdraw in 6 years or 2.18% per year	
post 1988	1989 -2000	1992 -2005		
198.000/3,1%	328.000/ 5%	353.000/5,2%	8.9% withdraw rate from the stock in 4 years or 2.2% per year	P 78% SR 19% PR 3%
Galerij				
Before 1966	before 1966	before 1964		
125.000/ 2%	112.000/ 1,7%	69.000/1%	43.2% withdraw rate from the stock in 10 years or 4.32% per year	P 33% SR 56% PR 11%
1966-1988	1966-1988	1965-1991		
240.000/ 3,9%	208.000/ 3,2%	283.000/4,2%	13.3% withdraw in 6 years or 2.2% per year.	+/-P 16% +/-SR 69% +/-PR 14%
na 1988	1989-2000	1992-2005		
55.000/0,9%	108.000/ 1,6%	113.000/1,7%	105% increase in 10 years or 10.5% per year	P 34% SR 59% PR 8%

>>>

ANNEX 6.34 **Comparative data according to building typology, construction year and tenancy**

2001 [1]	2007 [2]	2011 [3]	STOCK MUTATIONS	TENURE [3]
Portiek				
before 1966	before 1966	before 1964		
490.000/ 8%	458.000/ 7%	523.000/7,7%	6.5% withdraw in 6 years or 1.1% per year	P 23% SR 37% PR 40%
1966 -1988	1966 -1988	1965-1991		
175.000/ 2,8%	179.000/ 2,7%	254.000/3,8%	No demolition rate	+/-P 17% +/-SR 71% +/-PR 12%
post 1988	1989-2000	1992-2005		
55.000/0.9%	93.000/ 1,4%	70.000/1%	27% increase in 10 years or 2.7% per year	P 33% SR 62% PR 4%
Flat				
1966 -1988	1966 -1988	1965-1991		
150.000/ 2,4%	202.000/ 3,1%	250.000/3,6%	No demolition rate	+/-P 19% +/-SR 63 % +/-PR 18 %
	1989 -2000	1992-2005		
	72.000/ 1,1%	136.000/2%	89% increase in 4 years or 22.5% per year	P 33% SR 62% PR 4%

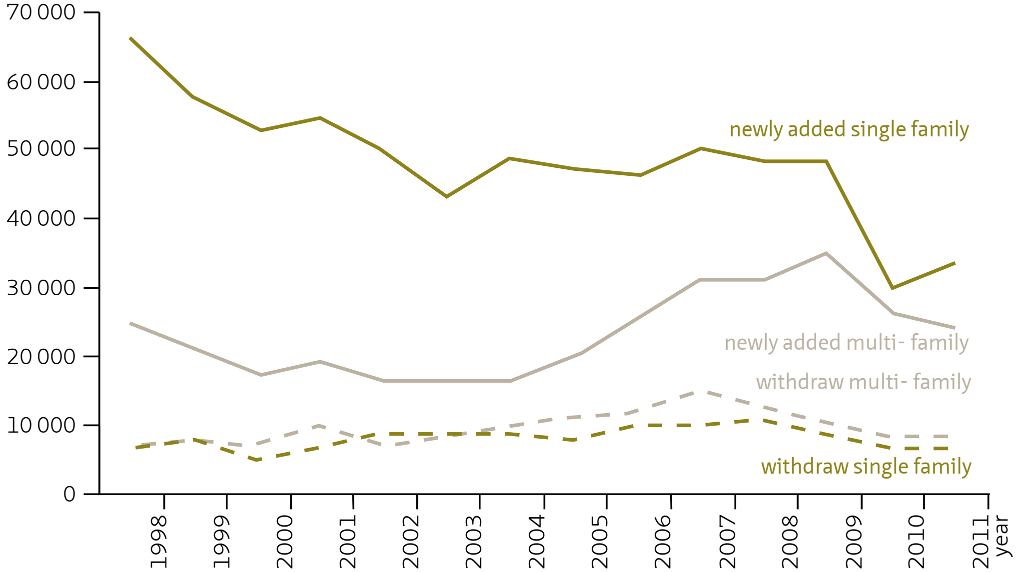
** Red text indicates where disparities occur when comparing three data sources (e.g. housing stock of houses built before 1966 increased rather than decreased between 2011 and 2007).*

[1] Novem (2001). "Referentiewoningen bestaande bouw." CE, Delft, The Netherlands.

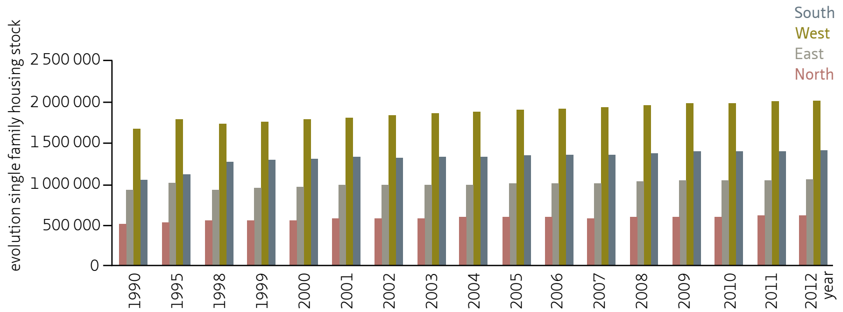
[2] Stenternovem (2007). "Voorbeeldwoningen bestaande bouw 2007 ".Ministerie van Economische Zaken. Publicatie, (2KPWB0618).

[3] Agentschap, Nl. (2011)c. Voorbeeldwoningen 2011, Onderzoeksverantwoording. Energie en Klimaat, Sittard.

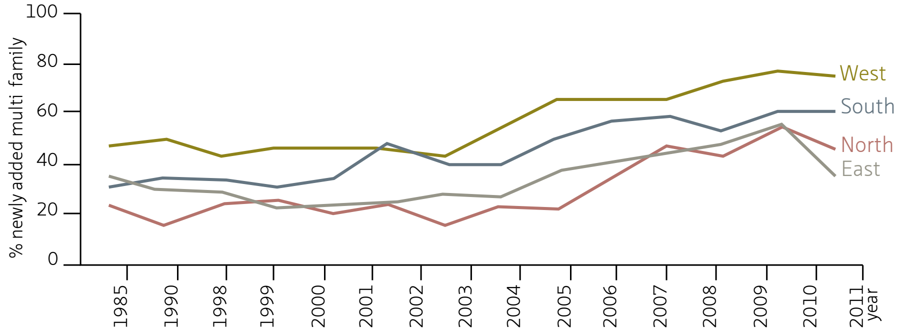
ANNEX 6.35 **New added houses and housing withdraw according to typology (absolute numbers) (ABF Research, Syswov)**

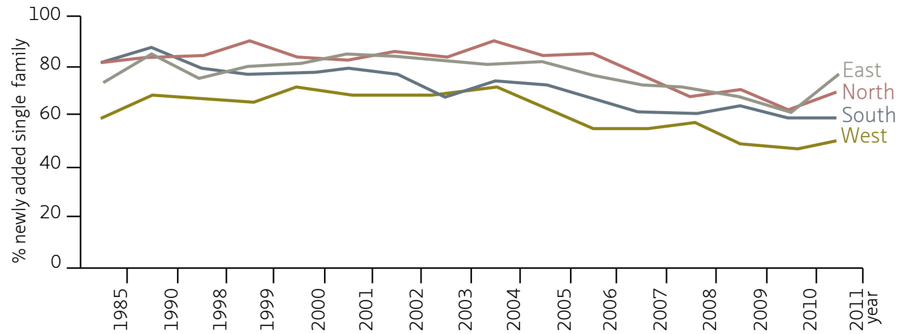


ANNEX 6.36 **Evolution of multi- family (top) and single-family (bottom) housing stocks according to region (absolute numbers) (ABF Research, Syswov)**



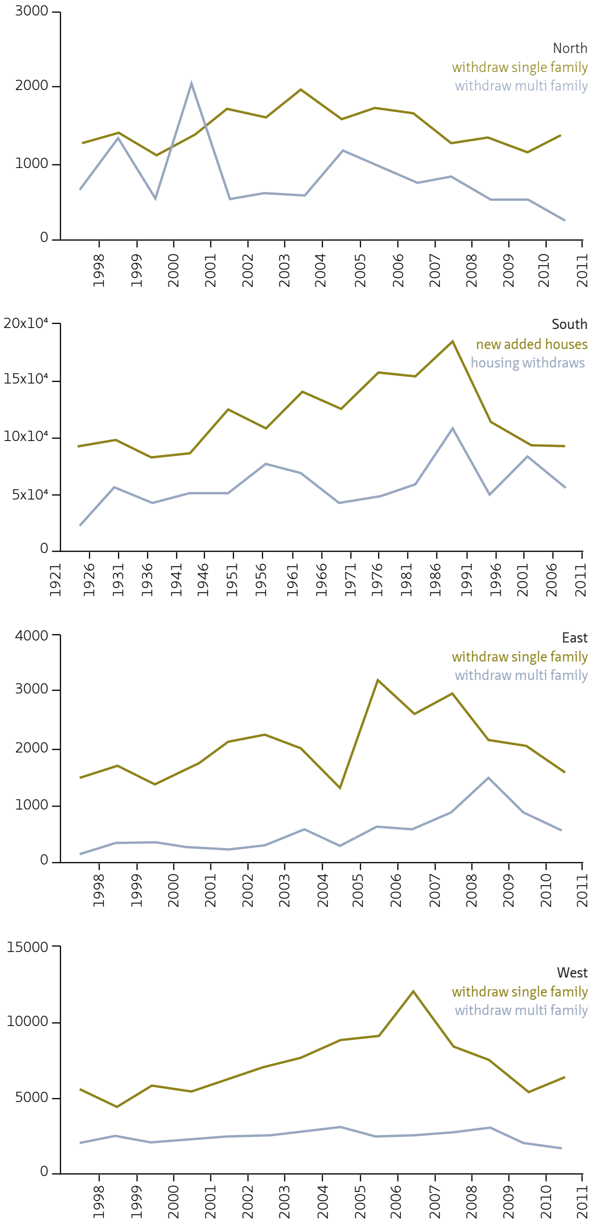
ANNEX 6.37 **New added houses by typology (percentages of all yearly added houses in each region) in the stock by region (ABF Research, Syswov)**





ANNEX 6.38 **Yearly new added houses by type and region (absolute numbers) (ABF Research, Syswov)**

ANNEX 6.39 **Yearly housing withdraws by type and region (absolute numbers) (ABF Research, Syswov)**



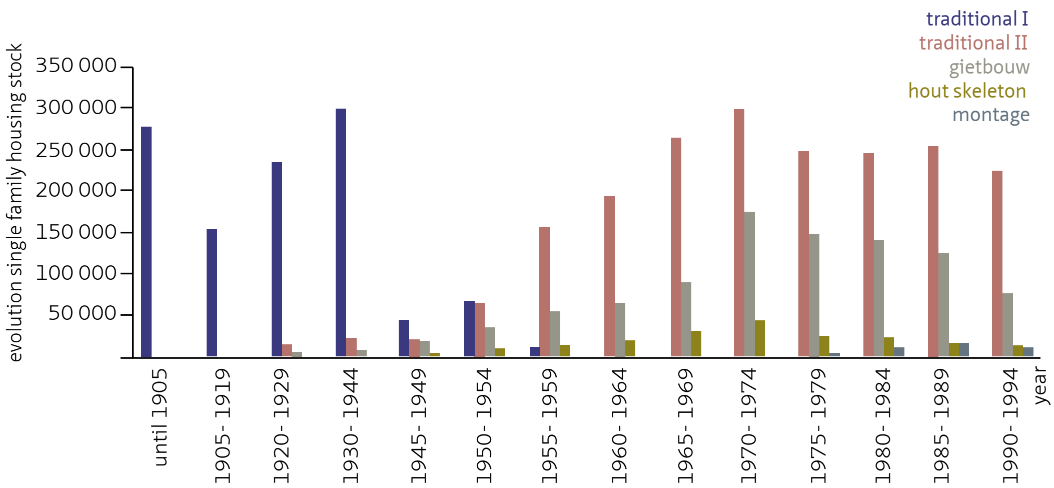
ANNEX 6.40 **Average yearly withdraw rates by typology and region 1998- 2011 (in %)(ABF Research, Syswov)**

	NORTH		EAST		WEST		SOUTH	
	withdraw single f	withdraw multi f	withdraw single f	withdraw multi f	withdraw single f	withdraw multi f	withdraw single f	withdraw multi f
1998	0.23%	0.54%	0.16%	0.07%	0.11%	0.42%	0.12%	0.16%
1999	0.25%	1.11%	0.17%	0.18%	0.14%	0.33%	0.13%	0.40%
2000	0.20%	0.45%	0.15%	0.17%	0.12%	0.43%	0.11%	0.29%
2001	0.24%	1.70%	0.18%	0.14%	0.13%	0.40%	0.11%	0.34%
2002	0.30%	0.44%	0.21%	0.12%	0.14%	0.45%	0.16%	0.34%
2003	0.28%	0.50%	0.23%	0.16%	0.14%	0.52%	0.14%	0.51%
2004	0.34%	0.45%	0.20%	0.29%	0.15%	0.55%	0.18%	0.46%
2005	0.27%	0.98%	0.13%	0.14%	0.16%	0.63%	0.16%	0.27%
2006	0.29%	0.76%	0.32%	0.32%	0.13%	0.65%	0.20%	0.31%
2007	0.28%	0.61%	0.25%	0.27%	0.13%	0.87%	0.19%	0.37%
2008	0.21%	0.67%	0.29%	0.41%	0.14%	0.61%	0.23%	0.66%
2009	0.22%	0.44%	0.20%	0.68%	0.16%	0.53%	0.14%	0.29%
2010	0.18%	0.40%	0.20%	0.39%	0.11%	0.36%	0.11%	0.49%
2011	0.23%	0.18%	0.15%	0.24%	0.09%	0.44%	0.11%	0.32%
Average	0.25%	0.66%	0.20%	0.26%	0.13%	0.51%	0.15%	0.37%

