Closing the loop; a circular construction sector by 2050.

Materials passports in the Dutch construction sector

Master thesis

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1 SUMMARY

The construction sector has a large environmental impact and waste contribution. The sector is the number one consumer of raw materials and 30% of global greenhouse gases can be attributed to the building sector. In the Netherlands the construction sector is accountable for 46% of total waste. This heavy environmental pressure stresses the need for reduction. The Dutch government has the ambition of having a circular economy (CE) by 2050 and a reduction of 50% in primary resource use by 2030 to decrease this environmental pressure. Fuelled by these ambitions, the development of tools that increase building circularity has been growing. So has the concept of a materials passport (MP). The materials passport can be considered as an inventory of building products used during construction and its characteristics. Rigid guidelines to what it should include are lacking and standardization is not present. Using qualitative interview data from experts and assessment of current existing MP practices, this research aims to identify the information needs, potential pitfalls to using the MP and assess its possible contribution in the transition towards a CE in 2050. Having information on what building materials, products and elements have been used in a building, is assumed to lead to more reuse at end of life (EOL). This research shows that for the implementation of the MP as a tool to accelerate the transition towards a circular construction sector, several important adjustments are necessary. The current existing MP practices do not resemble what the building sector thinks is necessary in a passport for it to be useful. According to the experts questioned in this research, information on releasability, material properties, dimensions, toxicity information and structuring based on lifetime is indispensable. Besides these information needs, the environment and infrastructure in which the passports operate can be considered as underdeveloped. Practices show that to achieve reuse, recovery or recycling, the passport is not necessarily the key to success. To use the passport as a tool that aids the transition from a linear construction sector to a circular sector, standardization according to previous needs is not the only necessity. Policymakers and the sector have to further develop the framework of the passport, the infrastructure it is embedded in and the supply chain cooperation that is required, whilst practices that achieve high reuse at EOL have to be supported to achieve short term impact.

3 ACKNOWLEDGMENTS

Having finished this research regarding the circular construction sector in the Netherland, embarks the end of my studies. This project hadn't been where it is right now without the didactic guidance of my supervisor Jesus Rosales Carreon. The past 6 months have been challenging. Working through summer, working from home and never actually physically meeting each other, is not how I'd envisioned my master thesis a few years ago. I'd like to express my thanks for listening and guiding me through different hurdles along the way.

Also doing an internship has been challenging, I'd like to thank my internship supervisor Menno Brouwer for making me feel comfortable (also from home) during the past half year. To all direct colleagues, I've learned a great deal regarding the Dutch transition agenda towards a circular economy in 2050 and am more aware of the policy processes and research it entails. The Dutch construction sector is still at the beginning of what will be a great shift from conventional, environmental depleting, practices towards innovative and sustainable buildings. I am excited to ride this rollercoaster with everyone that envisions a more sustainable built environment in the coming decades.

PREFACE

To contribute to the understanding a brief explanation and justification of word use is added. The word ‘losmaakbaarheid’ in Dutch means literally how easy something can be released or demounted when translated to English, this results in the term ‘releasability’ or ‘demountability’ the latter not being an existing noun. The used word in this research is either disassembly or detachability. E.g., something is designed for disassembly whilst the detachability is used as a noun to explain how well a product can be detached from another product or building element.

In figures and in text the following abbreviations are used:
MP: Materials Passport
CE: Circular Economy
EOL: End Of Life
GHG: Green House Gas
LCA: Life Cycle Analysis

4 INTRODUCTION

4.1.1 CLIMATE PERSPECTIVE

The world has become more populated and cultivated than ever, economic and population growth have led to an increase of material use during the 20th century (Krausmann et al., 2009). Increased carbon dioxide (CO2) emissions have already led to a change in the earth's climate. According to NOAA (2017) the global annual temperature has increased by 0.08 degrees Celsius per decade since 1880 and twice that rate since 1981. During recent years, the call for change has been increasing and so has the societal pressure for climate friendly practices become more important in recent years (Seiffert & Loch, 2005). The urge to increase the liveability of planet earth for future generations, is gaining more attention and initiatives to aid the cause of a sustainable future are rapidly increasing amongst society. One of the so called 'future-proof' solutions part of the sustainable development, to mitigate global warming can be found in limiting our finite material use. The concept of circular economy (CE) is seen as an operationalization concept of sustainable development (Ghisellini et al., 2016). In the circular economy, growth is decoupled from the use of (natural) virgin materials by reuse, reduce or recirculation (Corona et al., 2019), decoupling growth from material use in the circular economy can be seen as a tool within the greater scope of sustainable development. Switching from the conservative linear economy, towards a circular economy, leads to less depletion of raw materials, more innovation, and fewer emissions. Framed by the Ellen MacArthur foundation, the circular economy can be described as *''an industrial economy that is restorative by intention and design''* (Ellen MacArthur Foundation, 2013).

4.1.2 ENVIRONMENTAL IMPACT CONSTRUCTION SECTOR

This research focusses on one of the key sectors to achieve a circular economy: the construction sector. The construction sector includes both construction and demolition as well as renovation and rebuilding. As the world has seen a significant increase in urbanization and population growth during the past century, it has also seen an increased depletion of natural resources as construction materials (Krausmann et al., 2009). Globally, the construction sector is number one consumer of raw materials and 30% of total global greenhouse gas emissions can be related to buildings (WEF, 2016). On a smaller scale, hence in the Netherlands the construction sector is accountable for 50% of the raw material use and responsible for approximately 35% of CO2 emissions (Rijksoverheid, 2016). These numbers show that the environmental impact of the construction sector is very high. Not only material use, and emissions are significant in the Dutch construction sector, it is estimated that the Dutch construction sector is responsible for 46% of the total amount of waste in the Netherlands. In total the estimated construction and demolition waste (CDW) is 25 million tons per year (Yu et al., 2021). This large amount of waste consists for 85% of concrete (Rijksoverheid, 2016), concrete brings a huge amount of CO2 emissions as it cannot be decomposed naturally or utilized directly (de Brito & Saikia, 2013). The estimated contribution of cement production (from which concrete is made) to global GHG emissions is 5-7% (Allwood et al., 2010). This significant contribution to global carbon emissions and high scoring environmental impact indicators such as waste contribution, stress the need for a closed loop in the construction sector. If materials were to be reused in the built environment it would decrease the need for raw materials, enhancing the circular economy and reducing waste significantly (Andersen, 2007). It is calculated that successful waste management strategies, including reuse of second hand materials and using materials with recycled content can save up to 70% of the total embodied energy in buildings (Treloar et al., 2003).

4.1.3 CURRENT STATE OF RECYCLING IN DUTCH CONSTRUCTION SECTOR

In the Netherlands different circular practices are already in place or are part of the future governmental plans. In 2016 the Dutch government have addressed the ambition of having a circular economy in 2050 and a reduction of 50% of primary resource use in 2030 (Rijksoverheid, 2016) . In line with this goal, a circular built environment needs to be established in 2050 as well. In 2018 the Dutch government founded the

'transition agenda circular built economy ' (Rijksoverheid, 2018) an agenda that translates the principles from the raw materials convention (Grondstoffenakkoord, 2017), a voluntary letter of intent in which over 300 companies address to strive for a circular economy in 2050, into an operational agenda for the transition towards a circular economy in the Netherlands. The governmental intention of having a circular built environment in 2050 as part of having a circular economy in 2050, aligns with the sustainable development goals 9 (*Industry, Innovation and Infrastructure*) and 11 (*Sustainable Cities and Communities*) to which the Dutch government also committed (UN General Assembly, 2015).

One of the circular practices already in place in the Dutch construction sector is recycling. However, the commonly practiced form of recycling that is present in the Dutch construction sector can be referred to as downcycling, which isn't part of the circular economy principles (Heinrich & Lang, 2019). Downcycling is a form of recycling, where the recycled material is used in an application that is of less value than the original purpose (Allwood, 2014). In 2014, 95% of the demolition waste generated in the Netherlands was downcycled into aggregate for civil engineering, acting as a road base material or other forms of filler material, resulting in only 3% of construction waste being reused for other (high value) construction purposes (Schut et al., 2015). As can be seen in figure 1, adopted from Schut et al. (2015), the downcycling of demolition waste is a finite process, there will be a point in time where no more substrate is necessary, because 'old' substrate can be reused again. At this point the amount of and CDW will not be recycled at all. More use of all the available demolition waste in the Netherlands is therefore desirable.

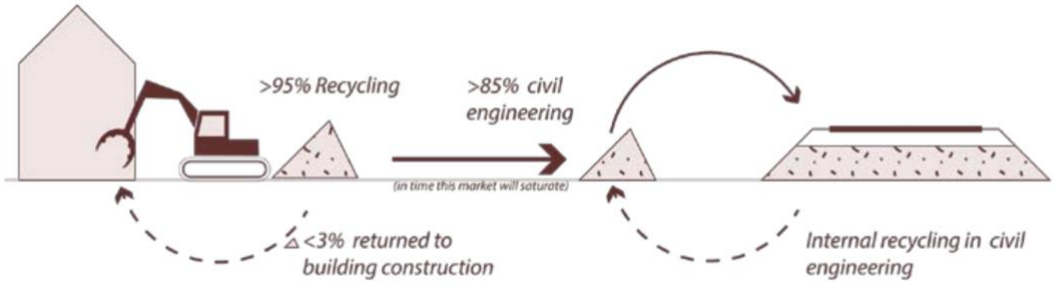

figure 1 demolition of buildings used in civil engineering from schut et al. (2015)

On different levels organizations are trying to accelerate the desired transition towards a circular economy with practices that aim for higher reuse and retrofitting in the construction sector. Governmental institutions try to encourage organizations and academics to create incentives, tools, and other beneficial measures to increase the transition towards a circular economy. To aid this transition, the introduction of a (obligatory) materials passport (MP) has been discussed by Transitieteam CBE (2020) . The report is stating that a MP could be a promising tool but needs further investigation regarding: information needs, circular acting as a result of the MP, possible alternatives and market development of the MP (Transitieteam CBE, 2020).

The MP as defined by Almusaed et al. (2020), is considered an advanced tool that can aid the transition towards a circular economy. Having prior knowledge on what is present in a building via a MP, could act as mechanism in building innovation (Luscuere, 2017). However, the use of a MP can also pose a burden to stakeholders. For example, architects and planners experience it as being a time consuming and difficult process, because information on material properties is not included (Honic et al., 2019). Furthermore, the information needs of the MP vary, as different user groups are interested in different levels of detail (Adisorn et al., 2021).

