8/16/2019

BIM-based material passport in Madaster during the operational and maintenance phase of a building

Bachelor Thesis

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5 MEI 2019 – 19 JULI 2019

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16 August 2019

Abstract

The building construction industry is responsible for 60 percent of the raw materials extracted from the lithosphere. Raw materials are scarce but limited and must therefore be well documented so that they remain unlimited. With the help of the material passport, materials get an identity, which means that they can never disappear in anonymity as waste. In this research the central question was how a material passport in Madaster can be generated from a BIM-model and be kept up-to-date during the operation and maintenance phase of a building. Madaster is a platform were material passport can be generated from BIM-models.

To study this question first the requirements of Madaster were compared to the specifications of BIM modeling standards. Secondly, data about the process of generating a material passport is collected with the help of interviews. The respondents of the interviews are employees of companies that have experience with generating a material passport in Madaster and an employee of Madaster.

The results of this study showed that the input BIM-models for Madaster often lack data which means they do not meet the requirements of Madaster. Generating a material passport in Madaster from a BIM-model should be an automatic process. However, there are some manually steps that needs to be taken. This study provides some optimization strategies to reduce the manually work needed to create a material passport and keep it up-to-date. Currently there is no motivation to keep a material passport up-to-date during the operation and maintenance phase. Certification and legislation of a material passport could increase the use of a material passport and make it common practice.

Firstly, from this research appeared to generate a material passport in Madaster the BIM-models need to meet the requirements of Madaster which is often not the case. Secondly from this study appeared to keep a material passport up-to-date it is important that there are motivations such as tax deductions or legislations to motivate property owners to keep the material passport up-to-date. Generating material passport from the data in the BIM-models will give the materials in a building an identity, which means the materials cannot be treated as waste. In this way BIM will contribute to a more sustainable and circular construction industry.

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1. Introduction

The building construction industry is responsible for 60 percent of the raw materials extracted from the lithosphere (Honic et al., 2019a). To minimize the extraction of raw materials, reduce waste and reduce the environmental impact of buildings the materials used in a building should be reused or recycled. Through identifying materials there is a better insight in where materials are located and materials get a value (Honic et al., 2019b). When materials and products have an identity and value their chances of being treated as waste is reduced because something that has value can be sold and will be disposed less easily. The reduction of waste and increase in reuse and recycling of materials is a step to a circular economy. A system that goes from cradle to grave is changed to a system from cradle to cradle. Identifying materials in buildings and documenting them in a material passport gives insight in the stock of materials in buildings.

More and more newly built buildings are modelled in Building Information Modeling (BIM) models. BIM-models contain information about a building and about the composition of the materials in a building. These data can be used to inventory the materials used in a building from which Life Cycle Analyses (LCA) can be performed and the impact of the building on the environment can be calculated (Honic et al., 2019a). BIM supports the circular economy by providing a way to share data through the lifecycle of a building. BIM can be used in the design, construction, management and deconstruction phase of a building to pass data. The ensure high-quality reuse of materials in a building it is essential that sufficient information is available about the composition of elements. As a BIM-model contains the geometry and material information of all elements in a building it could be used to generate a material passport. Besides information about the materials in a building, a material passport also contains information about the degree of circularity of a building and the residual value of the materials (Honic et al., 2019a; Munaro et al., 2019).

A material passport is interesting for property owners because it gives an overview of the materials in a building. As a result, materials get an identity, which means that they can never disappear in anonymity as waste. Besides a material passport is interesting for property owners to see their buildings' scores on circularity and sustainability, and what the residual value of the buildings is at the end of life phase. Madaster acts as a library and generator for material passports.

This research is initiated by the company PeoplePower. PeoplePower is an expert in the field of drawing management and making drawings and BIM models. This means that PeoplePower digitizes and updates drawings and makes information from drawings and BIM-models accessible for facility management. PeoplePower advises companies in recording there building information in CAD procedures and BIM protocols.

PeoplePower is looking to extend their services by providing material passports to give facility managers and property owners information about the circular and economic value of a building during the life cycle of their real estate. PeoplePower has no experience with a material passport in Madaster, an online platform that generates material passports. As a result, PeoplePower does not know whether their Revit-models correspond with the input of Madaster. Another problem PeoplePower encounters is that there is no framework on how to generate a material passports and keep it up-to-date during the operational and maintenance (O&M) phase of a building. This study will focus on the O&M phase because PeoplePower is interested in the material passport during the O&M phase of a building.