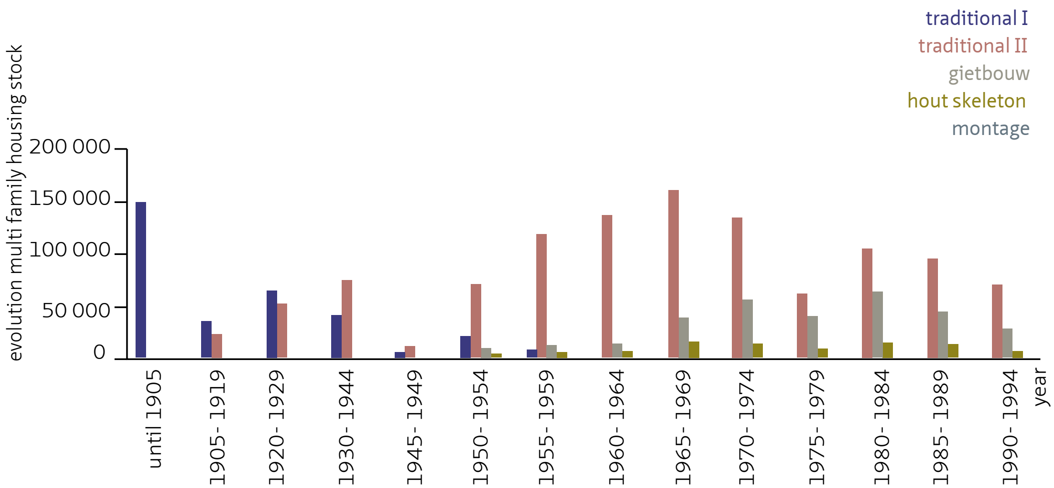
ANNEX 6.41 **Calculating amount of stony C&D per property per period of construction (adapted from Hofstra, U., et al., 2006)**

	<1900		1900-1950		>1950	
	Average amount of BSA for stony houses from the period before 1900 and from 1900 to 1950 is relatively fixed and in the calculation model in this study set at 100 or 125 tons per dwelling		The house from the period 1900 - 1950 is characterized by the wide use of brick in both facades and building walls. Floors were of wood. Flat roofs were not common. After 1950, comes the increase use of reinforced concrete in residential construction, which was crucial for the post war housing demand.		Assuming a density of 2,300 kg/m3 of concrete and a density of 1,600 kg/m3 of other stony demolition. The value for the average amount stony BSA per dwelling for dwellings from the period after 1950 is still subject to change and amounts to 175-215 tons per dwelling	
Characterization	Single family	Multi family	Single family	Multi family	Single family	Multi family
Average size (m2)	80-120	50-70	70-90	50-70	80-100	-
floor	wood	wood	wood	Wood/ceramic/concrete	concrete	concrete
Construction walls	brick	brick	brick	brick	ceramic/ limestone element/concrete	concrete
facade	brick	brick	brick	brick	Brick/ other	Brick/ other
roof	Ceramic tile	Ceramic tile/ flat	Ceramic tile/ flat	Ceramic tile/ flat	(concrete) tile	concrete
No of floors		4		4		5
Façade width (m)	5,1	5,4	5,1	7	5,4	6
Depth (m)	9	19	9	10	9	10
Floor height (m)	2,8	2,8	2,6	2,6	2,6	2,5
Floors	2	1	2	1	2	1
Floor thickness (m)			0,2	0,2	0,25	0,25
Construction walls thickness (m)	0,22	0,22	0,22	0,22	0,3	0,25
Façade thickness (excluding cavity) (m)	0,23	0,23	0,25	0,25	0,27	0,27
Partition walls (m2)	45,9	27	45,9	35	48,6	30
Roof (m2)	68,85	13,5	68,85	17,5	72,9	12
Housing size (m2)	92	54	92	70	97	60
Volume (m2 X floor height)	257	151	239	182	243	150
Concrete (m3)			3,7	2,8	34,3	59,4
Brick (m3)	37	18	36,3	20,8	14,6	8,1
Limestone (m3)	0	0	0	0	6,8	0
Gypsum (m3)	0	0	0	0	4,4	2,7

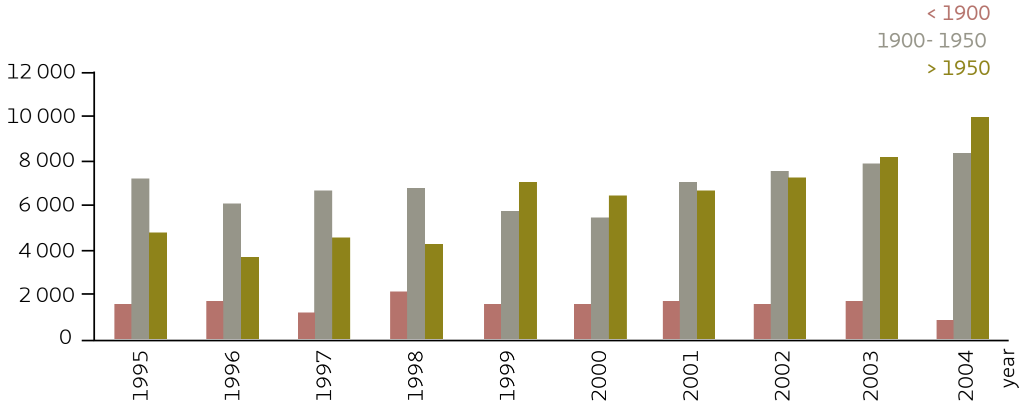
ANNEX 6.42 **Single family stock classification by construction year and building system in the Netherlands (CBS, 2000; CBS 2002 in Feijen, 2003)**



ANNEX 6.43 **Multi family stock classification by construction year and building system in the Netherlands (CBS, 2000; CBS 2002 in Feijen, 2003)**



ANNEX 6.44 **Housing demolition per year according to construction year (absolute numbers) (Hofstra et al., 2006)**



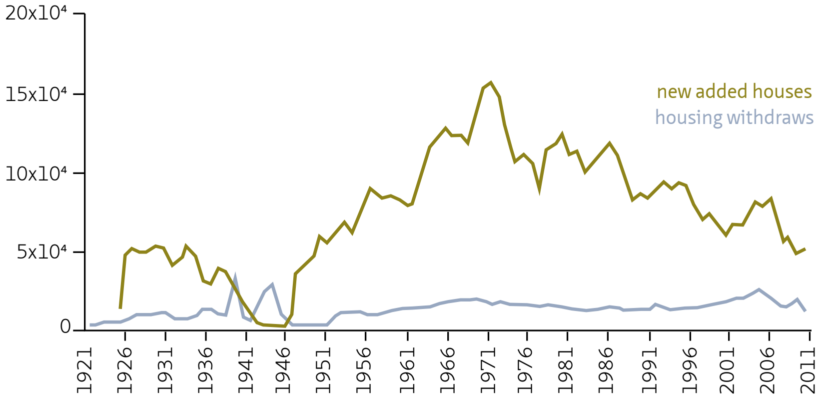
ANNEX 6.45 **Housing stock evolution per construction year 1985- 2011 (ABF Research, Syswov)**

STOCK	-1905	1906-1930	1931-1944	1945-1959	1960-1970	1971-1980	1981-1990	1991-2000	2001+
1985	483277	674004	422072	815067	1205611	1223530	465760	0	0
1986	482111	671063	422066	815139	1206322	1223613	563765	0	0
1987	480887	666935	422042	815162	1206994	1223830	667227	0	0
1988	479994	662088	421925	814932	1207703	1224449	777477	0	0
1989	479130	657064	421640	814000	1207512	1224393	895654	0	0
1990	478375	651869	421348	812918	1206585	1224349	1006918	0	0
1991	477933	647081	421068	811405	1206451	1224136	1104174	0	0
1992	477314	642886	421313	810879	1205943	1223200	1104043	82947	0
1993	476747	638349	420733	808808	1204064	1221982	1103238	169058	0
1994	476272	633107	420198	806973	1202428	1221442	1102907	252694	0
1995	476021	628358	419536	804182	1200193	1220698	1102782	340152	0
1996	476573	624298	418840	801773	1198104	1220186	1102464	433807	0
1997	477642	621018	418240	799879	1196915	1219396	1101916	522564	0
1998	470099	618099	420565	799547	1196755	1219828	1101300	614313	0
1999	470453	614409	419740	797484	1195089	1219086	1101267	704831	0
2000	471248	610664	419265	794549	1192328	1217521	1100820	783265	0
2001	472033	607674	418855	791919	1189541	1216470	1100751	853669	0
2002	473033	603737	418040	788281	1185974	1214624	1100031	853128	72884
2003	474244	599759	417350	783632	1183359	1213559	1099668	852979	139516
2004	475672	595186	416644	779901	1178959	1212193	1099265	852701	199060
2005	477898	590508	416040	775327	1174038	1210198	1098324	852170	264216
2006	479673	586304	415443	772032	1169948	1208430	1097753	851791	331031
2007	482488	581636	414078	767078	1165169	1205411	1096738	851239	403209
2008	485080	579089	413778	762867	1161503	1206498	1097884	852544	483969
2009	487697	574396	413254	757510	1155206	1204532	1097217	852213	562493
2010	490208	571337	412696	752266	1150322	1202225	1096423	851852	645107
2011	492535	568228	412103	748784	1146886	1201190	1095848	851536	700693
	-0.07%	-0.60%	-0.09%	-0.31%	-0.19%	-0.07%	-0.04%	-0.02%	95.71%

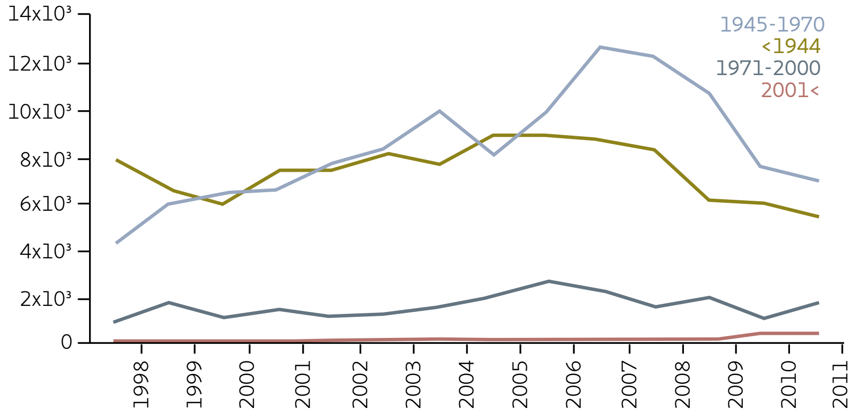
ANNEX 6.46 **Highest withdraw rates according to different sources**

SOURCE AND DATA RANGE	HOUSING TYPOLOGY	CONSTRUCTION YEAR	STOCK SHARE:
Agentschap Nl (2001, 2007, 2011[c])	Rijwoning	1946- 1965	+- 7% (2011)
	Galerij	Before 1964	1% (2011)
Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013 (1999-2012)	Not specified	1945- 1970	26.1% (2012)
ABF Research, Syswov (1985-2011)	Not specified	1906-1930	7.9% (2011)
	Not specified	1945- 1970	26.3% (2011)