5 PROBLEM DEFINITION & RESEARCH AIM

The Dutch construction sector is accountable for a significant part of national emissions and waste generation. Together with the high amount of depletion of natural resources a transition towards circular practices is necessary. The Dutch government tries to implement the use of MPs, asking for a MP in tenders or building plans as a requirement for subsidy schemes (RVO, 2019). This, together with examples of initiatives to centralize the information needs in MPs, such as CB'23 (PlatformCB'23, 2020), show that there is a willingness to increase the accessibility of MPs, however, it remains unclear to what extent the use of MPs leads to the adoption of circular building strategies and ultimately contribute to a circular economy in the Netherlands by 2050.

5.1 RESEARCH AIM

The MP as a tool to increase the circularity in the Dutch construction sector shows potential but it remains unclear how the passport leads to more circular practices, what information needs there are and what indicators for circularity can be included in a MP. The aim of this research is to find out to what extent a MP can contribute in the shift towards a circular economy in the Netherlands.

This can be translated into the main research question:
To which extent can the MP contribute to a shift towards circular construction sector in the context of the circular economy?

To answer the main research question 3 sub questions have formulated that help defining an answer.

SQ1) What indicators for circularity are present in the built environment?

Answering this sub question teaches us how to valuate different products and materials currently present in the built environment, their relationship with construction and it shows what information in the supply chain should be present and could possibly be included in a MP.

SQ2) What are the essential information needs of a MP in construction?

This sub question helps understand what is needed in a MP according to different stakeholders and according to theoretical literature. In other words, what is necessary to accelerate the adoption of secondary materials in the construction sector. E.g., the level of detail, whether to use products or materials or both. The format and accessibility of the MP can also be outlined using the answer to this sub question. The answer to this question aid describing conditions that must be met to ensure good information management and benefit from the use of a MP

SQ3) What makes successful MP practices lead to circular construction actions?

Answering this question will show how the conditions, defined in sub question 2, should lead to (successful) circular practices, when using a MP. What processes need to be considered and what hurdles need to be overcome to use the passport in a circular way.

6 METHODS

Two main methods of research have been pursued, the first method used is expert interviews to retrieve qualitative information on the information needs of a MP and how the MP is translated into actual circular practices. The second method is a comparative analysis of existing MPs using a pedigree matrix. The theoretical framework has provided input to what indicators are assessed, what topics were asked during the interviews and what indicators are used in the passport analysis. An overview of the methodological framework is displayed in figures 2&3.

6.1 METHODOLOGICAL FRAMEWORK

In the figures 2 and 3 the methodology has been visualized using a flow chart. In the framework there are 5 steps that make op the pursued research steps. In the first step a theoretical framework was drawn to partly answer sub question 1 and 2. Following on step one the theoretical framework was used to draw an interview guide, which was used during the interviews, besides increasing the knowledge regarding sub questions 1 and 2, the interviews provided input for the third sub question. Reviewing the theoretical framework and the interview results has led to defining indicators for circularity, information needs of a MP and conditions for circular action, these three components have been bundled into one set of ideal conditions in step 3.

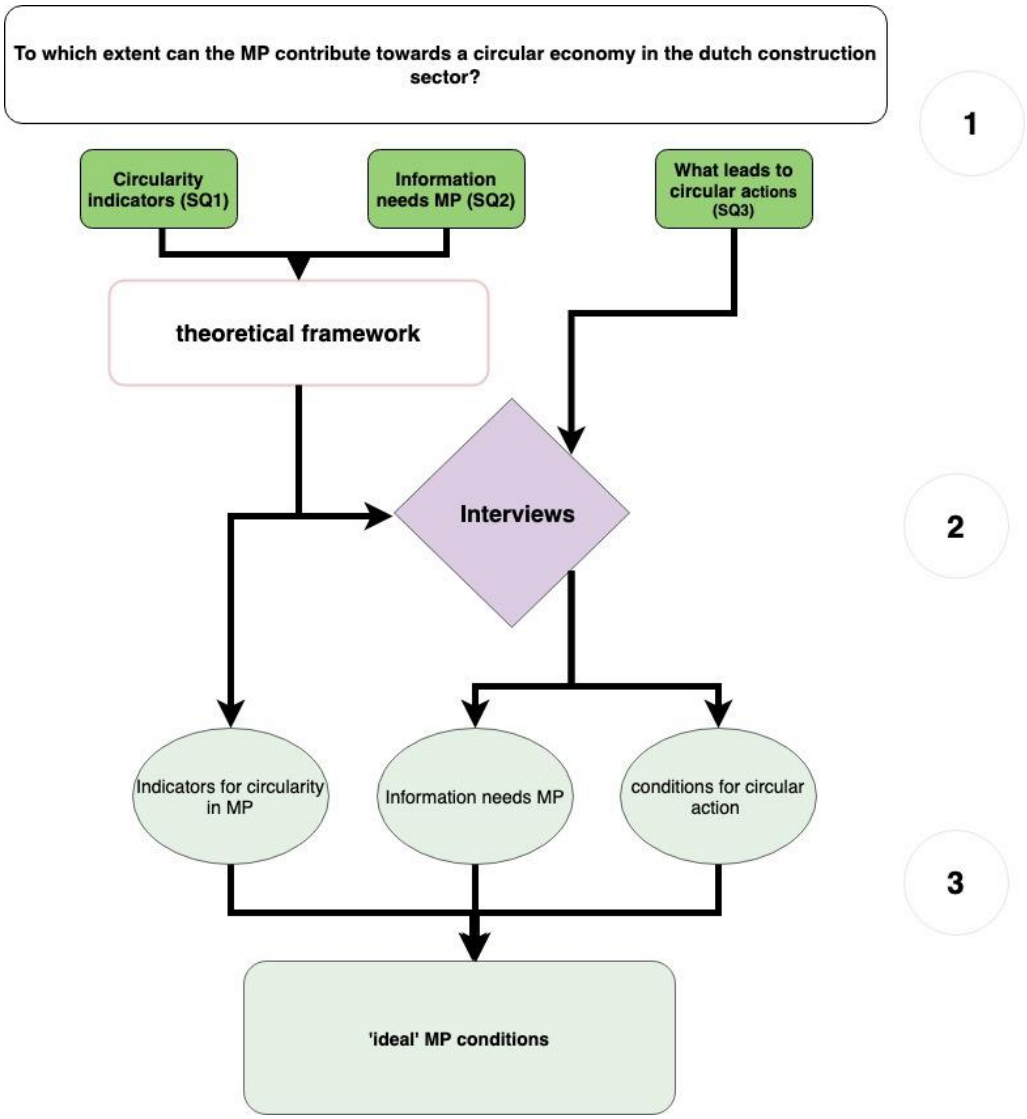

figure 2 methodological framework 1 (own elaboration)

The following figure (figure 3) shows the second research method. In step 4 a set of passports was scored on the conditions (from step 3) using a pedigree matrix. Ultimately identifying the strengths and weaknesses of these existing passports together with the MP conditions has led to the development of an advice on what strategy should be followed regarding MP practices in the Netherlands.

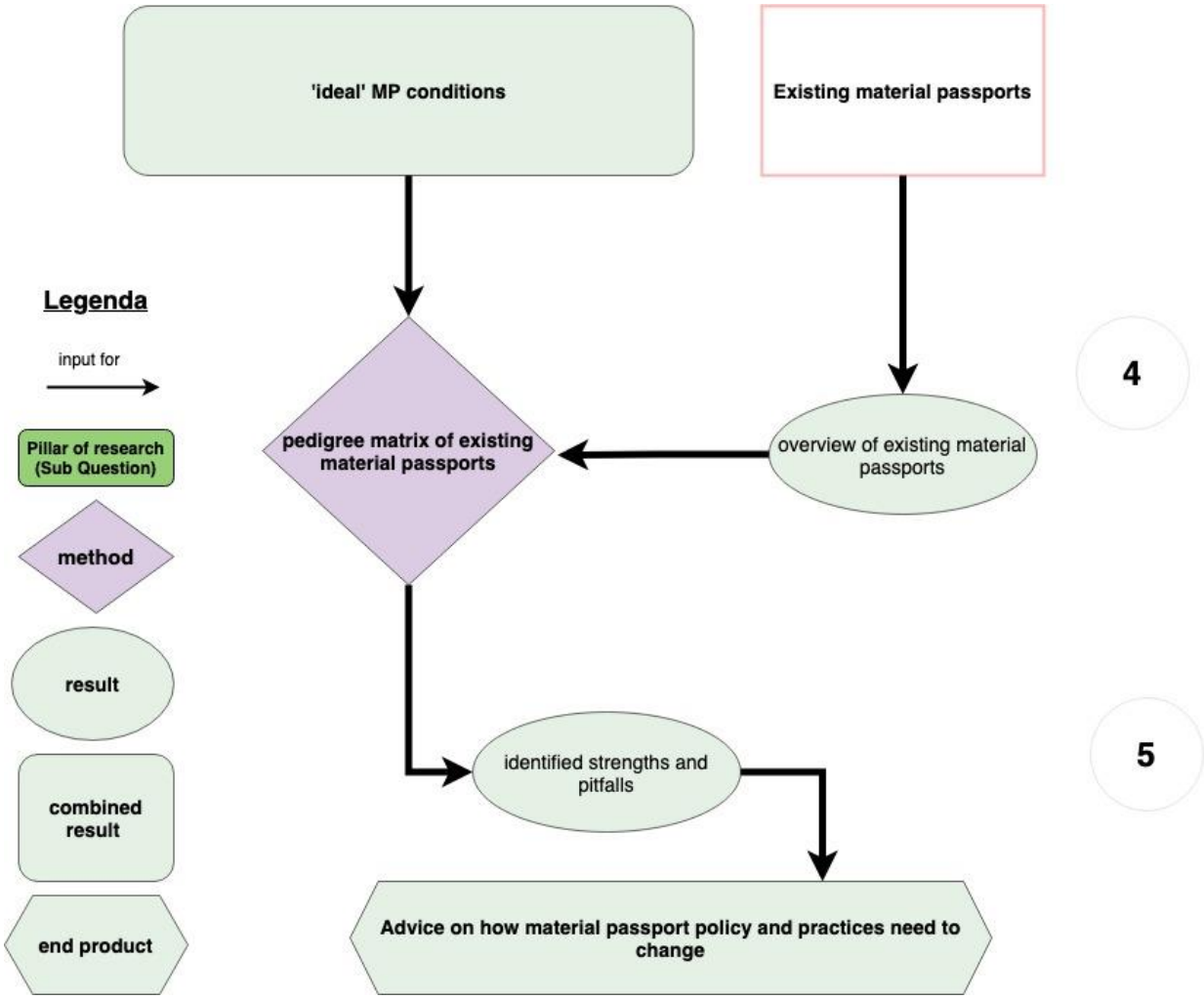

figure 3 methodological framework 2 (own elaboration)

6.2 INTERVIEWS

Semi structured interviews were conducted with experts from various organizations, differing from public officials to architects and developers. The purpose of the interviews has been to get insights on the expert perspective on various topics related to the information needs of the MP and how a passport possibly contributes to circular practices, thereby generating qualitative data (Jacob & Furgerson, 2012). An interview strategy has been taken where interviewer and interviewee have been discussing various concepts during a conversation. The interviewee shared hers/his opinion and the interviewer committed to the on forehand developed interview guide, this could be labelled as 'in-depth interviews' (Hennink et al., 2011). Using a semi-structured approach allowed flexibility during the interviews, new information that was touched upon the interview could be added to the qualitative data collection (Jacob & Furgerson, 2012). Two sets of experts were

consulted. The first group of experts (mainly consisting of consultants, public officials, and developers) has been questioned about the information needs of the MP and how they envision the development of the MP as a tool in the transition towards a circular economy in the Netherlands. The second group (mainly existing of architects, consultants, and developers) that has been consulted, has hands on experience with successful circular practices, it was asked primarily to what extent a MP has contributed to their projects. An interview guide (appendix 1) has been drawn with questions that correspond with concepts from the theoretical framework.

The interview guide was structured in the following order: first a general question regarding the concept of a MP. Here also the terminology was stated so that interviewee would feel free to use any term her/she felt comfortable with. Then the questions regarding the structuring/layering were asked, followed by the 'content' related questions (level of detail, disassembly, toxicity & environmental impact indicators) and ultimately ownership and presentation questions.

The interviewees received the interview questions on forehand on request. This ensured interviewees were able to prepare the questions. The interviews have been transcribed so all information is archived. All the interviewees have been anonymized, to ensure no political or commercial hesitance inflicts the results. The interview guides were tested with a pilot interview to strengthen the interview protocol (Castillo-Montoya, 2016), this allowed for changes in the question, the order of the questions and an indication of interview duration was obtained. All interviews followed the interview guide and were conducted via Microsoft Teams due to Covid-19 restrictions.

6.2.1 INTERVIEW ANALYSIS

To code the raw transcript data a software tool was used 'NVivo' (QSR, 2020) this software allowed to group corresponding or differing expert opinions. The interview data has been transcribed in Dutch, to make sure that the coding of the different interview data is not affected by translation, the coded data has been translated after the results were drawn. The concepts addressed in the theoretical framework, that have provided input for the interview guide, have been coded. When reading the transcripts, answers have been labelled to these codes (table 1). When drawing the results each code has been assessed individually to see how the expert's attitude was towards each concept.

Name	Files	References
accessibility and presentation	5	6
General content MP	5	6
ideal MP	5	5
Level of detail in information	5	5
Opinion on layering structure in MP	5	6
Other environmental impact indicators	5	7
Ownership	5	6
Opinion on including Removability/detachability	5	6
Opinion on including Toxicity	5	6

table 1 nodes used coding interview data (part 1) (own elaboration)

For the subjective concepts addressed in the first expert group, the attitude towards implementing a concept in the MP has been divided into three categories. Positive attitude towards concept, moderate attitude, and negative attitude. 'Positive' means that the expert believes that this concept needs to be incorporated in a MP. 'Moderate' attitude indicates that the expert poses some question marks or certain conditions on including the discussed concept in the MP. Lastly a 'negative' indicates that the expert believes a concept is not part of the information needs of a materials passport. Reflecting on interviewees attitude has been done using tables that contain interview citations to support the chosen attitude. In the discussion an implication of these results has been addressed. For the concepts that do not result into a certain attitude, a general description of the various

answers has been given supported with direct quotes. Analysis of the answers of the second group of experts has also been conducted using different nodes (table 2).

Name	Files	References
Incentive for circular practice	3	4
Used strategy to ensure circular practice	4	10
Use of MP	4	9
Ideal MP	4	4
Suggestions to circular strategies	4	7

table 2 nodes used for coding interview data (part 2) (own elaboration)

6.3 ANALYSIS OF EXISTING MATERIALS PASSPORTS

To perform an analysis of the existing MP, certain criteria have been selected. The selection of the criteria was based on key concepts according to (grey) literature addressed in the theoretical framework (chapter 7). To analyse the MPs a pedigree matrix (Weidema & Wesnæs, 1996) has been used, the pedigree matrix gives a score based on the different indicators. The indicator scores used for the pedigree matrix are corresponding with key concepts from the theoretical framework and/or addressed during the interviews. Hence the following indicator scores of the MP have been used:

- Web based document
- Dimensions and material properties
- Layering
- Environmental impact indicators (MPG)
- Toxicity information
- Disassembly information

The used scoring index is displayed in table 3. Each of the indicator scores has contributed to a passports individual score, resulting in an overall score for each MP. The total score, obtained from the indicator matrix has been used to pick the MP that has the most agreements with the indicators. Eventually the perceived expert valuation of the different indicators, has been compared with the MP overview. In this comparison the discrepancy between the expert's opinion on various concepts and the actual presence of the same concepts in the current available MPs has been explained.

Indicator score	5	4	3	2	1
Web based document	Web based document accessible via an application or viewer				No web-based MP
Dimensions& properties	All material properties and dimensions are included as well as location. Coherent and presented clearly.	Material properties and dimensions are included, however incomplete.	vague statements about material properties/dimensions present, no coherence	little to vague information on properties/dimensions, no coherence	no information on dimensions and properties
Layering	The passport is structured using the shearing layers of brand	some structure is present but not all layers are known	layering present but little coherence	some layering but no coherence	no layering structure
MPG/Environmental impact	A certified MPG calculation is included in the passport	A MPG is included	Manual calculated MPG is included	Similar calculation present but no MPG	No MPG or similar calculation present
Toxicity	The passport provides all relevant chemical toxic information of the used materials/products including a declaration of not having any banned substances. A clear distinction between human toxicity and environmental toxicity is present.	Information related to toxic chemistry of different materials is present, but information is not complete	vague information on toxicity is present but no detailed information on effects or severity is present	little to vague information on toxicity is present, information is incomplete	no information on toxicity
Disassembly	Thorough overview of disassembly methods of the various used products is present, disassembly manual of building is present and provides a concise overview	Information about disassembly of materials is present but not presented in a concise and clear manner	vague information on disassembly present	little information on disassembly is present, it is mentioned but vague	no information on disassembly

table 3 pedigree matrix passport analysis (own elaboration)

7 CONCEPTUALIZATION

This chapter highlights the results from literature studies, the concepts addressed are either relevant for the concept of circularity in the built environment or more specific concepts related to the MP. The latter also has been incorporated in the interviews see section 8.1.

7.1.1 CIRCULARITY

The concept of circular economy knows different interpretations and definitions. The circular economy is a restorative economy in which material and energy loops are closed (Geissdoerfer et al., 2017). The circularity of a product or material is often measured using the R-ladder, that describes the circularity. A higher circularity means that products will stay in the loop for a longer time and can be used in multiple chains. Figure 4 is adopted from (Potting et al., 2017) and shows an overview of the different R-strategies. If materials in construction where to be retrofitted into new buildings, repaired, or refurbished, the circularity, compared to the conventional incineration or downcycling of building materials would increase significantly. It shows that the construction sector has potentially significant circularity gains and thereby decrease natural resource extraction and environmental impact.

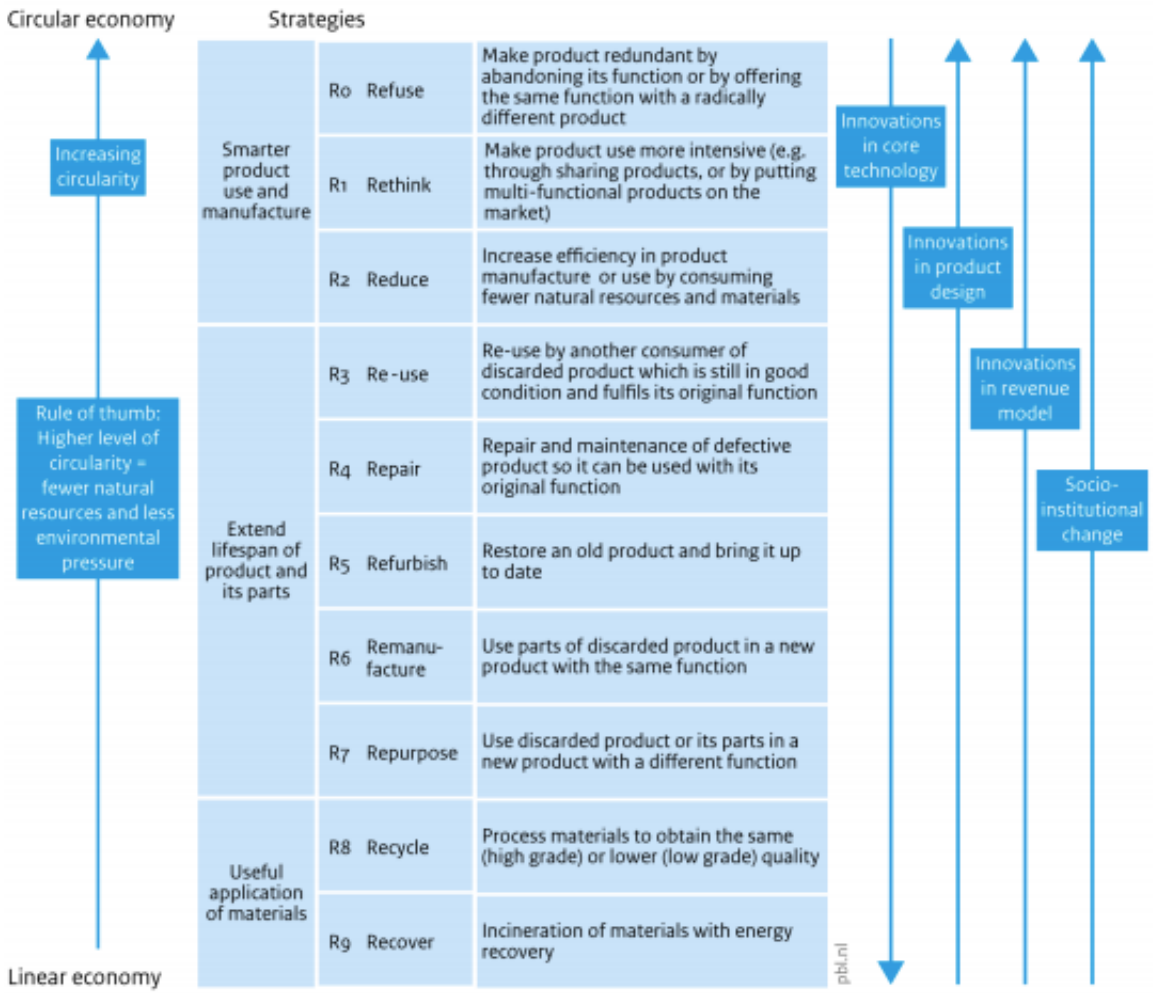

figure 4 R-ladder(Potting et al., 2017)

A circular construction sector can be defined as follows: ''building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles'' (Pomponi & Moncaster, 2017, p.711) or as described by Benachio et al. (2020): "the use of practices, in all stages of the life cycle of a building, to keep the materials as long as possible in a closed loop, to reduce the use of new natural resources in a construction project" (p.5). Hence, the circular construction industry could be described as a combination of both CE principles with life cycle assessment practices along the supply chain of buildings. According to Nuñez-Cacho et al. (2018) the construction sector needs to comply to the aforementioned strategies of the R-ladder, efficient management of energy water and materials to have a transition towards a circular economy. Research shows that a circular supply chain in the construction industry can lead to reduced carbon emissions when compared to a linear supply chain. For example, in Nasir et al. (2017) the supply chain of insulation material in construction was assessed and found to have lower emissions across the supply chain when using reused textile materials in a circular designed supply chain. Such changes across the various products used when composing a building need to be combined to have a less negative impact of a building itself.