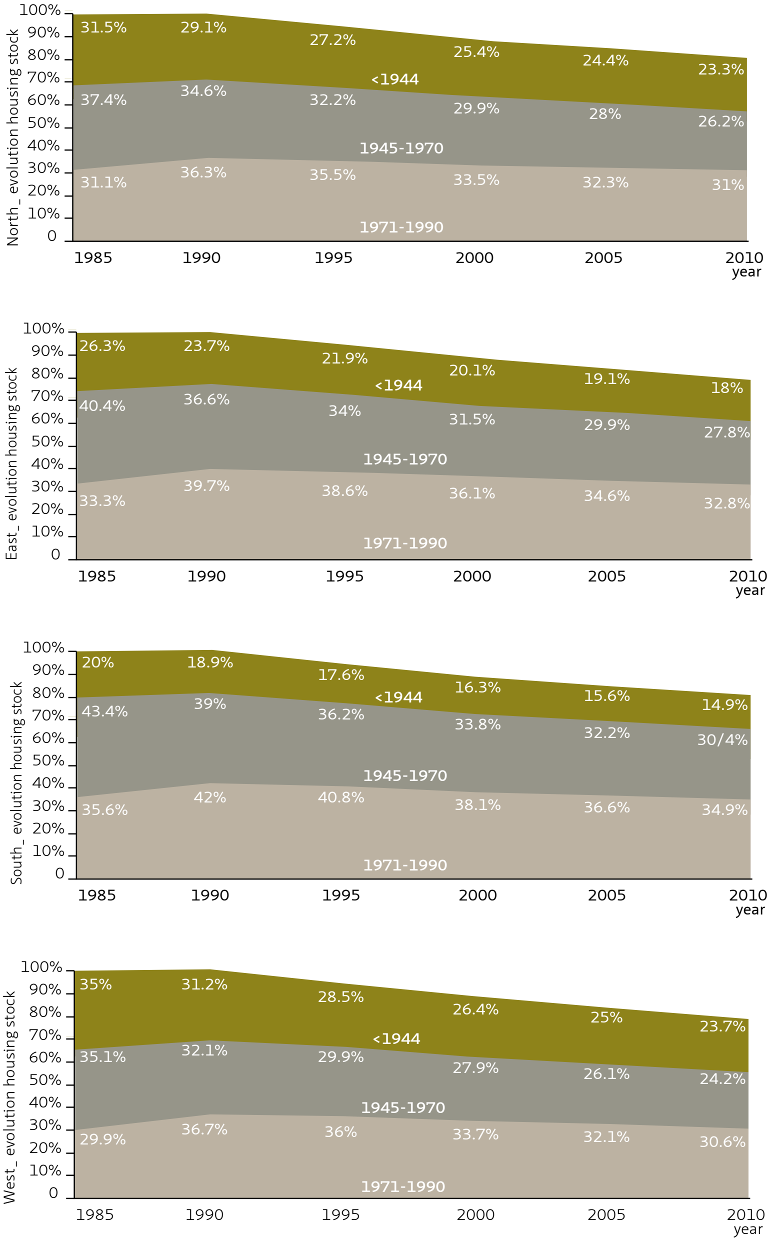
ANNEX 6.47 **Yearly new added houses (absolute numbers) (CBS)**



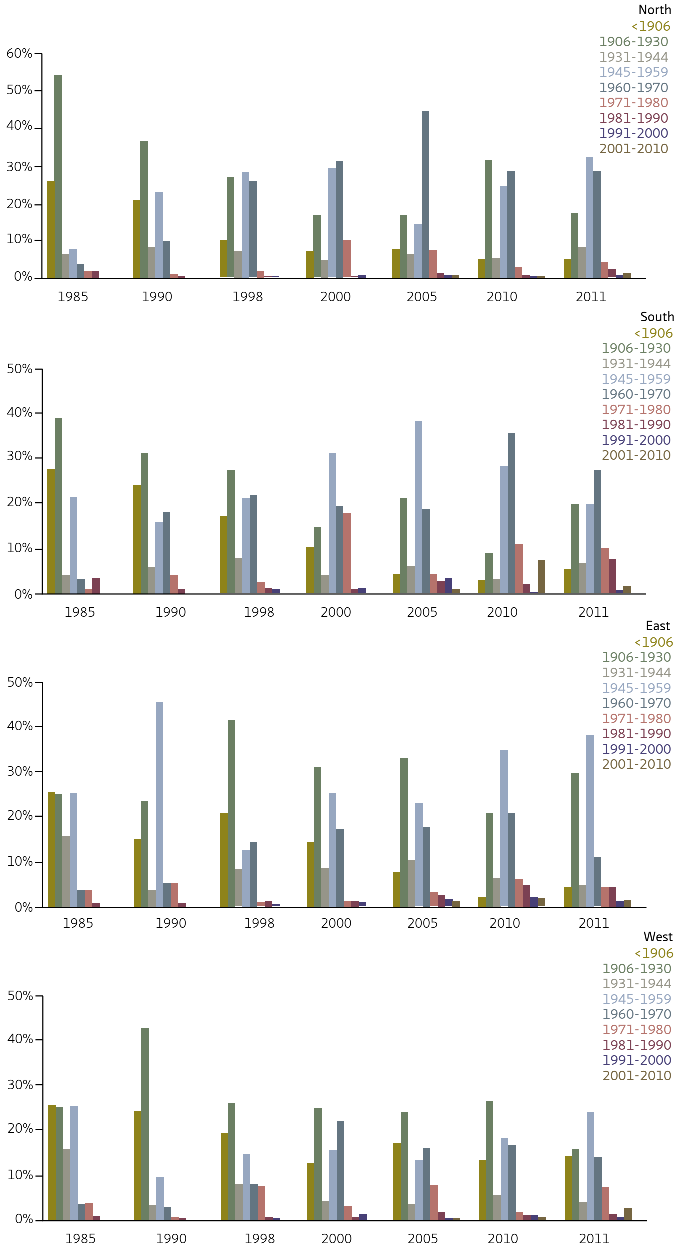
ANNEX 6.48 **Housing withdraws by construction year (absolute numbers) (ABF Research, Syswov)**



ANNEX 6.49 **Development of the housing stock according to construction year from 1985 and later in 2010 per region (in %) (ABF Research, Syswov)**



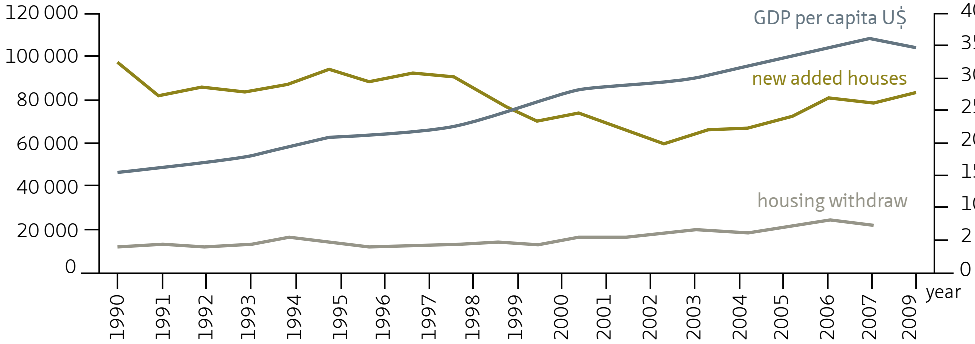
ANNEX 6.50 **Housing withdraws by construction year by region (ABF Research, Syswov)**



ANNEX 6.51 **Correlation analysis 1990- 2009 (CBS)**

GDP € MILL.	1	
GDP Per C.	0.999774679	1
Voorraad woningen	0.990574761	0.990063316
Woningvoorraad op 1 januari	0.990574761	0.990063316
Woningvoorraad toevoeging totaal	-0.645643245	-0.640211374
Woningvoorraad toevoeging door nieuwbouw	-0.709167852	-0.70380432
Woningvoorraad toevoeging anderszins	0.827183546	0.825754408
Woningonttrekking totaal	0.769259819	0.77644188
Woningonttrekking door verbouw	0.788552586	0.789253604
Woningvoorraad op 31 december	0.990122968	0.989691047
Totaal gereedgekomen huurwoningen	-0.582092395	-0.588592174
Gereedgekomen ééngezins huurwoningen	-0.72432147	-0.731853528
Gereedgekomen meergezins huurwoningen	-0.398207171	-0.403032585
Totaal gereedgekomen eigenwoningen	-0.552606428	-0.539437138
Gereedgekomen ééngezins eigenwoningen	-0.821948378	-0.812519736
Gereedgekomen meergezins eigenwoningen	0.858352999	0.863704521
Gereedgekomen ééngezinswoningen	-0.892648845	-0.88671713
Gereedgekomen meergezinswoningen	0.289188483	0.288865479
Completed houses with 1 room	0.732415766	0.730883975
Completed houses with 2 rooms	-0.115076196	-0.119100697
Completed houses with 3 rooms	-0.143559187	-0.143244716
Completed houses witht 4 rooms	-0.905104475	-0.900265582
Completed houses witht 5 rooms	-0.261143835	-0.24641618
Completed houses with 6 rooms or more	0.611683426	0.620271482
Totaal gereedgekomen huurwoningen	-0.582092395	-0.588592174
Gereedgekomen ééngezins huurwoningen	-0.72432147	-0.731853528
Gereedgekomen meergezins huurwoningen	-0.398207171	-0.403032585
Totaal gereedgekomen eigenwoningen	-0.552606428	-0.539437138
Gereedgekomen ééngezinswoningen	-0.892648845	-0.88671713
Gereedgekomen meergezinswoningen	0.289188483	0.288865479

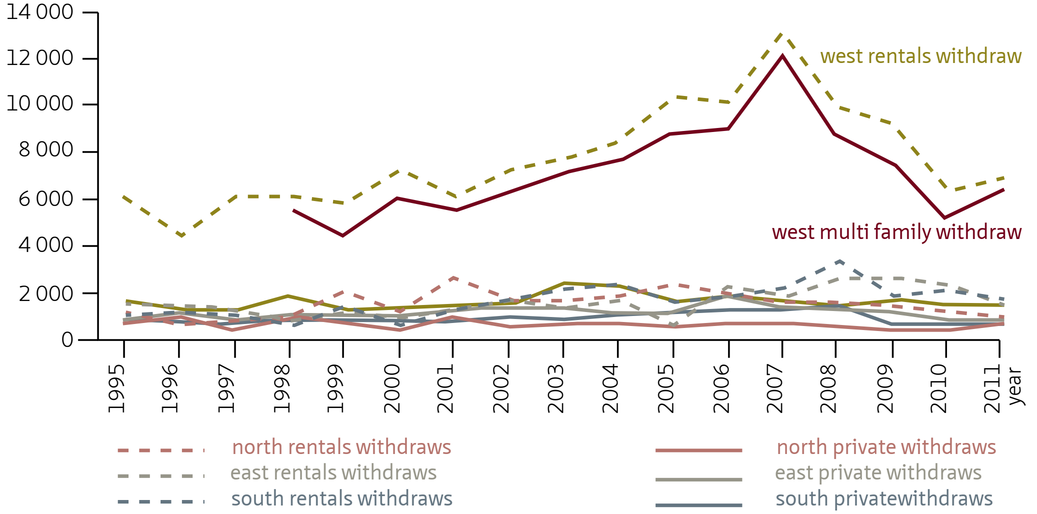
ANNEX 6.52 **GDP per capita in U$ and new housing construction and withdraws (left axis absolute numbers, right axis U$) (CBS)**



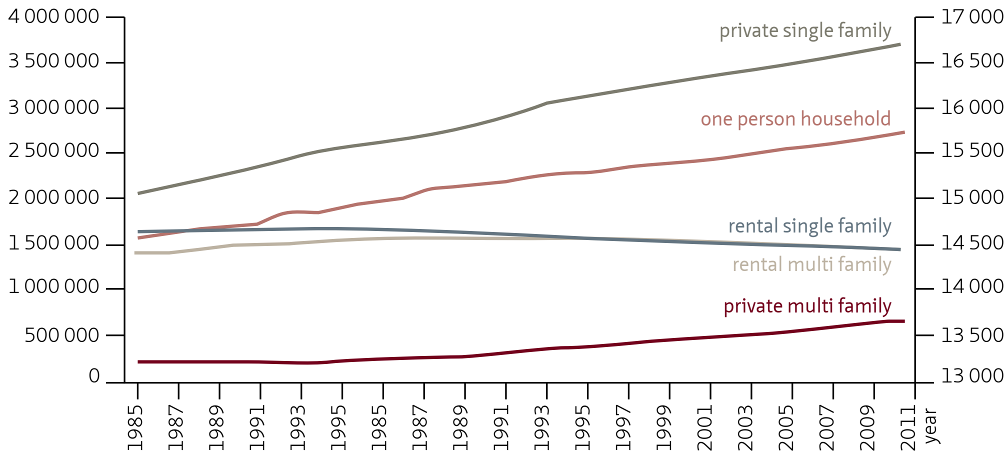
ANNEX 6.53 **Typology and tenancy (extracted from Annex 6.34)**

TYPOLOGY	TENANCY: RENTAL	TENANCY: PRIVATE
Flats	73.5%	26%
Portiek	75.33%	24.33%
Galery	72.33%	27.66%
Rijtjes	40.60%	59.40%
Maisonette	54%	46%
Twee o 1 kap	11.33%	88.33%
Vrijstand	6%	93.60%

ANNEX 6.54 **Yearly withdraws per region and tenancy and yearly withdraws of rental houses in the West 1995- 2011 (absolute numbers) (ABF Research, Syswov)**



ANNEX 6.55 **Evolution of the housing stock by tenancy and typology, evolution of the one person household group and population growth (left axis absolute numbers of houses and absolute number of one person households, right axis X1000 absolute numbers) (ABF Research, Syswov, CBS)**



ANNEX 6.56 **Brief description of the building material evolution in period 1840- 2005 (adapted from Piet Bot, 2009 and Symonds ARGUS, COWI and PRC Bouwcentrum, 1999)**

First half of the 19th century
1807 _ Arrival steam machines in NL. 1832 _ Dynamo introduction and then later the transformer. 1839 _ the first steam train. Infrastructure had to me made and lots of the wood used had to be impregnated for treatment. 1835 Gilardoni brothers started production of ceramic roof tiles. From 1878 these panels also started to be produced in Nl, also for flat roofs. 1839 _ Hischberg and the Samuel Hausler found wood fiber cement and in 1940 in Germany the floating stone was developed. Terra-cota as well started to be implemented, from the mid of this century zinc was used as roof materials.
Second half of the 19th century
The World Exhibition promoting innovation in the industry. Lime stone technology originating from Germany becomes more popular. Since 1898 this stone became also produced in the Netherlands. About the same time appears Portland cement. Bricks played an important role. In this period also the introduction of cast iron (spans were larger and higher buildings. Individual family dwellings are predominantly built of blocks, brick and wood, with wood much more widely used in Scandinavia than elsewhere in the EU*. 1895 _ Art Noveau. 1860 _ introduction of petrol from US. In 1870 the first asphalt road in Amsterdam. 10 years later comes in the telephone.
The twentieth century until the 1945
1906 _ introduction of white lead. 1910 _ Tri and multiplex in 1910. Many products appear in the market. 1912 _ first asbestos industry in the Netherlands. Also the first bronze and steel frames used. All kinds of artificial stones came in the market, as lime, concrete piles and floor systems. With the developments in foundation technologies allowed higher buildings to be constructed in wet terrain as in the Netherlands. Electric plants constructed in large cities in the Netherlands, and slowly more electric equipment get into the homes. In this period the housewife emerges as an important figure in the construction consumption trends.
1st World War
With borders close the input of wood was stagnated. The prices of building materials went high boosting local producers. 1924 _ blast furnace industry opened. Here was the further development in the insulation sector coupled; a waste product of blast furnaces was blown slag. Also different reinforced concrete systems were developed. 20's and 30's _ many panel materials were in the market as hardboard and soft board manufactured in US and Scandinavia. Late 20's _ first standard kitchens introduced. Hygene perception starts to play a roll within the development of finishing materials. Substances as melamine and styrene were used. 1926 _ the 1st cement industry appeared the ENCI. 1932 _ TNO (the Technological and Natural Scientific Research Institute of the Netherlands) started.