7.1.2 Materials passport

The concept of a MP can be described as a document or database that describes the characteristics of components or materials of a product (Guldager Jensen & Sommer, 2016) . In construction, a MP is a detailed inventory of all the components used in the building, it contains their characteristics, dimensions and location (Hutton et al., 2016). To meet the requirements of a circular built environment this knowledge on the material flows is essential (Heisel & Rau-Oberhuber, 2020). Unfortunately, there is little scientific consensus as to how the MP is being developed and what information is necessary. Standardization and registration of MPs are key for circular management in the built environment (Rau & Oberhuber, 2017).

To standardize MPs and circular construction practices in the Netherlands, CB'23 has published several guides regarding circular purchase practices, circular design practices and a longlist of materials that can be used as a guide when developing a MP (Platform CB'23, 2020). CB'23 is a platform that consists of different action teams that develop guides for the aforementioned topics related to circular construction, the research teams consist of a mix of both civil servants as representatives from different organizations across the construction sector and branch organizations. The platforms aims to develop conditions that need to be met in order to meet the governmental goal of having a circular economy in 2050 and has work agreements with the governmental transition team (Platform CB'23, 2019). On governmental level, the MP is seen as a promising tool but there is no obligation in procurements yet, in 2022 there will be a decision on whether the use of a MP becomes mandatory (Ollongren, 2020). Currently, already some of the subsidy schemes require a web-based MP in their requests. The assessed MPs as described in 5.1.4 require the following: To meet the subsidy requirement, project developers have free choice of how to present material information, however there are three main criteria that need to be met and that will be evaluated primarily. Firstly, information on toxicity of the used materials needs to be included, secondly the MP has to include all components and elements used and thirdly information of the releasability of the used materials is required (RVO, 2019).

7.1.3 Indicators for circularity

When assessing building circularity several different indicators exist, not all of them are direct indicators for circularity, however it can be assumed that using other environmental impact indicators for buildings does aid creating more sustainable buildings. In this (sub)chapter concepts that show potential of contributing to successful circular acting are featured.

7.1.3.1 (Design for) disassembly and detachability

One of many proposed indicators in circularity is disassembly of buildings, the concept of having a building that can be decomposed by future generations at the end of life, will increase the reuse/recycling potential of the different building components, thereby design for disassembly plays a key role in the transition towards a

circular economy (Mandolini et al., 2017). Design for disassembly can also allow more easy maintenance and thereby increasing the lifetime of a building (Talens Peiró et al., 2018). In Finch et al. (2021) the relevance of using mechanical connections in building instead of chemical connections to increase the possibility reuse is emphasized. Important for detachability is that it is already thought of during the design phase of building projects. In Geldermans (2016) it is also emphasized that so called relational properties are of high importance when designing for circularity, relational properties include connections between materials and products, as well as dimensions and performance time (lifespan). The first obviously having common ground with design for disassembly or detachability whilst the latter does with the shearing layers of Brand.

7.1.3.2 ENVIRONMENTAL IMPACT INDICATORS

In the Netherlands several different environmental impact scores are given to buildings and or building components. Most of the scores are based on LCA-practices and are required by legislation. The most used environmental impact score in the Netherlands is the so-called MPG. MPG (milieu prestatie gebouwen) is a yardstick for the sustainability of a building, a lower score for MPG means more sustainable material use. The score is calculated using life cycle analysis (LCA) based on material properties that exist in the Dutch database (NMD). A producer or manufacturer has to ensure that his products are recorded in the database by providing a certified LCA calculation of their products (RVO, 2021d).
For energy score of newly developed buildings the currently used guidelines are called BENG (bijna energie neutraal gebouw), the BENG requirements are corresponding with European guidelines regarding energy performance of buildings. The BENG is the successor of the EPG (Energie Prestatie Gebouwen) which is an energy performance rating of buildings. The three main requirements of the BENG are based on a maximum kWh/m2/year, a maximum amount of used conventional fossil energy and a minimum share of renewable energy (%) (RVO, 2021c).

7.1.3.3 TOXICITY

Toxicity of materials and or products highly affects the usability at the end of life, circulating material flows cannot hold contaminated materials. Toxicity is not only important for single materials that might have any carcinogenic or ecotoxic properties, sometimes contamination occurs as the result of a chemical reaction (Heijer & Kadijk, 2020). One profound issue in the reuse of materials or products from buildings, is the use of chemical solutions to perform repairs or fixing. These adhesives contaminate materials making the reuse purpose more difficult Finch et al., (2021) stating: ’Fixings, adhesives and inherently bonding materials (such as spray foam) are key weaknesses of conventional construction methods in respect to the circular economy’(p.4). A banned list of toxic materials is already present in cradle to cradle certification (LLC, 2012), which according to (Heijer & Kadijk, 2020) will be updated in the near future as it is regarded outdated and incomplete.

7.1.4 LAYERING

Steward brand developed a layering scheme for buildings that can be split up into 6 different so called shearing layers. The six shearing layers of Brand are often referred to when assessing a building after construction, the layers have different lifetime expectancies and purpose. The layers can be categorized into building layers (site, structure & skin) and service layers (services, space plan & stuff) (Brand, 1995). The different layers of brand are categorized based on lifespan; stuff (furniture etc) has a shorter lifespan than the exterior walls (skin) for example. A visualization of the six shearing layers can be found in figure 5.

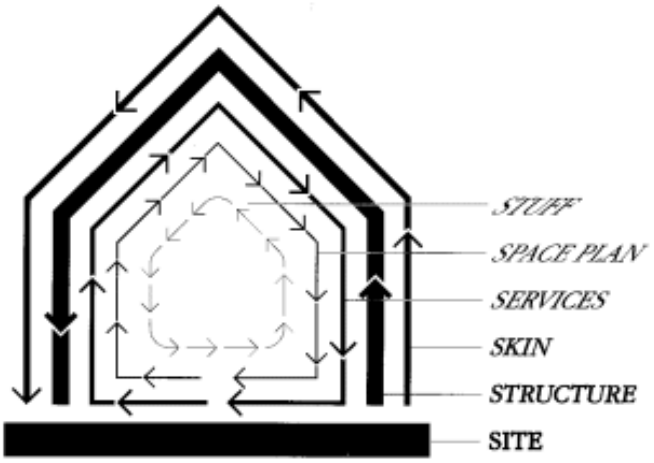

figure 5 shearing layers of Brand (Brand, 1995)

In recent literature it is also suggested that within a MP different layers are addressed that have different levels of detail and can be used for different purposes (Adisorn et al., 2021).

8 RESULTS

8.1 INTERVIEW RESULTS

The following section entails the qualitative results retrieved from the interviews, the first section covers the MP information needs and the second section covers the possible relation between the use of a MP and circular practices.

8.2 INFORMATION NEEDS MATERIALS PASSPORT

8.2.1 GENERAL CONTENT MATERIALS PASSPORT

The term MP is not acknowledged by all experts, some state that a passport is a rigid concept that does not allows for any dynamics, whilst dynamics are ought to be of high importance.
'I prefer to use the term 'log' rather than MP, as a passport implicates a snapshot, it can be useful as a starting point, in time it requires changes otherwise it grows old' (Expert 3, personal communication, August 2021)

Furthermore, the general content of a MP is described as 'an overview of all used materials' (Expert 4, personal communication, August, 2021), 'What materials are present in a building, what is their quality and how are the used materials assembled' (Expert 1, personal communication, September, 2021) and 'A data set of used materials & products in a building, having 3 goals: 1 circular reuse, 2 maintenance, 3 creating measurability' (Expert 5, personal communication, October, 2021).

According to the interview results, the general content of a MP can be described as a data set of all used materials and products in a building. It is also mentioned that the goal of a passport which ultimately should be to become circular and thereby contribute to sustainable development should not be neglected.

8.2.2 LAYERING STRUCTURE MATERIALS PASSPORT

In the theoretical framework it was discussed whether the shearing layers of Brand (Brand, 1995) possibly could be used as a point of departure to structure information on various levels in the passport. Various responses given by the experts indicate that, the general attitude towards using the layers of brand to structure the MP, is not unanimous. Cons of using these layers have also been given. Main cons of using layering are that the layers do not provide enough detail or that other ways of scaling should be used. Whilst pros are that scaling on lifetime is multi applicable contributing to maintenance and safety. In the following table, the attitude of the experts towards using the shearing layers of Brand is shown in the following table (table 4).

	Stating	**Attitude**
Expert 1	'We prefer talking about area, complex, building, building products, materials and raw materials. It might be possible to assign those to a shearing layer though. Within a layer it should be possible to find information on both products as materials. I don't see how services; space plan and stuff are of added value'	Moderate

Expert 2	'Different layers can be interpreted in various ways. I think it is very important that a MP has one goal, what is it used for? When you have defined that you can think of wat data requirements and layers are necessary'	Negative / not on all conditions
Expert 3	'I think it is a good starting point, the different layers project different life expectancies and corresponding maintenance instructions. If this is emphasized during design phase benefits will be present the entire lifetime.'	Positive
Expert 4	'For a lifetime of 80yrs for example not all components will last, differentiation based on lifetime is of high importance as after a certain period, safety requirements cannot be met for all building materials/products in the building.	Positive
Expert 5	'The spreading of information using layering should be a bit more precise than brand's layers. By using solely those you pose restrictions. The layers of Brand pose a good starting point from which you should try to define more details in time'	Positive

table 4 expert attitude towards including layering in MP (own elaboration)

8.2.3 LEVEL OF DETAIL IN INFORMATION STORED

According to the experts more detail does not translate automatically into more relevant information for the goal of developing a MP. It is however also argued that detailed information could be useful when assessing toxicity in products that are to be reused. Additionally, it could also be valuable information when calculating environmental impact, especially when calculation methods change.