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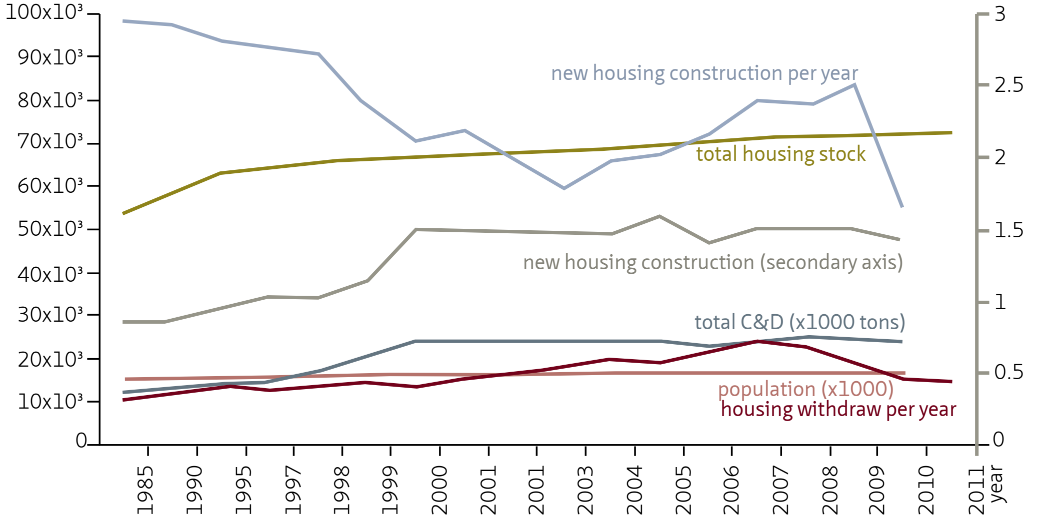
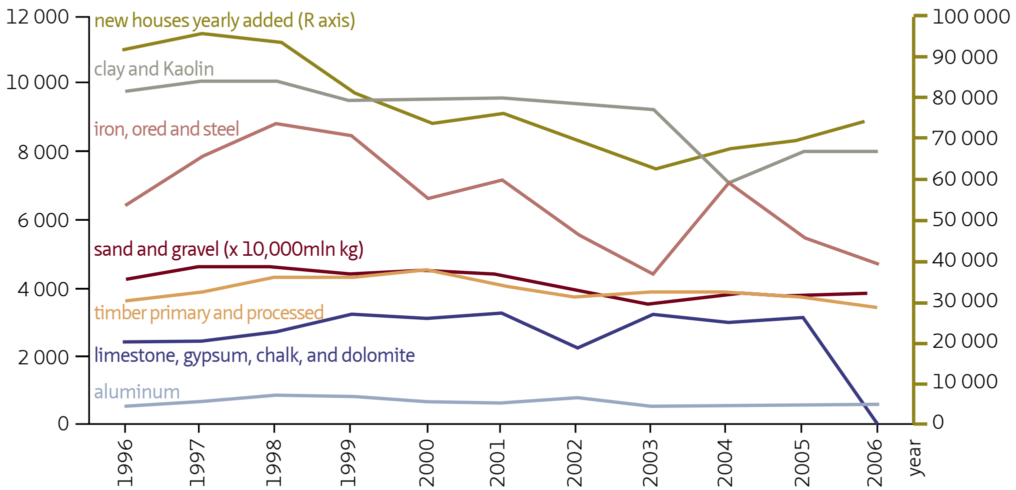
ANNEX 6.56 **Brief description of the building material evolution in period 1840- 2005 (adapted from Piet Bot, 2009 and Symonds ARGUS, COWI and PRC Bouwcentrum, 1999)**

2nd World War
Critical need of fast reconstruction. The great need stimulated the concrete and roof tiles industries and new wave of pre cast construction. The 1950s and 1960s apartment buildings which accommodated the flood of workers to post-war urban industrial centers in most Member States were generally built of reinforced concrete, with copper piping replacing lead*. The trend in fixatives, fillers and coatings has moved from nails, screws, plaster, mortar and emulsion paints to organic resins and solvent-based products which, although inert or at least non-hazardous in their final form, are made up on site from components which are often flammable and/or toxic, and whose residues and containers are therefore also potentially hazardous*. 1946 _ 125.000 per year by 1970. 1948 _ Thermopane double glass was already in the Dutch market. 1955 _ the plastic sandwich and different types of plastic cladding panels were developed. Also came in the aluminum ride profiles, water tables and condensing stripe came in the market. 1963 _ the 1st gas cv ketel installed. 1958 _ first aluminum façade. 1956 _ Suez crisis 1957 _ Eternit Gyproc Benelux the first gypsum carton panel industry. 1962 _ Knauf appears with stucco mortars in the market. Different products from Trespa, Formica, Isover, Perspex, Foamglas en Gibo and more a number of other released products in 1955-1965. Stoneware and cast iron sharply declined. 1973 _ came the oil crisis and the importance to insulate houses. 1980s _ plastics (especially PVC double glazing units) were becoming widespread in pipes and window frames in all sorts of residential buildings*. 1993 _ FSC wood certificate introduced. Since 1993 comes the prohibition of production and use asbestos. 1995 _ Energie Prestatie Norm is implemented and forcing new buildings to comply with Energy efficiency coefficient. That focus on insulation of walls, windows, floors, and the quality of installations as heating, solar panels and ventilation. 1999 _ Bouwbesluit bodem Oppervlaktewaterbescherming in force.

ANNEX 6.57 **C&D total evolution and housing and demographic process 1985-2008 (based on data from Hofstra et al., 2006, Agentschap Nl, AOO, RIVM, WAR 2011-2013)**



ANNEX 6.58 **Apparent consumption of resources (CBS) and national new housing construction (CBS) (left axis million kg, right axis house units).**



ANNEX 6.59 **Products, applications and recommendations softwood in construction***

	Floor	Subfloor	Construction	Façade finishings	Façade covering	Internal paneling	Staircase	Doors	Furniture	Internal paneling	Infrastructure and water management projects	Garden and recreation	Packaging
Grenen	X	X	X	T	X	X	X	X	X	X	X	X	X
Douglas	X	X	X	T	X	X				X	X	X	X
Lariks	X	X	X	T	X	X					X	X	X
Vuren	X	X	X	T	X	X	X	X	X	X	X	X	X
Triplex Chipboard High pressure laminate	Roof eaves and gutter linings												
Hardwood	External doors, windows, façade elements												
Chipboard MDF Oak, Beukenm Essen, Esdoorn	Furniture												

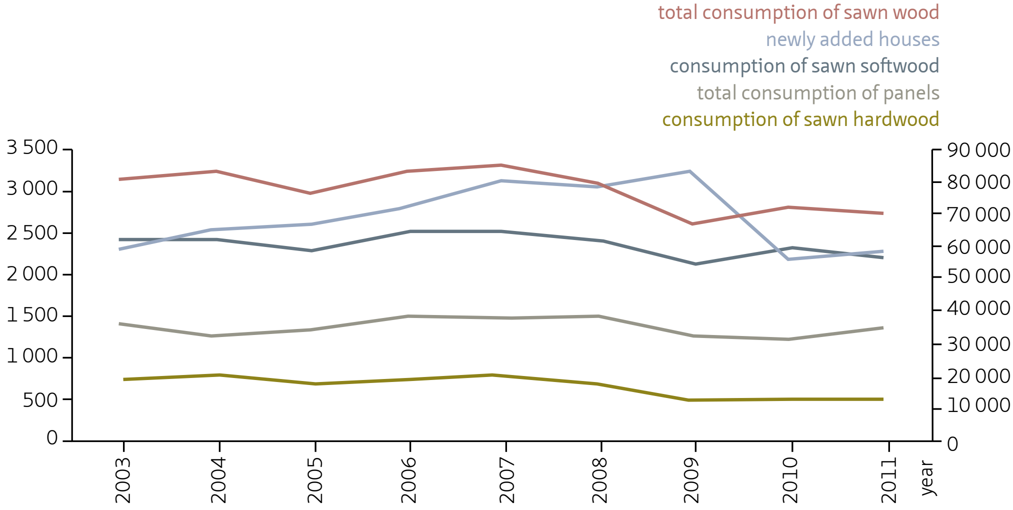
** Centrum Hout, 2005*

ANNEX 6.60 **Number of newly built houses and timber-framed houses in the Netherlands in 1980 and 2000***

YEAR NUMBER OF TIMBER	TOTAL NEW HOUSES	NUMBER OF TIMBER FRAMED HOUSES	% OF TIMBER FRAMED HOUSES
1980	100.000	5.000	5%
2000	65.000	5.000	8%

** Van der Meulen, et al., 2003*

ANNEX 6.61 **Wood consumption (Probos) and housing construction and withdraws from 2003 to 2011 (CBS) (left axis wood consumption in the Netherlands X1000m3 and right axis new housing construction absolute numbers)**



ANNEX 6.62 **Hardwood market share in 2010***

	HARDWOOD (TOTAL) %	TROPICAL HARDWOOD %	TEMPERATE %
Building construction	33	37	23
Infra structure	31	36	18
Furniture and interior	10	3	24
Garden/ do-it-yourself	15	19	7
Packaging	4	0	15
Others	7	5	13

** Based on Probos, 2011*

ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
mln kilos	Regkol	Burg&Ut. bouw				mln kg		Burg&Ut. bouw
GGE8	OMSCHRIJVING	41200				GGE8_agg_pub	OMSCHRIJVING_agg_pub	41200
200000	Bosbouw	1	200000	Bosbouw	1	116900	Ov.plant. mat (Fiber crops)	5
1030000	Turf	1	892000	Turf	11	200000	Bosbouw	1
1110200	Aardgas	1	620000	Aardgas	40	812200	Klei	38
1421100	Zand	3	812110	Zand	11298	892000	Turf	11
1421200	Grind	3	812120	Grind	2900	899900	Ov. Delfstoffen (quarrying)	53
1422000	Klei	2	812200	Klei	38	1399000	Ov.textl.war (Manufacture of other textiles n.e.c.)	1
1759900	Ov.textl.war	1	1399000	Ov.textl.war	1	1610000	Hout primair (Sawmilling and planing of wood, impregnation of wood)	49
2000900	Ov.hout-prod. (WOOD)	1				1621100	Triplex ed. (Manufacture of veneer sheets and wood-based panels)	22
2010900	Hout primair	1	1610000	Hout primair	49	1621200	Fineer/ plaat (Manufacture of veneer sheets and wood-based panels)	52

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TOC

ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2020100	Triplex ed.	1	1621100	Triplex ed.	22	1623111	Ramen kozijn (Manu-facturing of wooden doors, win-dows and frames)	160
2020200	Fineer/ plaat	1	1621200	Fineer/ plaat	52	1623112	Deuren (Manu-facturing of wooden doors, win-dows and frames)	128
2030111	Ramen kozijn	2	1623111	Ramen kozijn	160	1623120	Ov.timmer-wer (Man-ufacturing of wooden doors, win-dows and frames)	211
2030115	Deuren	2	1623112	Deuren	128	1629900	Houtprod. Neg (Man-ufacture of other products of wood; man-ufacture of articles of cork, straw and plaiting materials (no furni-ture))	2
2030190	Ov.timmer-wer	1	1623120	Ov.timmer-wer	211	1722990	Ov. Verband (Manu-facture of household and sanitary articles of paper)	1