'For product reuse, it is not necessary to have very detailed information, however when you want to account for toxicity for example, the composition of raw materials is very relevant.' (Expert 3, personal communication, August 2021)

'Data that underlies LCA-calculations, would ideally be available. However, you don't want to store it yourself as client, you just want it available when methods change in the future' (Expert 4, personal communication, August 2021)

Other suggestions regarding the level of detail that should be displayed in the MP refer to supply chain cooperation:

'It's a matter of supply chain cooperation, as client or owner of a building I want to know what products I have used in my building. Everyone in the supply chain should take hers/his own responsibility to achieve a high level of detail.' (Expert 5, personal communication, October 2021)

This indicates that the developer of the building should receive the detailed information about the used products from others along the supply chain. This would leave assembly of all given information to the developer.

8.2.4 DISASSEMBLY INFORMATION IN MATERIALS PASSPORT

As can be seen in table 5, disassembly is considered highly important as all experts have a positive attitude towards including information on disassembly in the MP. Information on disassembly of products in a building is considered essential in a MP. It is considered an important part of increasing the circularity in the construction sector but the lack of information on disassembly in the current building storage is also acknowledged. A few of the interviewed experts referred to the disassembly index co-developed by Alba concepts (BCI Gebouw, 2021), a tool that includes information on disassembly of the used products in a building and can be coupled with a MP.

	Stating	**Attitude**
Expert 1	'I consider detachability very important, in essence it is one of the perks of having a passport; knowledge on wat is located where and how it can be removed. If I explain to people what circularity in the built environment entails, this subject always comes up. I would be really pleased to see this incorporated in passports'	Positive

Expert 2	'A measuring tool has been developed, for detachability the different layers correspond with products assembled at the construction site. When it's about a brick, it is explained that it has been mounted using bricklayer etc. detachability is very important.'	Positive
Expert 3	'I think it should have high priority, Alba has developed a detachability index, I am not sure if that should be the system to use. I do believe it is good that such initiatives are around. detachability shows huge potential, I should read some more about it, I think it shows future directions'	Positive
Expert 4	'Detachability should be in the passport, there are however large problems with using on site poured concrete for example. Modular construction is prioritized right now, and disassembly information of existing buildings is being worked on as well'	Positive
Expert 5	'Detachability is very important, when something is assembled that can be disassembled, the goal of reuse of material is easier achieved.'	Positive

table 5 experts attitude towards including detachability in MP (own elaboration)

8.2.5 TOXICITY

In general, the experts have a positive attitude towards implementing toxicity in the MP. Not for everyone toxicity was an issue but nonetheless no one opposes against including information on toxicity to the MP as can be seen in table 6. Future development of toxic material research is key as products that might be considered safe today might turn out to pose some health risks.

	Stating	**Attitude**
Expert 1	'I am not sure whether we still use toxic materials in construction, so it won't be too much of an issue, I guess. I assume that materials are not used anymore if they are considered toxic. For existing buildings, it can be valuable to add toxicity if you are to draw a MP. Its logical because you know whether there are risks involved during dismantling of a building. '	Moderate/Positive
Expert 2	'Toxicity is very important. However, not all toxicity information is researched thoroughly. We all know several banned lists, but they remain vague. This mainly has to do with the fact that the responsibility for this information lies with the producers. It is key to have a passport that can be updated so if materials turn out to be toxic this can be added to the passport'	Positive
Expert 3	'I think it is very important and should be included'	Positive
Expert 4	'Toxicity is very important especially in coatings of various products. Think of PFAs, Cr6 al things that are now and in the future relevant.'	Positive

Expert 5	'We are developing a banned list of chemicals, that if you find such a possible toxic substance in the MP, this can be considered. Ultimately you just want to know for sure that some substances are not present in your building'	Positive

table 6 experts attitude towards including toxicity information in MP

8.2.6 ENVIRONMENTAL IMPACT INDICATORS

The use of environmental impact indicators in construction varies from MPG to EPG and MKI, all indicators for sustainable performance of a building on energy or material use. The experts are not all convinced of the fact that these indicators should be implemented in the MP as can be seen in table 7. Multiple experts are convinced of the fact that raw data that is used to calculate environmental impact scores should be included in the MP. This would in their opinion ensure that when methods change in the future, calculations with already present materials still can be made. The underlying data is considered more important than the score itself.

	Stating	**Attitude**
Expert 1	'The passport should contain all data to make these calculations, perhaps that in ten years methods have changed so much that they require raw data to generate scores. Then it would be important to have easy access to the relevant data.'	Moderate
Expert 2	'MKI says something about the emissions during the lifetime of a product, you'd need to change that if you are to reuse a product. To reuse products, you don't need these indicator scores'	Negative/moderate
Expert 3	'It is very important to be able to collect these scores from your BIM. The problem is that a lot of products do not have an extensive LCA meaning they will be valued unfair. Eventually what you would like to see would be one sustainability score of a building that includes circularity, MPG, reduction of virgin material use, renewable energy. '	Positive

Expert 4	'The data required to make calculations of environmental impact indicators should be present in a MP'	Moderate
Expert 5	'The passport could act as a proof of having a certain score (MPG for example), in other words: the data in the passport should provide input for calculating impact indicators. The passport should be a live document so that when things change during renovation or something, the impact indicators will be calculated automatically.'	Moderate/Positive

table 7 experts attitude towards implementing environmental impact indicators in MP

8.2.7 Ownership of the MP

The question regarding the ownership and responsibilities of the MP shows consensus between the experts. Ownership of the MP and forthcoming responsibilities are with the owner of the building. Additionally, some experts have added some conditions to ownership of the MP in their responses. Some state for example that a (financial) incentive should be created to stimulate property owners to have a MP of their buildings.

'If a building owner is to sell his/her property, he/she should provide a fully updated passport. It should be rewarded financially to have a sustainable building and accountancy systematics should be adapted to this' (Expert 3, personal communication, August 2021).

It should be the owner's responsibility to transfer the information about a building to a new owner, meaning it must be up to date. It is already an obligation to share energy performance of a building (labels) when selling a house, why not have such an obligation for a MP?' (Expert 5, personal communication, October 2021).

'Public organizations like to have their own data in control as they are not interested in selling, whilst commercial parties that are aiming to sell their properties, like to have their information at an external party so that they are not responsible for the correct data' (Expert 1, personal communication, September 2021).

The latter indicating that there might be a difference in thoughts about ownership of the MP, directly related to commercial interests of the property owner.

8.2.8 Accessibility and presentation of the materials passport

The considerations towards accessibility and presentation of the MP have been split. Accessibility of the data in the passport is split into two different opinions that have been given by the experts namely: Private data storage (commercial) and open data storage (public). Having publicly available data benefits the possibilities to reuse or recover materials from projects that are being demolished, it does cost money as product information has a high value, especially to producers.

'Data is not publicly available, if I want to build next to a soon to be demolished building, it would be necessary for me to retrieve the passport from that building. It allows for a judgement of what can be reused or bought. The main problem with having this information public is that producers of building materials invest a lot in R&D

of their products, for them it would be killing to have this information available to everyone. There are quite some hurdles to overcome.' (Expert 2, personal communication, August 2021)

'I think there should be one large data base with access to all material/product and building information. It might be an illusion, but such a platform would really speed up the transition. I don't think such a platform should be commercialized, having everyone to pay for storage and or access. It would however be very expensive if it is a governmental authority.' (Expert 1, personal communication, September 2021)

'Insights into MPs is now still mainly commercialized, if it were to be a governmental obligation, this commercial part would require change as well.' (Expert 3, personal communication, August 2021)

For the presentation of the MP, the experts show similar answers. The term BIM is mentioned in all answers and is considered a good model to structure the passport information around. The term digital twin is also mentioned, indicating that a model should be an exact digital representation of reality. It is also argued that developing a model is only relevant when you are developing a new building, if a building is already there and it lacks a BIM, developing a model is not necessary to reach the goal of being able to reuse materials at the end of life. An end-of-life building inventory can also be made with demolishers at less expenses and at a reasonable accuracy.

'Ideally a 3d BIM-model that allows for extracting all kinds of information' (Expert 3, personal communication, August 2021)

'A Bim-model or something like a BIM that can generate a MP, including information on environmental impact, not only dimensions and volumes' (Expert 4, personal communication, August 2021)

'Information presentation would be ideally in a digital twin' (Expert 2, personal communication, August 2021)

'The ideal model is that for building management you would have an 'as built' BIM and that when there are mutations in the building you would add those to the model, automatically updating the passport.' (Expert 5, personal communication, October 2021)

'I want to note that at the end of life, when you ask a demolisher to walk around and trough your building, he can estimate with an accuracy of 5/10% what is present in the building and what products have reusable value/potential. Having a very sophisticated passport is not always necessary to meet your goals' (Expert 5, personal communication, October 2021)

The latter quote is something that is also supported by an interviewee from the second group. Stating that to have a measurable and quick impact on reducing the use of virgin materials, we can already by making an inventory at end of life.

8.3 CIRCULAR PRACTICES

When describing the results of the second interview group the nodes in table 2 have been used as a guide. All interviewees agreed on the fact that having a client with a clear sustainable vision is the main success factor of circular projects. Whether it was a municipality or a private developer, sustainability was considered important by clients to have a successful circular project. The ambition to be ahead of the heard was also mentioned by an interviewee: 'Circularity is often overlooked when having sustainable ambitions, the municipality insisted on being ahead of the mass' (Expert 7, personal communication, August 2021).

When assessing the importance of having a MP, it is stands out that only in 2 of the four circular projects a MP has been used. As two of the assessed projects involved a demolished or renovated older (+25yr) building, there was no digitalized information other than some basic blueprints which in both cases weren't up to date. The presence of digitalized information systems of building, has only been introduced in the 90's and is commonly practiced since the 00's (Nederveen et al., 2010). The absence of an existing MP has led to other approaches in building or renovating circular, indicating that having a MP is no hard condition to develop or construct according to CE principles. In one example the use of a modular way of construction led to circular development and facilitated the development of a MP.

Involvement of an architect when making an inventory of a to be demolished building was found to be crucial. It was stated by two experts that involving an architect in this early development phase of a building (design phase) is crucial as it lets architects design buildings with the products situated in buildings that are to be demolished.

'When designing a circular building it remains very important to ensure it is also regarded from a developer's point of view. I understand that we want to move to a system in which all information about a building that is to be demolished, is at hand. However, for the design of a building it is important to include this vision in the first stage of development.' (Expert 8, personal communication, September 2021)

'When you are demolishing a building, you must consult architects, it ensures that she/he can include the materials or products from the old building into a new design.' (Expert 6, personal communication, August 2021)

In one successful case project, the presence of the old 'donating' building very close to the new project, brought significant advantages as it allowed for a temporary storage of secondary materials and reduced transport movements drastically. It even inspired the client to use the parts of the old building that weren't transferred into the new building (Expert 8, personal communication, September 2021).