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ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2122900	Hu/san. pap.w	1				1723000	Kant.ben. pap (Manufacture of paper stationery)	1
2123000	Kant.ben. pap	1	1723000	Kant.ben. pap (Manufacture of paper stationery)	1	1729900	Ov. p/k waren (Manufacture of other articles of paper and paperboard)	1
2125199	Ov.p/ k0waren	1	1729900	Ov. p/k waren (Manufacture of other articles of paper and paperboard)	1	2016550	Polyurethaan (Manufacture of plastics in primary forms)	11
2222120	Reclamedrukw	1				2016590	Ov. ksthrs. rubr. ed. (manufact. plastic in primary form)	1
2229000	Ov.drukw. neg	1				2221290	Sta/slan.kst (Manufacture of plastic plates, sheets, tubes and profiles)	32
2416550	Polyurethaan	1	2016550	Polyurethaan	11	2221300	Pla.ongec.ks (Manufacture of plastic plates, sheets, tubes and profiles)	12
2451300	Zeep/poetspr	1				2221400	Ov.platen ks (Manufacture of plastic plates, sheets, tubes and profiles)	7

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ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2521290	Sta/slan.kst	1	2221290	Sta/slan.kst (Manufacture of plastic plates, sheets, tubes and profiles)	32	2223000	Bouwart. knst (Manufacture of builders' ware of plastic)	52
2521300	Pla.ongec.ks	1	2221300	Pla.ongec.ks (Manufacture of plastic plates, sheets, tubes and profiles)	12	2229000	Ov.prod.kst. (Manufacture of other plastic products)	4
2521400	Ov.platen ks	1	2221400	Ov.platen ks (Manufacture of plastic plates, sheets, tubes and profiles)	7	2312199	Prod. vlakglas (Shaping and processing of flat glass)	95
2523000	Bouwart. knst	1	2223000	Bouwart. knst (Manufacture of builders' ware of plastic)	52	2314990	Ov.bew.glas (Manufacture of glass fibres)	10
2524000	Ov.prod.kst.	1	2229000	Ov.prod.kst. (Manufacture of other plastic products)	4	2323400	Ov. keram. pr (Manufacture of refractory products)	24
2612199	Prod. vlakglas	2	2312199	Prod. vlakglas (Shaping and processing of flat glass)	95	2339000	Ker. Bwmat/tgls (Manufacture of clay building materials)	657
2615990	Ov.bew.glas	1	2314990	Ov.bew.glas (Manufacture of glass fibres)	10	2361110	Stenen beton (Manufacturing of concrete products for construction)	2204

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ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2629000	Ov. keram. pr	1	2323400	Ov. keram. pr (Manu-facture of refractory products)	24	2361199	Ov.beton-waar (Man-ufacturing of concrete products for construc-tion)	2173
2649000	Ker. Bw-mat/tgls	3	2339000	Ker. Bw-mat/tgls	657	2361900	Bwelem. beton (Manu-facture of concrete products for construc-tion pur-poses and sand-lime bricks)	6179
2651900	Cement/kalk/g	1				2363400	Beton/mor-tel (Manu-facture of ready mix concrete)	1489
2661110	Stenen beton	3	2361110	Stenen beton	2204	2370000	Bew.natu-urst (Stone dressing)	175
2661199	Ov.beton-waar	3	2361199	Ov.beton-waar	2173	2399000	Ov. Bouwmat (Manufac-ture of other non-metal-lic mineral products (no abrasive products)	340
2661900	Bwelem. beton	3	2361900	Bwelem. beton	6179	2439900	IJzer en staal (Other first processing of steel)	172
2663000	Beton/mortel	3	2363400	Beton/mortel	1489	2442900	Alumin-ium ed (Aluminium production)	39

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ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2670000	Bew.natu-urst	2	2370000	Bew.natu-urst	175	2444900	Koper ed (Copper production)	7
2682990	Ov. bouw-mat.	2	2399000	Ov. bouw-mat	340	2449199	Non ferro neg (Man-ufacture of basic precious and other non-ferrous metals)	9
2710410	Fe gewal. onb (Gew-alste platte produkten van ijzer of van staal, onbewerkt)	1				2511000	Constr.werk (Manufac-ture of met-al structures and parts of structures0	302
2710420	Fe gewl.bekl (Gewalste platte produkten van ijzer of van staal, geplateerd of bekleed)	1				2512000	Constrw. bouw (Man-ufacture of metal doors, windows and their frames)	59
2710500	Fe walsdraad (Walsdraad en staven, warm gewalst)	1				2521100	Cv.ketels/rad(Man-ufacture of boilers and radiators for central heating)	16

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GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2710700	Fe profielen (Damwand-profielen, bestand-delen van spoorbanen en andere profielen van ijzer of van staal; warm gewalst, getrokken of geperst)	1				2572000	Hang/slu-itw (Man-ufacture of locks and hinges)	23
2720000	Ferro buizen (Buizen van gietijzer, van ijzer of van staal)	1				2593900	Spyker/draad (Manufac-ture of wire products, chain and springs)	93
2742200	Alumin. halff (Half-fabrikaten van alumin-ium of van legeringen van alumin-ium)	1				2594900	Bout/moer ed (Manu-facture of fasteners and screw machine products)	1
2743220	Zink halffab (Halffabri-katen van zink)	1				2599100	Met.hh.san. (Manufac-ture of other fabricated metal products)	2
2744200	Koper halff. (Halffabri-katen van koper of van koper-legeringen)	1				2599290	Metaalpr. Neg (Man-ufacture of other fabri-cated metal products)	50

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ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2749190	Ov. non0Fe (Ruw nikkel, tin, lood en andere ruwe non-ferrometalen)	1				2619900	Elec. Comp. neg (Manufacture of electronic components and boards)	2
2812000	Constrw. bouw (Deuren en ramen, alsmede kozijnen daarvoor en drempels, van ijzer, van staal en van aluminium)	2				2814000	Kranen ed. (Manufacture of other taps and valves)	4
2862190	Handgereeds.ed	1				3100200	Meub. del+afw (Manufacture of furniture)	94
2863000	Hang/ sluitw	1				3102000	Keukenmeubel (Manufacture of kitchen furniture)	1
2873000	Spyker/ draad (Spijkers, prikkeldraad, kabels, strengen, metaalgaas, traliewerk, naainaalden, breipennen en andere artikelen van draad)	1	2593900	Spyker/ draad	93	116	AfvalMineraal	24

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ANNEX 6.63 **PSUT 2010***

GEBRUIK TABEL						92A1 PUT_DETAIL KRUISTABEL VAN QUERY 92A 2010		
2875100	Met.hh.san. (Keukengerei en huishoudelijke artikelen, alsmede delen daarvan, van ijzer, staal, koper of aluminium)	1				216	RecycleMineraal	280
2875900	Ov.metaalpr. (Brandkasten, scheepsschroeven en andere artikelen van onedel metaal, n.e.g.)	1				401	BalansInO2Verbranding	441
2913000	Kranen ed.	1	2814000	Kranen ed.	4			698
2971400	Elek. kookapp	1						
3120000	Schakel/verd/ond	1						
3150000	Verlicht.art/ond	1	2740000	Verlicht.art/ond	3			
3613000	Keukenmeubel	1	3102000	Keukenmeubel	24			
3619000	Meub. del+afw	1	3100200	Meub. del+afw	1			
3663990	Ov.artik.neg	1						
7420000	Ing./archit.	1						
	Totale gebruik regkol	3						
Mineraal afval		2	116	AfvalMineraal	280			

** CBS*

ANNEX 6.64 **Market share of material for window frames in 1995***

NON-TROPICAL	24%
Tropical	29%
PVC	35%
Aluminum	11%
Others	1%

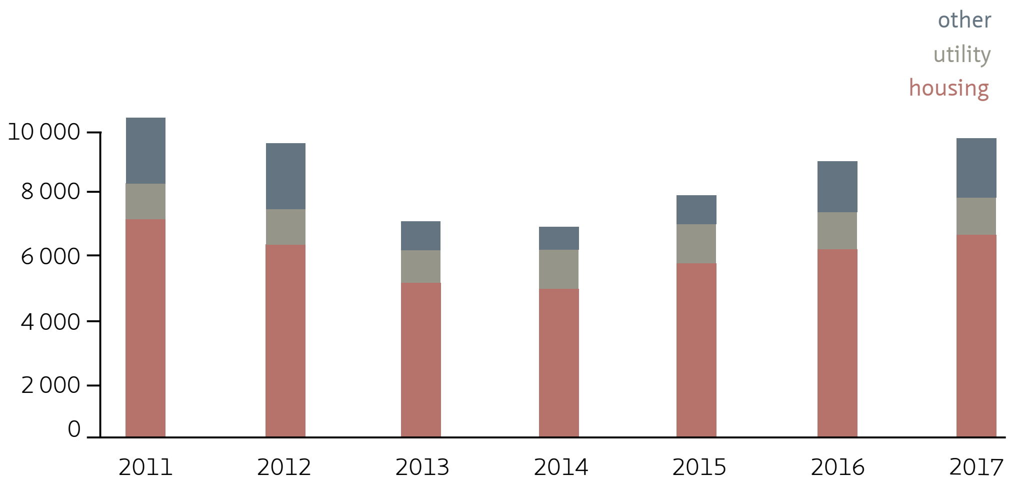
** De Boer,1995 in Goverse et al., 2001*

ANNEX 6.65 **Domestic consumption of construction brick _ average type (million WF _ 1WF= 1,73kg)****

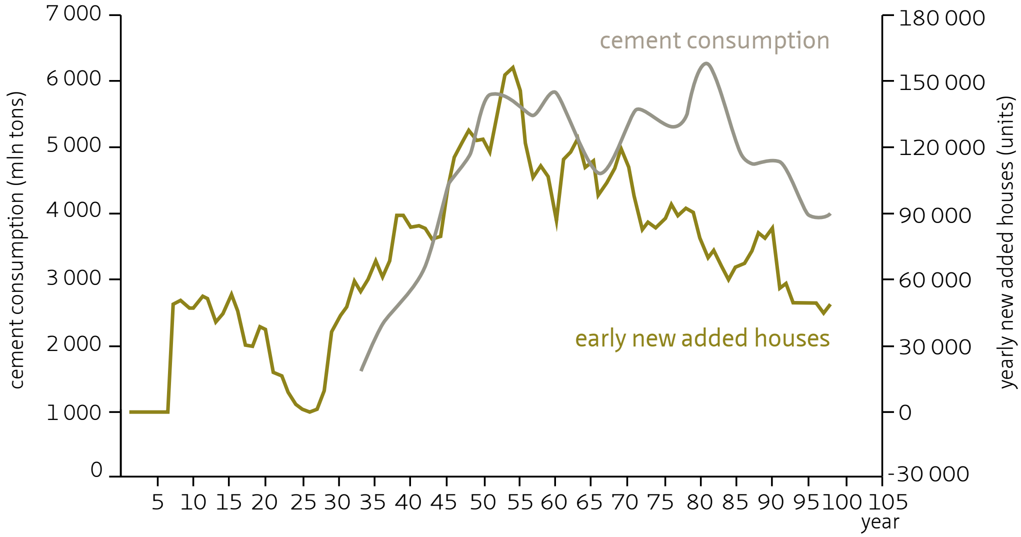
	MILLION WF[1]	1000 TONS	NEW HOUSES PER YEAR
1992	1048	1,813.04	86164
1995	886	1,532.78	83689
2000	1044	1,806.12	70650
2005	897	1,551.81	67016
2006	925	1,600.25	72382
2007	1012	1,750.76	80193
2008	968	1,674.64	78882
2009	818	1,415.14	82932
2010	666	1,152.18	82932
2011	639	1,105.47	57703
2012	515	890.95	48668
2013	423	731.79	49311
2014	440	761.20	45170

** Jaarverslag KNB, 2005, 2012 and 2014*
1 WF means Waalformaat, measures 21cm x 10cm x 5cm, is the main type of brick used in NL nowadays.

ANNEX 6.66 **Prognoses brick usage in surface consumption (Buildsight in Jaarslag 2014, KNB)**



ANNEX 6.67 **Historical cement consumption (million tons) and yearly new added houses (absolute numbers) (Quantitative data of the ready mixed concrete industry, ERMCO, 2008; Global Cement, 2012[1]; Hargreaves, 2005; Hostra et al., 2006; Cement & Beton Centrum[2]; CBS)**



1 http://www.globalcement.com/magazine/articles/663-cement-in-belgium-and-the-netherlands
2 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.68 **Concrete (mix) consumption according to new housing construction divided in low rise and high-rise (Cement and Beton Centrum)**[1]

	1996	1999	2002	2005	2008	2011
Low rise	67%	65%	61%	54%	60%	40%
High rise	33%	35%	39%	46%	40%	60%

1 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.69 **Consumption of poured concrete (mix) in the housing sector (Cement and Beton Centrum)**[1]

	1999: TOTAL CA. 8.700.000 M3 / YEAR	2002:	2005: TOTAL CA. 8.300.000 M3	2008: -	2011: TOTAL CA. 8.000.000 M3
Housing segment	Ca. 3.200.000 m3 (36.7%)	-	Ca. 3.350.000 m3 (40.3%)	Ca. 2.600.000 m3 (41%)	Ca. 2.140.000 m3 (26.7%)
Foundation	28%	21%	23%	31%	23%
Ground floor	15%	18%	14%	13%	21%
Upper floor	31%	37%	30%	35%	42%
Walls	14%	15%	16%	15%	7%
Roof	2%	2%		1%	
Others including mortar	10%	7%	17%	5%	7%

1 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.70 **Concrete-mix consumption (Cement and Beton Centrum)**[1]

	GROUND FLOOR	UPPER FLOORS	WALLS	FOUNDATION	ROOF	OTHER
Low rise	23%	31%	10%	26%	1%	9%
High rise	10%	44%	25%	13%	4%	4%

1 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.71 **Floor applications (Cement and Beton Centrum, 2007)**[1]

FLOORS	GROUND FLOOR (%)	UPPER FLOORS (%)
In situ	12	14
Hollow core slab	17	29
Wide slab	7	53
Cassette	42 (39% in 2006)	-
Combi	11	-
Other	11	4 Wood (6% in 2006)

1 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.72 **Roof applications (Cement and Beton Centrum, 2007)**[1]

ROOFS	SLOPE	FLAT
Concrete	53%	-
Ceramic	39%	-
Slate	1%	-
Zinc	2%	
Bitumen	2%	74%
Other	3%	26%

1 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.73 **Facade applications in 2007 (Cement and Beton Centrum)**[1]

ENVELOPE	INNER LEAF			OUTER LEAF
	2000	2006	2007	2007
Lime -silica	73%	57%	63%	-
Concrete	10%	17%	19%	1%
			30% in situ / 60% pre cast / 10% block	
Cellular concrete	-	-	2%	-
Ceramic	-	-	6%	97%
Wood	-	-	10%	1%
Other	-	-	-	1%

1 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.74 **Wall applications in 2007 (Cement and Beton Centrum)**[1]

Walls	Housing separating wall			Housing walls			Inter-nal walls
	2000	2006	2007	2000	2006	2007	2007
Lime-silica	60%	55%	54%	71%	63%	59%	9%
Concrete	36%	42%	44%	19%	16%	22%	2%
	80% in situ / 20% pre-cast	75% in situ / 25% pre-cast	70% in situ / 30% pre-cast		35% in situ / 53% pre-cast / 12% block	30% in situ / 60% pre-cast / 10% block	
Cellular concrete	-	-	-	-	-	1%	47%
Sheets	-	-	2%		-	-	-
Ceramic	-	-	-	8%	16%	14%	5%
Gypsum	-	-	-	-	-	-	36%

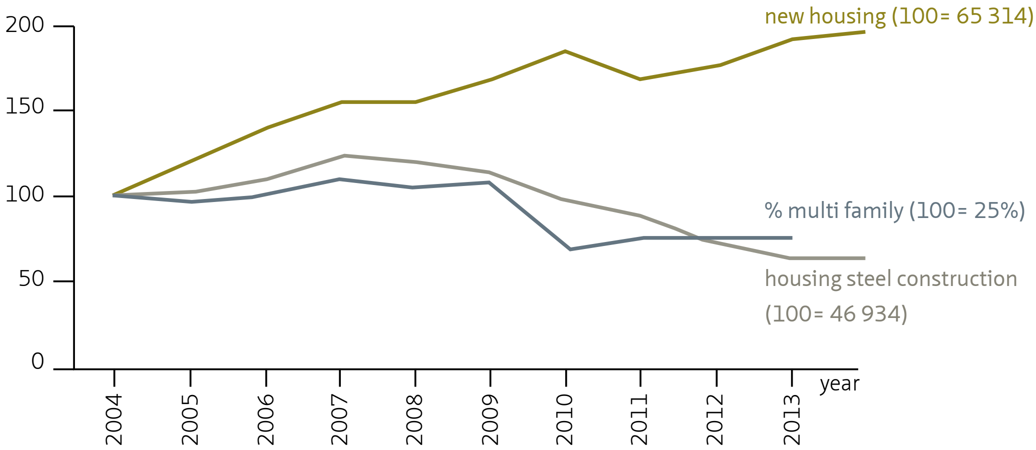
1 E-mail Wim Kramer (Cement and Beton Centrum)

ANNEX 6.75 **Market share of steel in multi-family buildings between 1990 and 2009 according to building floor numbers (Bowmetsataal, 2010)**[1]

STORES/YEARS	2	3	4/5	≥6	≥2	≥3
90	48	15	5	4	17	7
91	49	18	6	4	19	8
92	49	20	7	5	20	10
93	50	23	9	5	23	12
94	51	23	8	4	25	12
95	51	23	9	3	26	12
96	51	24	11	3	27	14
97	54	28	13	4	29	16
98	58	30	16	6	33	16
99	63	33	16	8	35	19
00	63	38	19	10	35	20
01	64	43	20	11	35	20
02	62	42	22	13	34	22
03	63	38	22	13	33	21
04	60	36	23	15	33	23
05	60	39	26	23	38	28
06	58	42	32	37	44	37
07	57	44	31	47	46	41
08	59	45	25	41	45	37
09	54	42	23	28	39	31

1 E-mail Mic Barendz, Bouw met Staal

ANNEX 6.76 **Share of multifamily completed projects in relation to total new housing construction (prediction 2012, 2013 and 2014) (Bouwkennis., 2012)**[1]



1 Bouwkennis. "Whitepaper marktomvang Daken." (2012). http://www.bouwkennis.nl.

ANNEX 6.77 **Steel consumption by the housing sector in tons***

YEAR	STEEL CONSUMPTION BY THE HOUSING SEGMENT TONS	NEW HOUSES ADDED PER YEAR
2000	50905	70650
2001	52187	72958
2002	47659	66704
2003	41909	59629
2004	46934	65314
2005	46235	67016
2006	47482	72382
2007	50956	80193
2008	49789	78882
2009	50909	82932
2010	32928	55999
2011	35414	57703
2012	35414	48668
2013	35414	45170

** Bouwenmetstaal, 2012 and CBS*

ANNEX 6.78 **Polymers concentration in reference house in the Netherlands***

POLYMER TYPE[1]	AMOUNT
Acrylonitrilebutadiene styrene	8,9 kg
Chloroprene (monomer)	1,1 kg
Ethylene propylene dipolymer	3,1 kg
Expanded polystyrene	329 kg
Polyamide	1,93 Kg
Polyester	10,6 kg
Polyester concrete	140 kg
Polyethylene, high Density	47 kg
Polyethylene, low Density	99 kg
Polypropylene	2,7 kg
Polysulfide	61 kg
Polyurethane foam blown with air	51,4 kg
Polyvinyl chloride	139 kg
Total:	1866 kg

** W/E Adviseurs,1999*
1 Glues, coatings and packaging not included

ANNEX 6.79 **Houses with insulation application in time (Agenstchap, NL)**[1]

	1995	2000	2006	2012
Ground floor	24%	34%	43%	56%
Closed facade	41%	50%	55%	70%
Roof	51%	63%	76%	79%
Glazing	57%	69%	82%	86%

1 https://vois.datawonen.nl/report/cow13_701.html

ANNEX 6.80 **Insulation material consumption in Western Europe, 1991***

	106 M3/YEAR	MILLION TONS/YEAR
Mineral wool	52.7	0.8
EPS	20.2	0.5
Poly Urethane	3.5	0.1
Miscellaneous	2.8	0.1

** Buttenwieser, C. et al 1993 in Gielen 1997*

ANNEX 6.81 **Sales of plastic insulation (Buildsight in Agentschap NL, 2012)**

	2010	2011
Sales (million m2)	16,9	18,6
Sales (Rd in m2 K/W)	2,7	2,9
New construction (million m2)	11,5	11,3
Existing construction (Rd in m2 K/W)	2,8	3,2
New construction (million m2)	5,4	7,3
Existing construction (Rd in m2 K/W)	2,4	2,5

ANNEX 6.82 **Loose insulation (Buildsight in Agentschap NL, 2012)**

	2010	2011
Cavity wall million m2	1,5	2,4
Rm (traditional 7cm cavity)	2,2	2,2

ANNEX 6.83 **References used for hosing stock characterization according to material content, typology and construction year**

HISTORIC ANALYSES (A)	ENERGY PERFORMANCE REPORTS (B)	OTHER SPECIFIC STUDIES (C)
Bot, 2009	Novem, 2001	Symonds et al., 2000
Van Elk and Priemus, 1971	VROM, 2006	VROM, 2003
Lijbers et al., 1984	Senternovem, 2007	RiHofstra et al., 2006
Noy and Maessen, 2011	Senternovem, 2006	Feijen, 2003
Blaazer and van Gessel, 2011	Agentschap Nl, 2011c	de Lange, 2011
Oosterhoff, 1990	Itard et al, 2008	van Battum, 2002
Leupen et al., 2011	Koppert, 2012	Thijssen, 1990;1999
http://www.rotterdamwoont.nl/pages/view/1	Archidat, 2012[1]	Verhoeks et al., 1995
	Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2010	Straub, 2001
	Blije et al., 2010	Norris and Shiels, 2004
		Gort, R. et al., 2007
		Meijer and Thomsen, 2006
		Hasselaar, 2001
		ABF Research -Systeem woningvoorraad (ABF Research, Syswov)
		Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013
		Van Elke and Priemus, 1971
		Diederen et al., 1989

(a) Evolution of building technology in the Netherlands.
(b) Reports focused on energy performance.
(c) Specific studies of focused on segments of the housing stock.
1 http://bouwdetails.bouwformatie.nl/renovatie-verbouw/

ANNEX 6.84 **Wood stock in the assessed housing group.**

Wooden structure floors were more frequent until about 1950- 1970, and lately more systematically substituted to stone-based materials (Lijbers et al., 1984; Straub, 2001; Itard et al., 2008; de Lange, 2011; Senternovem, 2007). Until 1970, roofs were also constructed with wood beams and planking (Straub, 2001; Itard et. al., 2008)[1]. Solid wood in construction remained therefore mainly used for the manufacture of rafters, roof, floor, window and doorframes, doors, wall finishing and pillars (Blaazer and van Gessel, 2011).

Chapters 4 and 6 identified that single-family houses built until 1945 and at times until 1950 are commonly characterized by traditional construction (Thijssen, 1999). These houses had different combinations of floors, and some of them had no attic. Most of them had wooden floors applied on the first floor and attic, and wood floors or stony based materials on the ground floor (Thijssen,1999). One reference house within this group identified a livable attic (Novem, 2001) and characterized by wood floors. In single-family houses built until 1975 wood was applied in the ground floor construction (Lijbers et al., 1984).

In the period from 1945 to 1954, post-war reconstruction started and new faster and cheaper building technologies were introduced in particular in the multi-family housing group (van Elk and Priemus, 1971; Lijbers et al., 1984). Within this group, traditional construction was the conventional system used with 41% houses with wooden floors and 21% traditional with stony based material floor (RIVM/TNO, 2000). Archidat (2012) considered that houses built between 1946 and 1964 were mainly traditionally built with wood flooring and Hofstra et al. (2006) considered houses between 1900-190 mainly characterized by wooden floors. Even though during this period housing construction increased, demolition rates of houses built in the period 1945-1970 are high according to ABF Research, Syswov. Between 1954 and 1964, 884.034 houses in total were built (including multi-family) (CBS). The housing group built before 1964 has also a relevant share in square meters in the total stock (Agenstcap Nl, 2011).

According to Novem (2001) and Senternovem (2007), Vrijstaand built until 1966; Rijtjes built between 1946-1964[2]; Twee onder een kap and Maisonette built before 1964 are characterized with wooden floors. As a result, it is estimated that wooden products concentrate in traditionally single-family dwellings built until mid-1960's[3]. Within this group, Vrijstaand, Rijwoning, Twee onder een kap and Maisonette (the only multi-family typology included in this group) have different constructive characteristics.

Other housing groups are also a relevant source of wood to be reused as wood skeleton buildings and other housing groups built between 1965- 1974. The challenge to include these other groups in this assessment regards the lack of suitable data able to compare housing stock classifications from different reports. Table 1 describes one of the few sources available describing information about the housing stock according to building systems, typology, and construction year combined, however, detailed information regarding building sizes and other physical characteristics are omitted.

1 Despite the references mentioned above, another report from 1995 that described the housing stock according to building technology could not be retrieved from its sources (TNO and RIVM).

2 Rijtjes built between 1946-1964 (wood floors decreases during this period according to the report from 2007.

3 According to bibliography described in this chapter and building energy assessment reports from Novem (2001); VROM (2007) and Agentschap Nl (2011).