According to two experts, the involvement of producers and manufacturers of the products and materials, used in the buildings has been key in developing a circular strategy. Using the network of a manufacturer and producers involved in the initial construction of the building, it was possible to find a new destination for the recovered products and materials. Whilst the use of manufacturers knowledge on certain elements in one case also led to extensive revision of the used products to extend their lifetime and thereby reduce environmental impact. The following quotes refer to the mentioned projects:

'We went to look for companies that were able to overhaul the installations present in the building, we made new agreements and they also provided us with renewed warranties' (Expert 7, personal communication, August 2021)

'The presence of product and material specifications and what manufacture produced them, led to finding a customer for the recovered product much easier.' (Expert 6, personal communication, August 2021)

'We had a 3d-model of the building and all contact data of the suppliers involved during construction' (Expert 6, personal communication, August 2021)

In general, there are a few key lessons learned from the discussed successful projects. Firstly, the use of a MP is not necessary to retrieve circular success. Secondly the involvement of an architect in the early stages of development and when a building is being demolished could possibly increase the success of circular building development. Thirdly knowledge on where the products have been produced can aid the circular practice as well as the presence of a digital information of the building.

8.4 THE IDEAL MATERIALS PASSPORT

The first expert group has provided several statements regarding their vision on what could be described as the ideal MP. Major findings are that a digital model such as BIM is desired, the passport should be dynamic, include detachability information, material characteristics and relevant information to make environmental impact calculations.

'At a developer they have BIM models with different elements that you can click on and where everything is linked. The ideal passport has a strong visual presentation and user experience. It should include Material + year of use, how it's mounted, density, material strength/value' (Expert 1, personal communication, September 2021)

'The ideal passport is one of which we understand what we use it for, subsequently it is depending on the generated data, ideally coupled with a BIM. It might even be good to have it coupled with product databases that can be accessed via the BIM link. Detachability should be available separately, except when it is useful for internal product levels and it can be coupled with product cards.' (Expert 2, personal communication, August 2021)

'Every individual material or product should be weighed as fair as possible. The passport should be dynamic. An overall score for the passport, in which circularity and environmental impact are combined, would be interesting. It should be including detachability, MPG etc.' (Expert 3, personal communication, August 2021)

'In the ideal world we have a model of a building, in the model we can retrieve element information when clicking on a product, showing how products are mounted and the raw materials used. There should be a central point that provides acces to all necessary information when developing or demolishing a building'. (Expert 4, personal communication, August 2021)

'What I think is ..., we are seriously occupied with what a MP is or should be, but we don't spend enough attention to the environment in which this passport is operating. The idea of supply chain contribution, how do we establish that? The architecture outside the passport needs further development. Databases that track the value of raw materials, marketplaces. I have the idea that we do not consider these topics enough. We are developing the product (MP) but how much relevance does it has if we want to use it and it's been on the shelf for a significant time? It should always be a tool and not a goal itself.' (Expert 5, personal communication, October 2021)

The second expert group shows similar ideas as the first group to how the ideal MP would be. Some question marks regarding the feasibility of the MP are posed.

'The MP should include the following: type of material (you'd need to be able to know whether its suitable for reuse and how perhaps. In detachability of products is where the risks are involved, if a contractor knows how products are mounted, this is very useful information. Too often products are broken during demolishing, that should have been recovered. Toxicity and material characteristics are somewhat relevant, but detachability is considered the most important to me.' (Expert 6, personal communication, August 2021)

'a BIM model, including the layers of Brand, information on the product supplier, it needs to be up to date, and detachability is very important also for maintenance.' (Expert 7, personal communication, August 2021)

'It is more important to act circular from design principles, this should be arranged by cooperation between designers and demolishers. Before we have developed the ideal MP it is already too late. Especially for the existing building stock it is way too expensive to digitalize everything into BIM.' (Expert 8, personal communication, September 2021)

'The environmental impact (MPG) of materials should be visible in a passport, this makes it useful on the short-term when having to choose materials.' (Expert 9, personal communication, September 2021)

To summarize the ideal MP a schematic overview was drawn as can be seen in figure 6. The Ideal Materials passport is a BIM model or digital twin that includes building information, the information is structured using a layering system and is retrievable on different levels. The information includes material properties & dimensions, detachability, toxicity, and environmental impact data. The passport is drawn using cooperation across the supply chain and is a dynamic model that is kept up to date. It is important to note that, according to the interview data, the feasibility of the passport for the existing building stock is questioned and that the infrastructure around the passport needs further development.

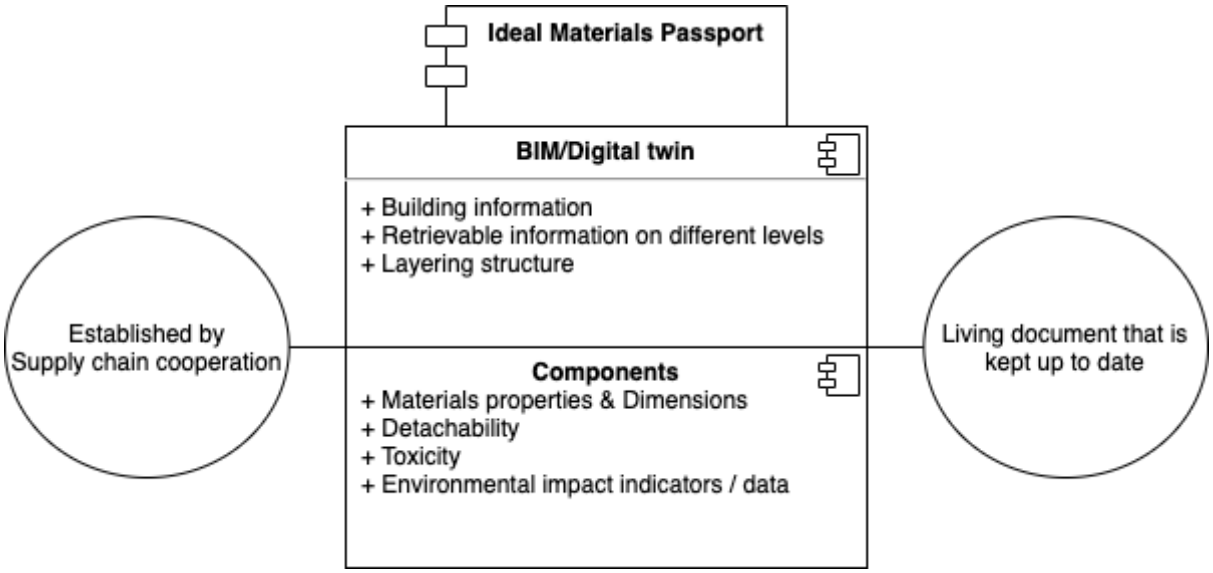

Figure 6 'ideal' MP (own elaboration)

8.5 MATERIALS PASSPORT ANALYSIS

In table 8 the different assessed passports have been scored. There are many passports that are lacking the same concepts. Passports 1-11 all lack information on toxicity and disassembly. The same passports, however, do provide a web-based passport that includes dimensions and properties. Passport 11 shows the highest scores on all indicators, being the best performing passport according to these indicators. All assessed passports provide a web-based version, and all assessed passports show thorough information on dimensions and properties of the used materials in the building.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
web based	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Dimensions & Properties	4	4	4	4	4	4	4	4	4	4	5	5	5	4	5
layering	4	3	3	4	4	4	4	4	4	3	5	1	1	1	4
MPG	3	3	3	3	3	3	3	3	3	1	5	4	4	1	3
Toxicity	1	1	1	1	1	1	1	1	1	1	5	5	5	5	1
disassembly	1	1	1	1	1	1	1	1	1	1	4	4	4	5	1
Total score	18	17	17	18	18	18	18	18	18	15	**29**	24	24	21	19

table 8 matrix of mp scoring on indicators

Table 8 shows that of the 15 assessed passports, 11 have been developed by the same producer, these passports are all missing the same concepts and have roughly identical total scores. These passports all lack information on toxicity present of building materials, and they haven't included information on disassembly of the used products and materials. What can be distinguished as well, is the inclusion of a manual MPG score in 11 of the 15 assessed passports and the fact that layering is common present amongst all passports. Three passports (12, 13 & 14) have a good overall score (+20), they have disassembly and toxicity incorporated in the MP; they do however lack a layered structure. All other passports show layering and are using the shearing layers by Brand (1995) that provide a structure to the passport.

Disassembly, considered as a very important part of the MP according to both literature and experts, has not found its way into most of the current available MP practices as can be seen in figure 6. Furthermore, it is clear that whereas the experts show a slight mixed consensus regarding the implementation of layering according to the shearing layers of Brand, this layering structure is extensively present in the assessed passports. The market development of MPs shows mixed results regarding the implementation of environmental impact scores, which corresponds with the lack of consensus on this topic, displayed by the experts.

9 DISCUSSION

9.1 IMPLICATIONS OF RESULTS

9.1.1 INFORMATION NEEDS MATERIALS PASSPORT

Analysis of the interview results and the theoretical findings shows some implications, the main interpretations are elaborated on in this subchapter.

In chapter 7 the possibility of using the shearing layers of a building (Brand, 1995) is described. After consulting the first set of experts it shows that using these shearing layers is considered useful and important part of the information needs of a MP. This agreement indicates that this theory is endorsed by the experts and should be part of the MP.

Multiple experts noted the need for detailed information in the passport. This was due to the possibility to use the data for updated calculations in the future. The possibility of changing calculations for these impact scores is already considered at policy level, Fraanje et al. (2021) have suggested to change things such as the visibility of the provided recycled and reused content within the life cycle assessment of buildings. As explained earlier, LCA calculations of building products are the base of the environmental impact calculation of buildings in the Netherlands. Currently the used calculations for environmental impact of buildings do not include a lower impact score for reused materials in the MPG (RVO, 2021d).

Detachability as part of the information needs of the MP is considered very important indicated by both the expert groups and literature review. When assessing successful circular practices to see whether detachability is already considered, demountable building products are considered valuable. The development of modular buildings has increased. According to Saidani et al. (2019) standardization of building materials is a key development to ensure future reuse. Standardized and demountable building practices are currently present in the form of modular buildings. To increase future reuse of building products, information on how things are mounted and can be detached is important, hence it should be part of the MP. Currently available indices such as the Building Circularity Index (Alba Concepts, 2018) are trying to meet this need by implementing detachability into MP practices.

The information on toxicity in the MP is very important according to both experts and literature. If building products are to be reused it is important to exclude any toxic content. When implementing toxicity in a MP it should provide information on products/materials that should be excluded for reuse. It is important to also account for chemical bindings that make a product unsuitable for reuse.

Ownership of the MP, hence who must carry responsibility for it being complete and up to date, is an important topic. The results from expert group 1 show that it should be the responsibility of the building owners. This responsibility could be rewarded and incentivized. Having a reward system in place would encourage building owners to ensure an up-to-date MP. Having updated building information in would increase information transfer and increase the possible future reuse. Such an incentive would require policy changes and a different approach. It could be realized by means of subsidies or legal obligations. Legal obligations are already in place regarding energy performance of buildings, in the Netherlands an energy label is required when selling or renting houses/apartments or utility buildings (RVO, 2021a, 2021b). This obligation could also be made for MPs of buildings. In the new subsidy requirements for 2022 a MP that can be updated is already required, a policy change that is supported by experts' vision on enhancing the value of a MP.

9.1.2 THE IDEAL MATERIAL PASSPORT

The analysed MPs, currently available do not match the Ideal MP as drawn in figure 6. According to the experts the Ideal MP consists of an integrated digital model that includes information from all products and materials. For each element, information on toxicity, disassembly and environmental impact can be retrieved and assessed individually. In the ideal situation, supply chain cooperation is well developed, all available data can be combined easily. Ideally the passport is structured around a layering system such as the shearing layers from Brand (1995) and is a living database that is updated whenever changes to the building occur.

Between the two groups of experts' little differences in how the ideal material passport is described can be distinguished. The second group, however, shows more interest in quick solutions that aid the practice on short-term, such as quick building inventory practices, design/architect involvement and producer or manufacturer involvement. This makes sense as the second group of experts consists of experts that have built, renovated, or designed in a circular way, making them more in favour of methods that have proven to be successful already. When comparing the ideal material passport as suggested by the expert groups, with the concepts currently present in the various assessed passports, it shows that detachability, considered extremely valuable by both expert groups is lacking in most current practices. Digital twins and sophisticated BIM models that allow for information retrieval are not amongst the current present passports. The latter, presentation and infrastructure of the digital environment is considered very valuable and according to experts and needs optimization. This digital environment could play a key role in the transition towards a circular construction sector and might be the biggest improvement to meet the experts' standards of an ideal passport. Information exchange is key to ensure circular practices, at DigiGo a digital environment is developed that could possibly meet these requirements (*DigiGO - DigiGO*, n.d.).

9.1.3 DISCREPANCY INFORMATION NEEDS & PASSPORT ANALYSIS

It is possible that in recent years the passport as emerging theme in circular construction, has led to a sentiment in the sector that a passport might be necessary soon. This could be the result of the publication of the governmental ambition of becoming circular in 2050 (Rijksoverheid, 2016) and the parliamentary letter regarding the possible obligation of MP. Currently this has led to a market for passports that have been developed without having a clear definition of what it entails. Policymakers start to define the system boundaries of passports only recently. This development is clearly visible when assessing the subsidy requirements for building sustainability (RVO, 2019) and comparing them with the requirements in 2017 and 2018 (RVO, 2017, 2018). No requirements regarding a passport were in place. The sudden surge of the MP as a topic without having clear definition of what a MP is according to governmental institutions, might have been the catalyser for the now observed discrepancy between information needs and current development. In the construction sector this topic might have received more attention after the parliamentary letter from (Ollongren, 2020), after which speculation on a possible obligation for passports in construction arose.

9.2 LIMITATIONS TO THE RESEARCH

9.2.1 BIASED PASSPORT ANALYSIS DUE TO MARKET SHARE OF DEVELOPER

From the 15 MPs that have been analysed, 11 passports have the same developer. This organization can be seen as the most known and common developer of MPs. It has taken advantage on the increase in passport demand in recent years, that can be attributed to the increased attention for MPs in the sector. The MP can be considered as an innovative product that is in its early stages of development and adoption. The high market share of this organization shows that if there is information lacking compared to the information needs, this is widely spread across the sector. This is can be confirmed by the theory on innovation (Rogers, 2003) the developers of MP's nowadays can be considered as 'early adaptors' or even innovators, the system boundaries of the MP have not been defined. The early adaptors can be described as technology enthusiasts that are motivated by the idea of being a change agent and are willing to take risks (Rogers, 2003). In the case of the MP, the governmental

institutions steering its development could be described as the 'early majority' within the diffusion of innovation adopter categories (figure 7).

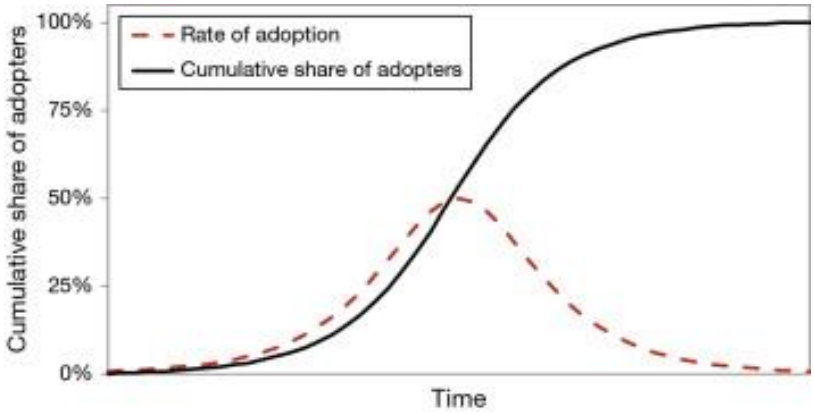

figure 7 diffusion of innovations according to rogers (fleiter & plötz, 2013)

Being in the early stages of innovation shows according to the figure, that mass adoption is not present. In the early stages of diffusion only a small group of users can propagate the usefulness of the innovation (Fleiter & Plötz, 2013). Mass adoption will not occur before governmental institutions have defined the boundaries of the MP (early majority). After the early majority is adapted, increased adaptation will decrease the monopoly. Besides that, well-defined system boundaries, will reduce flaws, both decreasing the discrepancy between information needs and the information presented. Over time the adoption of passport use will increase across the market as shown by the cumulative share of adopters in figure 7. It is possible that the observed information discrepancy is due to the early stages of innovation in which we consider the MP as a product currently resides. As adoption will grow, steering by institutions and improvement due to competition of other developers will lead to an improved and useful MP. The importance of competition on the passport market is supported by one of the experts, stating: *'to aid the development of MPs in the future it would be good to have a healthy competitor.' (Expert 9, personal communication, September 2021)*

9.2.2 LIMITED NUMBER OF INTERVIEWEES

The limited number of 5 interviews for the information needs (4 for the circular practices) questions poses a limitation to the results. Having a larger group of respondents strengthens the findings regarding the information needs and interview analysis in general. The claims made in this research are based on a small pool of experts, this is important to consider. In possible further research this number of experts could be increased to see whether a broad group of experts agrees on the findings. It is also worth able to mention that the approached experts cooperated in the research on voluntary base, not all requests have been honoured and not all desired experts have replied/ found any time to cooperate. The results might be slightly affected by this voluntary cooperation as people that have a more positive attitude towards the development of MPs in the Netherlands might be more willing to cooperate. This can be referred to as the self-selection bias (Robinson, 2013). A biased positive attitude towards implementing the MP as a result of the self-selection bias, needs to be taken into consideration.

9.2.3 TRANSLATION LIMITATIONS

The interviews have been conducted with different experts across the Dutch construction sector, this meant that all the interviews were in Dutch. During the interview analysis a translation of the quotes was made to ensure the readability of the research. Translating a transcript, however, does pose a limitation, the exact formulation of the experts answers in Dutch are due to language and spoken language issues possibly prone to misinterpretation or similar issues. Using Brislin's seven-step translation model (Brislin, 1970) is amongst the solutions for translational issues in qualitative research (Lopez et al., 2008). For this research it is considered unrealistic to have multiple translators review the interview transcripts and to rate the translations.

9.2.4 THE TERM 'MATERIALS PASSPORT' & THE CIRCULAR ECONOMY IN 2050

The term MP suggests that it represents a snapshot at one point in time, whilst when assessing the expert's opinion, it becomes clear that one of the most important requirements for a passport would be that it would need to be updated frequently. It allows not only for insight during operation and maintenance, but it also ensures that the correct information is retrievable at the end of life, when it can be used. This updating of the MP can also be combined with the use of the shearing layers of brand within the passport system. It shows based on life expectancy when, what products or materials are to be revised or renewed, giving the opportunity to find a new use for to be recovered materials.

The governmental ambition of having a circular economy and with it a circular construction sector in 2050, the term circular in 2050 suggests that all buildings in the Dutch construction sector are circular. When thinking of a construction sector that is circular, all the principles or concepts aiding the increase of reuse at the end of life, are part of this transition. It is however difficult to define how the existing building stock should be changed or adapted to these circular construction principles. If we agree on using modular construction methods for example. These buildings will not be at their end of life in 2050, however they are built according to the principles that ultimately lead to circular practices. Unfortunately, a large part of the currently existing building stock will still be around in 2050, having no circular principles in place. One could question whether reaching a circular construction sector is possible. Looking at the average lifetime of buildings, it might be more realistic to set the year of reaching this goal further into the future or to limit these ambitions to buildings that have been built after 2016.

9.3 FURTHER RESEARCH

In literature the absence of an integral approach across the supply chain of building materials is discussed by (Adams et al., 2017), from the interview results one expert also suggested that to have a comprehensive set of information, the responsibility should be across the entire supply chain. Arguably a bottom-up approach to compile the information in a MP, could work better than a top-down approach that implies defining the boundaries of the MP before asking the sector to develop them. According to some interviewed experts, there is a lot of essential LCA-data from various product groups lacking in the NMD, resulting in less accurate environmental impact scores for buildings. However, if you would combine both statements, the absence of detailed LCA data and the responsibility of the entire supply chain, it is arguable that using the supply chain of building products, is how the information should be gathered. Further research on supply chain cooperation in the Dutch construction sector could help increase the information availability and MP content.

Detachability is considered a key concept of circular construction hence further research is necessary regarding its measurability and applicability. Measuring circularity is an important question and offers plenty possibilities for further research within the Dutch construction sector. ALBA concepts have a tool that allows for defining a building its circularity score, based on underlying connections of building elements (Alba Concepts, 2018; BCI Gebouw, 2021). It would be interesting to test in further research and see how it contributes to the information needs of a material passport and how it could aid circular practices as described in this research. Currently the principles of detachability do not reverberate in the most adopted building or product sustainability tool; Life

Cycle Assessment (LCA). Having principles in place that include detachability in LCA calculations would increase the value of demountable products and ensure increased use of demountable solutions. Having a method to implement information on detachability within the Dutch framework of LCA (e.g., MPG), could possibly increase the design for disassembly in the Netherlands entirely, especially if it were to be included in subsidy requirements of some sort. Research could be a solution to further develop these tools and thereby enhance building circularity policies and aid the ambition of having a circular economy in 2050.