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ANNEX 6.84 **Wood stock in the assessed housing group.**

BUILDING TYPOLOGY ACCORDING TO CONSTRUCTION SYSTEMS AND CONSTRUCTION YEAR (FEIJEN, 2003)										
	tot 1905	1905-1919	1920-1929	1930-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974
	1	2	3	4	5	6	7	8	9	10
Single family 1 floor traditional	5,360	2,958	4,515	5,719	723	1,099	226	-	-	-
Single family 1 floor traditional 2	-	-	278	440	362	1,049	2,537	3,129	4,317	7,924
Single family 1fl gietbouw	-	-	139	220	310	600	902	1,081	1,477	4,670
Single family 1fl houtskeletbouw	-	-	-	-	103	200	282	341	511	1,132
Single family 1fl montagebouw	-	-	-	-	-	-	-	-	-	-
Single family 2 floors traditional	209,044	115,373	175,268	222,963	33,796	51,770	9,919	-	-	-
Single family 2fl traditional 2	-	-	11,513	18,210	17,250	49,885	119,615	148,084	202,339	162,196
Single family 2fl gietbouw	-	-	5,558	7,623	14,786	28,285	42,789	50,352	68,881	95,555
Single family 2fl houtskeletbouw	-	-	-	-	4,401	8,228	12,642	14,868	24,265	23,862
Single family 2fl montagebouw	-	-	-	-	-	-	-	-	-	-
Single family >2 floors traditional	65,896	36,368	55,261	70,339	9,635	14,754	2,790	-	-	-
Single family >2 fl traditional 2	-	-	3,631	5,728	4,945	14,139	34,036	42,160	57,551	128,664
Single family >2 fl gietbouw	-	-	1,737	2,359	4,184	8,053	12,205	14,290	19,581	75,780
Single family >2 fl houtskelet-bouw	-	-	-	-	1,204	2,336	3,557	4,195	6,878	18,918
Single family >2 fl montagebouw	-	-	-	-	-	-	-	-	-	-

The predominance of the single- family houses in the Netherlands has been constant reaching 84% of the total housing stock where 71% of the total built surface of the housing stock is constituted by single-family typologies: Rijwoning, Vrijstaand and Twee onder een kap (Agentschap Nl, 2011[c]).
Stony based materials were initially more often concentrated in multi-family building structures (Feijen, 2003). From 1905 to 2000, data shows how newer construction systems substituted theTotal Traditionele system (Figure A). Deconstruction of multi-family buildings for products reuse will mainly focus on sanitary, doors, windows, kitchen cabinets and other non-structural elements as described by the data collected from Bowcarroussel inventory (Rob Gort[1]).

1 Interview Rob Gort, Bouwcarroussel

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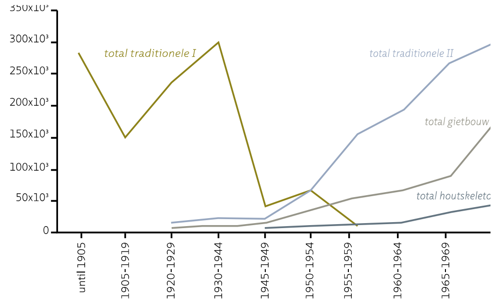
TOC

ANNEX 6.84 **Wood stock in the assessed housing group.**

Construction systems trend in the housing stock from 1900 to 1974. Housing stock in the Netherlands according to construction year and type of housing, accounted in January 16.81995. (Feijen, 2003).



The dominant typologies (in square meters) representing more than 50% of the built housing stock are Rijwoning houses from all periods and Vrijstaand from before 1964 and between 1975-2005 (Figure B). Within these housing groups, there are different types of material concentrations and building technologies. According to Hoftra et al. (2006), the stony fraction from housing groups built before 1900 and between 1900 and 1950 was estimated between 100 and 125 tons per dwelling respectively[1]. The housing group after 1950 was within an average of 175- 215 tons per dwelling. In their scenario, these rates would grow until 2025 reaching 250 tons per dwelling. This present study case focuses on evaluating reusable materials from traditional constructions with wooden floor in single-family houses built until 1964 (despite data from RIVM/TNO_1995/2000 (in Feijen, 2003)_ indicating increase diffusion of Traditional II and Gietbouw constructive systems after 1949). Finally, the building groups included in this assessment are:

Vrijstaand <1964

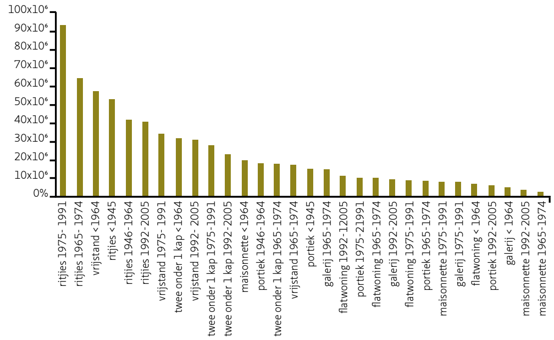
Rijtjes <1945

Rijtjes 1946- 1964

Twee onde een Kap < 1964

Maisonnete <1966

According to these references, most of the single-family housing plans from this period were characterized by two main navies, a large one and a narrow one parallel to each other where the beam sizes are built according to the size of the spans Novem (2001), resulting in an average 0,025 m^3/m^2 of usable area.



1 For Hofstra et al. (2006), a general house with no specification of construction year, the waste composition varies around 200-250 tons of stony fraction, 10 tons of non stony fraction and 15 tons of wood.

ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

For the wooden floors, two sets of floor beams are used as references according to Noy and Maessen (2011) and Bone and Kemps (2000): 71 X 196mm and 46 X 171mm. According to interviews[1] and to Leijendeckers et al. (2003) a common wood density for the reference house is 510 kg/m^3 as in Grenen_ a type of wood broadly applied in civil construction in the Netherlands (Centrum Hout, 2005), resulting in an average of 12,75kg/m^2 of wood for the floor structure. Using a different density reference as the Netherlands wood conversion factor by the Fonseca (2010) of 1,67, the result is an average of 14,9kg/m^2 of wood in the floor structure. Finally, wood concentrations adopted for the reference house were 13kg/m^2 for floor structure and 10kg/m^2 for wood covering. For the roof, only pitched roof structure types are included according to the housing references with an average wood content of 22,6kg/m^2, and the average wood estimated for window frames is 13,5kg/m^2. No wood panels are included in the calculation such as multiplex, triplex.

1 Interview Jan van Eijken (Oude bouwmaterialen).

RECOVERABLE MATERIAL FOR REUSE BY HOUSING GROUP TYPE

	Demli-tion rate pe year	0.08%		1.65%		3.24%		1.66%		0.15%
	1. Vrijstand <64	441000	2. rijtjes <45	523000	3. rijtjes 46-64	478000	4. Twee o e Kap voor <1964	285000	5. Maison-nette < 1966	226000
	wood recoverable in stock	wood recoverable per year in stock	wood recoverable in stock	wood recoverable per year in stock	wood recoverable in stock	wood recoverable per year in stock	wood recoverable in stock	wood recoverable per year in stock	wood recoverable in stock	wood recoverable per year in stock
upperfloors	121,540	97	130,541	2,154	86,996	2,819	71,136	1,181	63,226	95
floorcovering	93,492	75	100,416	1,657	66,920	2,168	54,720	908	48,635	73
roof/floor zolder	75,676	61	87,027	1,436	49,712	1,611	42,978	713		-
floorcovering	58,212	47	66,944	1,105	38,240	1,239	33,060	549		-
floor ground	126,126	101	135,980	2,244	86,996	2,819	78,546	1,304	40,192	60
floorcovering	97,020	78	104,600	1,726	66,920	2,168	60,420	1,003	30,917	46
pitched roof	321,489	257	305,955	5,048	202,194	6,551	207,765	3,449	151,533	227
flat roofs		-	10,878	179	-	-	7,410	123	-	-
windows	67,394	54	64,674	1,067	59,884	1,940	32,935	547	24,774	37
TOTALS	960,948	769	1,007,015	16,616	657,862	21,315	588,970	9,777	359,277	539
		97.23		2,153.92		2,818.67		1,180.86	Total wood recoverable in stock	3,574,071
									Current av-erage wood recoverable per year in stock	49,015
recov roof tiles	657,266	525.81	625,508	10,320	413,374	13,393	424,764	7,051	309,800	464.70
Total:	1,643,166		1,563,770		1,033,436		1,061,910		774,502	

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ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

RECOVERABLE MATERIAL FOR REUSE BY HOUSING GROUP TYPE										
	Demli-tion rate pe year	0.08%		1.65%		3.24%		1.66%		0.15%
									Ceramic roof tiles ecoverable in stock	2,430,713
									Current average ceramic roof tiles recoverable per year in stock	31,755
recov exter-nal wall	7,830,043	6,264	6,642,518	109,601	5,885,136	190,678.41	3,619,728	60,087	2,167,430	3,251
Totals	19,575,108		16,606,296		14,712,840		9,049,320		5,418,576	
per unit avg	44.39		31.75		30.78		31.75		Clay bricks ecoverable in stock	26,144,856

ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

RECOVERABLE MATERIAL FOR REUSE FOR HOUSING GROUP VRIJSTAAND <1964					
	Vrijstand voor 1964	441.000 6,5%			
	Internal brick walls. Empty cavity brick walls (45%). Wooden floor. Pitched roof with clay tiles, an air cavity and wood roof paneling. [2] High ceilings. Wooden ground floor (until the 70's) [3] The older generation of concrete tiles was not of good quality, which affected sales. During the 70's the consumption of this type of tiles significantly increased. [4]				
	Number of households	Average 3 per house	Private	Social rental	private rental
	m2/ capita	43,3m2/capita	91%	_	8%
	Usable surface	141 m2 [5]			
	Ground floor surface	55 m2 [5]			
	Floors	2 to 4			
	Demolition rate (per year)	1.18%		Current stock	Demolition rate per year
	SURFACE	Material per house	40% recoverable	441,000 units	1.18%
Floor (upper floors)	53 m2 [5]	689.0kg	275.6kg	121,540 metric ton	1,434.2 metric ton
floor covering	53 m2 [5]	530.0kg	212.0kg	93,492 metric ton	1,103.2 metric ton
Roof floor (zolder)	33 m2 [5]	429.0kg	171.6kg	75,676 metric ton	893.0 metric ton
floor covering	33 m2 [5]	330.0kg	132.0kg	58,212 metric ton	686.9 metric ton
Floor (ground floor)	55 m2 [5]	715.0kg	286.0kg	126,126 metric ton	1,488.3 metric ton
floor covering	55 m2 [5]	550.0kg	220.0kg	97,020 metric ton	1,144.8 metric ton
Pitched roof	81 m2 [5]	1,822.5kg	729.0kg	321,489 metric ton	3,793.6 metric ton
roof tiles	81 m2 [5]	3,726.0kg	1,490.4kg	657,266 metric ton	7,755.7 metric ton
Flat roof					
External wall (façade) solid wall (55%)	137m2	44,388.0kg	17,755.2kg	7,830,043 metric ton	92,394.5 metric ton
cavity wall half brick(45%)					
Windows	28.3m2	382.1kg	152.8kg	67,394 metric ton	795.2 metric ton
Doors (buiten)	2.9m2	59.1kg	23,3kg	10275300 kg	
Doors (binnen)	10 pieces [5]		4	1764000	

[1] Data based on 2011 report [2] report from 2001 [3] report from 2007 [4] Peit Bot
[5] Referentiewoningen bestaande bouw, 2001 Novem [6] Cijfers report 2013

ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

RECOVERABLE MATERIAL FOR REUSE FOR HOUSING GROUP RIJTJES < 1945					
	Rijtjes < 1945	523.000/ 7,7%			
	Internal brick walls. Empty cavity brick walls (38%). Wooden floor. Pitched roof with clay tiles, an air cavity and wood roof paneling. [2] Ground floor which is made of wood. The houses were therefore not insulated. [3] The older generation of concrete tiles was not of good quality, which affected sales. During the 70's the consumption of this type of tiles significantly increased. [4]				
	Number of households	3	Private	Social rental	private rental
	Number of households	3	Private	Social rental	private rental
	m2/ capita	34 m2	71%	23%	6%
	Usable surface	130 m2 [5]			
	Ground floor surface	50 m2 [5]			
	Floors	3			
	Demolition rate (per year)	2.75%		Current stock	Demolition rate per year
	SURFACE	Material per house	40% recoverable	523,000 units	2.75%
Floor (upper floors)	48 m2 [5]	624.0kg	249.6kg	130,541 metric ton	3,589.9 metric ton
floor covering	48m2	480.0kg	192.0kg	100,416 metric ton	2,761.4 metric ton
Roof floor (zolder)	32 m2 [5]	416.0kg	166.4kg	87,027 metric ton	2,393.2 metric ton
floor covering	32m2	320.0kg	128.0kg	66,944 metric ton	1,841.0 metric ton
Floor (ground floor)	50 m2 [5]	650.0kg	260.0kg	135,980 metric ton	3,739.5 metric ton
floor covering	50 m2 [5]	500.0kg	200.0kg	104,600 metric ton	2,876.5 metric ton
Pitched roof	65 m2 [5]	1,462.5kg	585.0kg	305,955 metric ton	8,413.8 metric ton
roof tiles	65m2	2,990.0kg	1,196.0kg	625,508 metric ton	17,201.5 metric ton
Flat roof	4 m2 [5]	52.0kg	20.8kg	10,878 metric ton	299.2 metric ton
External wall (façade) solid wall (62%)	98m2	31,752.0kg	12,700.8kg	6,642,518 metric ton	182,669.3 metric ton
cavity wall half brick(38%)					
Windows	22.9m2	309.2kg	123.7kg	64,674 metric ton	1,778.5 metric ton
Doors(buiten)	2.5m2	52.25kg	20.9kg	10930700 kg	
Doors and frame (binnen)	12 pieces [5]		5	2615000	
Sanitaire	1 wastafel; 2 wcs; 1 shower [5]				

ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

RECOVERABLE MATERIAL FOR REUSE FOR HOUSING GROUP RIJTJES 1946-1964					
	Rijtjes 1946- 1964	478.000/7%			
	Internal brick walls. Empty cavity brick walls (80%). Wooden floor. Pitched roof with clay tiles, an air cavity and wood roof paneling. [2] During this period a major shift from traditional to build more industrial construction. Notable in this period of construction is that the use of wooden floors decreases. Houses were not isolated in the dwellings built before 1960.[3] The older generation of concrete tiles was not of good quality, which affected sales. During the 70's the consumption of this type of tiles significantly increased. [4]				
	Number of house-holds	2,8	Private	Social rental	private rental
	Number of house-holds	2,8	Private	Social rental	private rental
	m2/ capita	31 m2/ capita	40%	57%	3%
	Usable surface	90 m2 [5]			
	Ground floor surface	35 m2[5]			
	Floors	3			
	Demolition rate (per year)	3.13%		Current stock x	Demolition rate per year
	SURFACE	Material per house	40% recoverable	478,000 units	3.13%
Floor (upper floors)	35 m2 [5]	455.0kg	182.0kg	86,996 metric ton	2,723.0 metric ton
floor covering	35m2	350.0kg	140.0kg	66,920 metric ton	2,094.6 metric ton
Roof floor (zolder)	20 m2 [5]	260.0kg	104.0kg	49,712 metric ton	1,556.0 metric ton
floor covering	20m2	200.0kg	80.0kg	38,240 metric ton	1,196.9 metric ton
Floor (ground floor)	35 m2 [5]	455.0kg	182.0kg	86,996 metric ton	2,723.0 metric ton
floor covering	35m2	350.0kg	140.0kg	66,920 metric ton	2,094.6 metric ton
Pitched roof	47 m2 [5]	1,057.5kg	423.0kg	202,194 metric ton	6,328.7 metric ton
roof tiles	47m2	2,162.0kg	864.8kg	413,374 metric ton	12,938.6 metric ton
Flat roof		0.0kg	0.0kg	0 metric ton	0.0 metric ton
External wall (façade) solid wall (20%)	95m2	30,780.0kg	12,312.0kg	5,885,136 metric ton	184,204.8 metric ton
cavity wall half brick(80%)					
Windows	23.2m2	313.2kg	125.3kg	59,884 metric ton	1,874.4 metric ton
Doors (buiten)	1.3m2	27.17kg	10.8kg	5194904 kg	
Doors (binnen)	8 pieces [5]		3	1434000	

ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

RECOVERABLE MATERIAL FOR REUSE FOR HOUSING GROUP TWEE ONDER EEN KAP VOOR <1964					
	Twee o e Kap voor <1964	285.000/ 4,2%			
	Internal brick walls. Empty cavity brick walls (64%). Wooden floor. Pitched roof with clay tiles, an air cavity and wood roof paneling. [2] High ceilings on the ground. The ground floors are made of wood in this type of homes even late '70s. No insulation until 1966. [3] The older generation of concrete tiles was not of good quality, which affected sales. During the 70's the consumption of this type of tiles significantly increased. [4]				
	Number of house-holds	3	Private	Social rental	private rental
	Number of house-holds	3	Private	Social rental	private rental
	m2/ capita	36,6 m2/ capita	84%	10%	6%
	Usable surface	130 m2 [5]			
	Ground floor surface	53 m2 [5]			
	Floors	3 to 4			
	Demolition rate (per year)	1.50*% [6]		Current stock	Demolition rate per year
	SURFACE	Material per house	40% recoverable	285,000 units	2.50%
Floor (upper floors)	48 m2 [5]	624.0kg	249.6kg	71,136 metric ton	1,778.4 metric ton
floor covering	48m2	480.0kg	192.0kg	54,720 metric ton	1,368.0 metric ton
Roof floor (zolder)	29 m2 [5]	377.0kg	150.8kg	42,978 metric ton	1,074.5 metric ton
floor covering	29m2	290.0kg	116.0kg	33,060 metric ton	826.5 metric ton
Floor (ground floor)	53 m2 [5]	689.0kg	275.6kg	78,546 metric ton	1,963.7 metric ton
floor covering	53m2	530.0kg	212.0kg	60,420 metric ton	1,510.5 metric ton
Pitched roof	81 m2 [5]	1,822.5kg	729.0kg	207,765 metric ton	5,194.1 metric ton
roof tiles	81m2	3,726.0kg	1,490.4kg	424,764 metric ton	10,619.1 metric ton
Flat roof	5 m2 [5]	65.0kg	26.0kg	7,410 metric ton	185.3 metric ton
External wall (façade) solid wall (36%)	98m2	31,752.0kg	12,700.8kg	3,619,728 metric ton	90,493.2 metric ton
cavity wall half brick(64%)					
Windows	21.4m2	288.9kg	115.6kg	32,935 metric ton	823.4 metric ton
Doors (buiten)	2.3m2	46.2kg	18.4kg	5267598 kg	
Doors and frame (binnen)	10 pieces		4	1140000	

ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

RECOVERABLE MATERIAL FOR REUSE FOR HOUSING GROUP MAISONNETTE < 1966					
	Maisonnette < 1966	226.000/ 3,3%			
	Full single wall façade. Internal brick wall. Wooden floor. Pitched roof [2] The floors and the roof boards are often made of wood. Not insulated until 1966. Until about 1930, there is no cavity walls applied. [3] The older generation of concrete tiles was not of good quality, which affected sales. During the 70's the consumption of this type of tiles significantly increased. [4]				
	Number of house-holds	2,8	Private	Social rental	private rental
	Number of house-holds		Private	Social rental	private rental
	m2/ capita		29%	44%	27%
	Usable surface	88m2			
	Ground floor surface	34,2m2			
	Floors				
	Demolition rate (per year)	1.95%		Current stock x	1.95%
6.725 units per year	SURFACE	Material per house	40% recoverable	226,000 units	Demolition rate per year
Floor structure (upper floors)	53.8m2	699.4kg	279.8kg	63,226 tons	1,232.9 tons
floor covering	53.8m2	538.0kg	215.2kg	48,635 tons	948.4 tons
Roof floor (zolder)	X				
floor covering	X				
Floor structure (ground floor)	34.2m2	444.6kg	177.8kg	40,192 tons	783.7 tons
floor covering	34.2m2	342.0kg	136.8kg	30,917 tons	602.9 tons
Pitched roof structure	74.5m2	1,676.3kg	670.5kg	151,533 tons	2,954.9 tons
roof tiles	74.5m2	3,427.0kg	1,370.8kg	309,801 tons	6,041.1 tons
Flat roof structure	X				
External wall (façade) solid wall (100%)	74m2	23,976.0kg	9,590.4kg	2,167,430 tons	42,264.9 tons
cavity wall half brick(%)					
Windows	20.3m2	274.1kg	109.6kg	24,774 tons	483.1 tons
Doors (buiten)	2.3m2	46.2kg	18.4kg	5267598 kg	
Doors and frame (binnen)	8 pieces		3	678000	

ANNEX 6.85 **Assessment for recoverable wood in pre-determined housing group.**

SUMMARY OF WOOD STOCK AND RECOVERABLE PERCENTAGE FROM THE HOUSING GROUP REPRESENTED IN THE STUDY CASE.					
	1. Vrijstaand <64	2. Rijtjes <45	3. Rijtjes 46-64	4. Twee o e Kap <1964	5. Maisonnet. < 1966
Recoverable wood (40%)	960.948 mt	1.007.015 mt	657.862 mt	588.970 mt	359.277 mt
Total estimated wood recoverable in the selected housing stock group				3.574.071 mt	

ANNEX 6.86 **Withdraw rates in the housing stock according to construction year and building type**

2001 [1]	2007 [2]	2011 [3]	STOCK DYNAMICS	TENURE [3]
Population: 15 863 950 (CBS)	Population: 16 357 992 (CBS)	Population: 16 655 799 (CBS)		
Eurostat: GDP p capita 134. Real GDP growth rate 3,9% Eurostat: GDP p capita 132. Real GDP growth rate 3,2% Eurostat: GDP p capita 131. Real GDP growth rate 1,5%				
CBS Stock: 6.589.662 Newly built: 70 650 Withdraw: 13 528	CBS Stock: 6 967 046 Newly built: 80 193 Withdraw: 23 840	CBS Stock: 7 217 803. Newly built: 57 703 Withdraw: 14 467		Private Social Rental Private Rental
Vrijstaand				
voor 1966	voor 1966	voor 1964		
500.000/ 8%	513.000 8%	441.000 6,5%	11.8% withdraw rate in 10 years or average 1.18% per year.	P 91% SR 1% PR 8%
Twee o e Kap				
voor 1966	voor 1966	voor 1964		
380.000/ 6%	393.000/ 6%	285.000 6,5%	25% withdraw rate in 10 years or average 2.5% per year.	P 84% SR 10% PR 6%
Maisonnette				
voor 1966	voor 1966	voor 1964		
230.000/ 3,5%	203.000/ 3%	226.000/3,3%	11.7% withdraw rate in 6 years or 1.95% per year	P 29% SR 44% PR 27%
Rijtjes				
< 1946	< 1946	< 1945		
600.000/ 9,5%	501.000/ 7,5%	523.000/ 7,7%	16.5% withdraw rate from the stock in 6 years or 2.75% per year	P 71% SR 23% PR 6%
1946 -1965	1946 -1965	1946 -1964		
735.000/ 12%	669.000/ 10%	478.000/7%	31.3% withdraw rate from the stock in 10 years or 3.13% per year	P 40% SR 57% PR 3%

[1] Novem (2001). "Referentiewoningen bestaande bouw." CE, Delft,The Netherlands.
[2] Stenternovem (2007). "Voorbeeldwoningen bestaande bouw 2007 ".Ministerie van Economische Zaken. Publicatie, (2KP-WB0618).
[3] Agentschap, N. L. (2011)c. Voorbeeldwoningen 2011, Onderzoeksverantwoording. Energie en Klimaat, Sittard.
** red text indicate defective data*

ANNEX 6.87 **Comparison of housing stock built before 1906 until 1970 from 1985 until 2012 (based on data from en Koninkrijksrelaties, Ministerie van Binnenlandse Zaken. "Cijfers over Wonen en Bouwen 2013."[1]**

	1985	1990	1995	2000	2005	2010	2012
<1906	476038	464188	495353	461276	480110	502070	508640
1906-1930	687611	638259	619192	593069	617284	573794	581303
1931-1944	423145	406165	433434	395379	411523	430346	435977
1945-1959	793398	812330	804949	790759	754459	788967	726629
1960-1970	1216543	1218496	1176465	1186138	1165982	1147589	1162607
Total	3596735	3539438	3529393	3426621	3429358	3442766	3415156

** Brown cells indicate defective data*

1 http://www. rijksoverheid.nl/onderwerpen/woningmarkt/documentenenpublicaties/rapporten/2013/04/11/cijfers-over-wonen-en-bouwen-2013. html (2013).

ANNEX 6.88 **Housing Stock according to construction year from 1985-2011***

CON-STRUCTION YEAR	-1905	1906-1930	1931-1944	1945-1959	1960-1970	1971-1980	1981-1990	1991-2000	2001+
Withdraw rates from 1985 to 2011	-0.07%	-0.60%	-0.09%	-0.31%	-0.19%	-0.07%	-0.04%	-0.02%	-95.71%

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ANNEX 6.89 **Scenarios for recoverable wood for reuse from housing sample**

Scenarios for recoverable wood for reuse from housing sample in 1 year	Total consumed sawn wood in Nl 20008 (tons)	Domestic sawn production in Nl 2008 (tons)	Total sawn wood and panels in buildings in 2008 (tons)	Total certified sawn wood and panels in Nl by construction 2008	Window frames used by building sector 2010 (tons)	Doors used by building sector 2010 (tons)	General carpentry used by the building sector 2010 (tons)
	1.806.093	146.103	1.400.000	956.700	160.000	128.000	211.000
S1: 49.015 tons	2,71%	33,54%	3,5%	5,12%	30,63%	38,29%	23,22%
S2: 6.433 tons	0,35%	4,4%	0,45%	0,6%	4%	5%	3%
S3: 8.935 tons	0,38%	4,7%	0,63%	0,93%	5,58%	6,98%	4,2%

ANNEX 6.90 **Sawn wood in the Netherlands***

SAWN WOOD (PROBOS, 2011)	SOFTWOOD (TONS)	HARDWOOD (TONS)	TOTAL (TONS)
2008			
Domestic production	87362	58741	146103
Import	1388461	544055	1932516
Export	164285	107692	271977
Consumption	1310989	495104	1806093

** Probos*

Coniferous 1.82m3 per Mt non coniferous 1.43m3 per Mt. Unit conversion in this stable has been based on the method published by UNECE, 2009. Forest Product Conversion Factors: Project Overview And Status. www.unece.org.

ANNEX 6.91 **Construction and demolition waste of wood from 2002-2010 (X1000 tons)***

YEAR	SBI	TOTAL
2002	Wood_45	589.38
2003	Wood_45	591.25
2004	Wood_45	594.64
2005	Wood_45	547.32
2006	Wood_45	507.56
2007	Wood_45	584.69
2008	Wood_43	66.08
2009	Wood_43	130.60
2010	Wood_43	150.90

** LMA*

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