10 CONCLUSION

The Dutch government has the ambition of having a circular economy in 2050, to achieve this goal a circular construction sector is desired, together with that a reduction of 50% in virgin material use in 2030 needs to be established. Policymakers try to enhance this transition by implementing the Materials Passport. It is assumed that having prior knowledge on the products and materials used in buildings, leads to higher reuse and less waste at EOL. Using qualitative research, the information needs of the MP have been defined, the usefulness of a MP in actual circular practices is assessed and what indicators for circularity exist in the built environment is assessed. Ultimately, the defined indicators and information needs of the MP have been compared with existing MP practices to assess the current state of development.

Answering the sub questions is threefold. Firstly, indicators for circularity in the built environment have been identified, mostly by literature review. These indicators have been addressed in the interviews and used in the passport analysis. Hence the most important indicators for circularity in the built environment are, the detachability of building products, what environmental impact can be attributed to used building products, furthermore, it is important to know volume, dimensions, and location of the used products in a building as well as whether toxic materials or connections have been used/ are in place.
Secondly, these indicators for building circularity also provide part of the answer to the second sub question, The key information needs in a MP. The information needs of the MP also omit detachability, toxicity, and material properties (dimensions & location). It is also considered valuable to structure the MP with a layering system based on life expectancy as it provides a guideline in revision or renovation practices. For environmental impact of building products, it is more convenient to include the data underlying the various existing calculation methods, to ensure future useability and increase supply chain cooperation. MP information is kept up to date during the lifetime of a building. The assessment of the currently existing MPs shows that the implementation of the indicators is not fulfilled in most of the assessed passports. A discrepancy between the identified information needs and what can be found in current MP, is present. This is mainly because information on disassembly, toxicity and environmental impact of used building products is lacking.
Thirdly, circular practices show that circular building or demolition can be achieved without the use of a MP. But having one makes the reuse of materials less complicated and provides valuable building information. It is found that having an overview on what stakeholders have contributed along the supply chain of the building, increases reuse, repurpose and refurbishment at EOL. When demolishing a building it is important to ensure architect and developer's participation. In the early stages of building development there is room for implementation of reused building materials and products. For the existing building stock this involvement shows more potential than developing a MP. Designing with what is available from a depreciated building leads to successful circular practices without developing a MP.
Answering the main research question, '*To which extent can the MP contribute to a shift towards circular construction sector in the context of the circular economy?':* Having a clearly defined framework and infrastructure for the MP is essential to increase the reuse potential of used building products thereby enhancing CE. However, for the existing building stock in the Netherlands other solutions need to be found as developing passports for existing buildings is not only expensive, but it might not be necessary either. Passports describe buildings and not materials only, the term MP suggests different, other options such as building passport are more appropriate.

In summary, a well-developed digital infrastructure in which a clearly defined passport is placed, is essential for it to be purposeful. Accessibility, responsibility, protection, and data exchange across the supply chain and at the use-end need to be developed. The ideal passport does not only have well defined content, but it also needs (ICT-) tools and handles for the sector to work with. If the MP can meet these conditions, it has the possibility of enhancing the ambitions of having a circular economy in the Netherlands. It can contribute to the shift towards a circular construction sector, but further development is needed before it can be implemented.

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12 APPENDICES

12.1 APPENDIX I - INTERVIEW GUIDE

Dear, …

A vast range of parties in the Netherlands are trying to establish a transition towards a circular economy. Part of this, is the development of a circular construction sector. As my masters-thesis from the study 'Sustainable Development' at Utrecht university I am researching the role of a materials passport within this transition. I am combining my research with an internship at the Dutch Enterprise Agency (RVO). For my research I am looking for experts that can provide me with qualitative input from various parties across the construction sector. I was wondering whether it is possible to schedule an interview, preferably the interview will be online (Teams/Webex/Zoom/phone whatever has your preference). Ideally it would be an interview in the coming weeks, but as I know it might be holidays for people, I'd also like to know if you have any availability later. The interview will take approximately 45 minutes, I'd be happy to send you the questions in advance if you prefer so.

Expert group 1: INFORMATION NEEDS MP

Disclaimer

Het materialenpaspoort is geen vast begrip, op verschillende niveaus en in sectoren hanteert men verschillende definities, het staat de geïnterviewde vrij om een eigen definitie of term te gebruiken. De definitie van materialenpaspoort volgens dit onderzoek is als volgt:

The concept of a MP is having multiple understandings, the following definition resulting from the theoretical framework is used in this research: The concept of a MP can be described as a document or database that describes the characteristics of components or materials of a product (Guldager Jensen & Sommer, 2016). In construction a MP is a detailed inventory of all the components used in the building, it contains their characteristics, dimensions, and location (Hutton et al., 2016).

1) What is your opinion on the concept of a MP and what should be in there if we are to have one?
   Hoe denkt u over het concept van een materialenpaspoort en wat zou erin moeten staan?

2) Would you say that there should be information on different levels in the MP, if so what layers/levels would you distinguish such as the layers of brand?

Denkt u dat er in een materialenpaspoort onderscheid gemaakt dient te worden tussen verschillende schillen/niveaus in een materialenpaspoort? Zo ja welke schillen zouden uws inziens apart gepresenteerd moeten worden?

[The six shearing layers of brand are often referred to when assessing a building after construction, the layers have different lifetime expectancies and purpose. The layers can be categorized into building layers (site, structure & skin) and service layers (services, space plan & stuff) (Brand, 1994), this question tries to find a MP structure that is somewhat corresponding to this theory. Also, in literature (Adisorn et al., 2021) is suggested that different user groups are interested in different levels of detail]

3) How would you valuate detailed information on origin of materials and or products in a MP (perhaps to connect with LCA-scores of certain producers)?
   Hoe belangrijk is het om de exacte herkomst van materialen op te Zou het van toegevoegde waarde zijn om de herkomst van materialen op te nemen in het materialen paspoort? Materiaal = opgebouwd uit grondstoffen (Material is made from raw materials) (beton, mdf…) Product = opgebouwd uit materialen (Product is crafted with materials) (Doors, ceilings, floors)

Question 2&3 can be grouped as questions about the detail level of information in a passport and how'd should be structured. Environmental impact scores often require information on very detailed level such as origin, if you want to have a full overview it might be good to also add this in the MP

4) How valuable would you consider the removability/detachability of products, does it need to be included in a MP and if so on what level and what specific releasability information must be included?
   In welke mate dient losmaakbaarheid opgenomen te worden in een materialenpaspoort en in welke schil zou dit dan moeten zijn en welke informatie over losmaakbaarheid zou het specifiek moeten zijn?

Disassembly is one of the addressed indicators resulting from the theoretical chapter(RVO, 2019; Talens Peiró et al., 2018)

5) what do you think about the inclusion of information concerning toxicity/health related risks within the MP?"
   Hoe denkt u over het opnemen van toxiciteit in een materialenpaspoort?

In the subsidy requests information on toxicity of materials is required (RVO, 2019). Hence the question on whether experts think it should be included

6) What existing environmental impact indicators would you consider to be essential in a MP (MKI, MPG …)?
   Welke milieuimpact scores zouden wel en niet opgenomen moeten worden in een materialenpaspoort en waarom?

For buildings many environmental performance scores and certificates exist, it is interesting to learn whether experts see them as a part of a potential MP or rather an addition to

7) What about ownership, who's responsibility should it be?
Hoe denkt u over het eigenaarschap van een materialenpaspoort?

(Gaat de privacy van informatie boven het toegankelijk maken van informatie)

In the report from Jonge honden (Mijl et al., 2020) also adressed, to have a up to date MP for any building it is important to have clear agreements on who is responsible for what information.

8) What do you think is the best way to access and present information in a MP?
Hoe denkt u dat informatie beschikbaarheid en presentatie van informatie in een materialenpaspoort geregeld dient te zijn?

9) Could you maybe sketch the ideal MP and describe what is in the passport?

Zou het mogelijk zijn een omschrijving te geven van hoe een ideaal materialenpaspoort (of iets anders) er uit zou zien en wat erin staat?

Expert group 2: circular practices

1) Can you briefly describe the project, what circular practices are present and what the incentive was to use circular practices?

Kunt u een toelichting geven over het project waar u betrokken bij bent en waarom er is gekozen voor het gebruik van circulaire toepassingen?*

**Hieronder te verstaan: Secundair materiaalgebruik, circulair slopen, direct hergebruik, hoogwaardig recyclen etc.*

2) What pre knowledge on the building existed (applicable in case of demolition/renovation project is addressed)

Welke informatie was op voorhand beschikbaar over het gebouw (in het geval van een renovatie of sloopopgave?

Disclaimer:

Het materialenpaspoort is geen vast begrip, op verschillende niveaus en in sectoren hanteert men verschillende definities, het staat de geïnterviewde vrij om een eigen definitie of term te gebruiken. De definitie van materialenpaspoort volgens dit onderzoek is als volgt:

The concept of a MP can be described as a document or database that describes the characteristics of components or materials of a product (Guldager Jensen & Sommer, 2016). In construction a MP is a detailed inventory of all the components used in the building, it contains their characteristics, dimensions and location (Hutton et al., 2016).

3) Is a MP involved in your project?

Is er gebruik gemaakt van een materialenpaspoort voor dit project?

[yes]

4) Where in the process was the MP included?

Waar in het proces is het materialenpaspoort in beeld gekomen?

5) Did the use of a MP lead to more circular practices?

Heeft het materialenpaspoort bijgedragen aan circulaire toepassingen?

6) Why not? (if applicable)

Waarom niet?

7) If so, can you express the role of the MP in circular practices (was it essential)?

Hoe heeft het paspoort bijgedragen aan de circulaire toepassingen (hoe belangrijk is het geweest)?

8) Is there any specific information or data in the used MP that lead to circular practices?

Is er specifieke informatie in het gebruikte materialenpaspoort dat heeft geleid tot circulair handelen?

Often the MP is assumed to lead to circular practices, but that might not always be the case, for example when we looked at the demolition of an USP building it turned out to be much more (cost) effective to make a material inventory at the end of life, these questions try to find an answer as to what extent it is necessary in successful practices

9) Is there any other tool or strategy (besides a MP) that has been used in the project that aids circular practices?

Is er een andere tool of strategie (los van een materialenpaspoort) geweest die heeft bijgedragen aan circulaire handelingen gedurende uw project?

10) What information in whatever tool used has proven to be essential in developing a project with circular actions?

Welke informatie of data (hoeft niet perse uit een materialenpaspoort) is nou het allerbelangrijkste gebleken tijdens uw project en bijkomende circulaire handelingen?

11) Could you maybe sketch the ideal MP and describe what is in the passport?

Zou het mogelijk zijn een omschrijving te geven van hoe een ideaal materialenpaspoort er uit zou zien en wat er in staat?

[The second group of experts is also given this question, mainly to see whether there are differences between the experts that have either positive or negative experience with a MP and the other experts]

12.2 APPENDIX II – INTERVIEW TRANSCRIPTS