This study will give insight in the extra data needed in BIM-models to generate a BIM based material passport in Madaster. Secondly, it also gives insight in what additions need to be made to modeling standards so BIM-models can be transferred directly into a material passport in Madaster. With regards to scientific relevance, the current study is the first to design a framework for generating a BIM-based material passport in Madaster. In addition, it will provide recommendations on how the process could be optimized. The main objective of this study is to get insight into how a material passport in Madaster can be generated from a BIM-model and be kept up-to-date during the operation and maintenance phase.

In chapter 1 and 2, research background, a theoretical framework about BIM and a material passport are provided. In chapter 3, the research questions are presented. In chapter 4, the research methodology is presented. In chapter 5, the result of the research will be presented and in chapter 6 the results will be discussed. In chapter 7 the results will be verified and validated and chapter 8 will provide the overall conclusion and limitations of the research and recommendations for follow-up research.

2. Theoretical framework

First, the definition of BIM in the literature and the role of BIM in the life cycle of a building is discussed. Section 2.2 elaborates on the role of BIM during the O&M phase. In section 2.3, a description of the BIM modeling standards that are used for the case BIM-model is given. Thereafter, in section 2.4 a description of a material passport as given in the literature is discussed. In section 2.5, the platform Madaster is described. Section 2.6 elaborates on the input of Madaster.

2.1. BIM

According to Matějka and Tomek (2017), there is a different understanding about the definition of BIM between researchers. While some see BIM as a product in the design phase other see it as a methodology for the whole life cycle of a construction project. In this study, BIM will be considered as a methodology which means that the different models Asset Information Model (AIM), Project Information Modeling (PIM), Facility Information Modeling (FIM) and Project Life Cycle Information (PLIM) are a component of BIM (see Figure 1). This corresponds to the definition of BIM that Becker et al. (2018) use, they define BIM as a method for the digital way of planning and building. They see the aim of BIM, a digital model of all the features of a building, to support the building processes through the whole life cycle of a building.

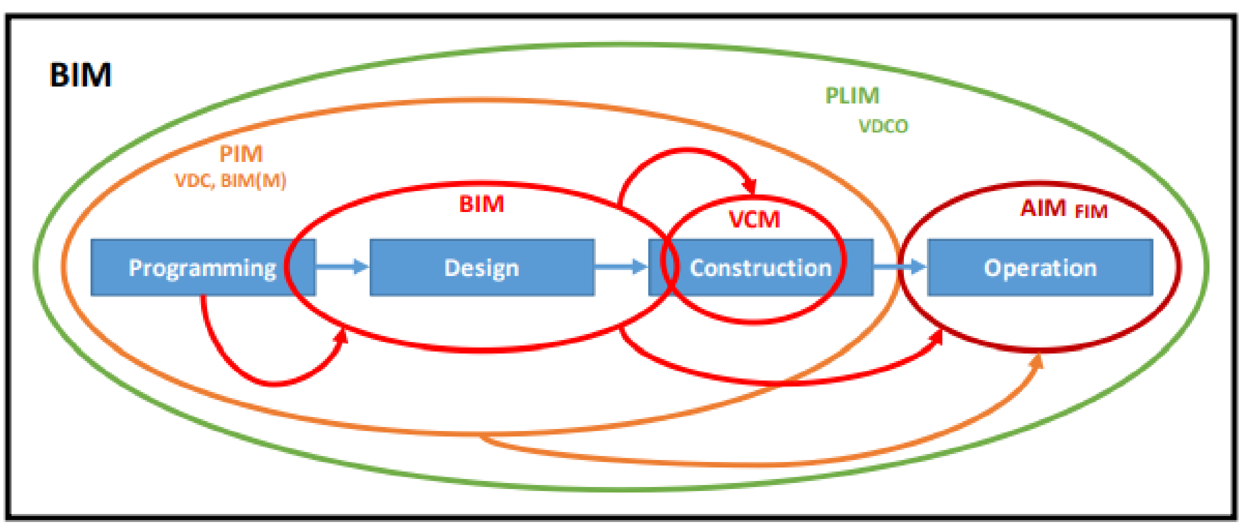

Figure 1: Disorganized BIM-related acronyms in construction project life cycle (Matějka & Tomek, 2017)

BIM is a way to easily exchange data between different Architecture, Engineering and Construction (AEC) partners. To improve the exchange of data between several BIM software programs, actors developed standards to decrease variations in parameters and prevent conflicts.

A consistent use of BIM does not only improve the data exchange between parties involved in a construction project but also increases the transparency for an optimized coordination between the different parties involved (Becker et al., 2018). The transparency makes easier and earlier detection of collision between different elements of the different AEC partners possible, so the failure costs are reduced.

As BIM contains all the information of the materials and products used in a building it should not be only used in the construction phase but also in the O&M phase and the end of life phase as is shown in figure 2.

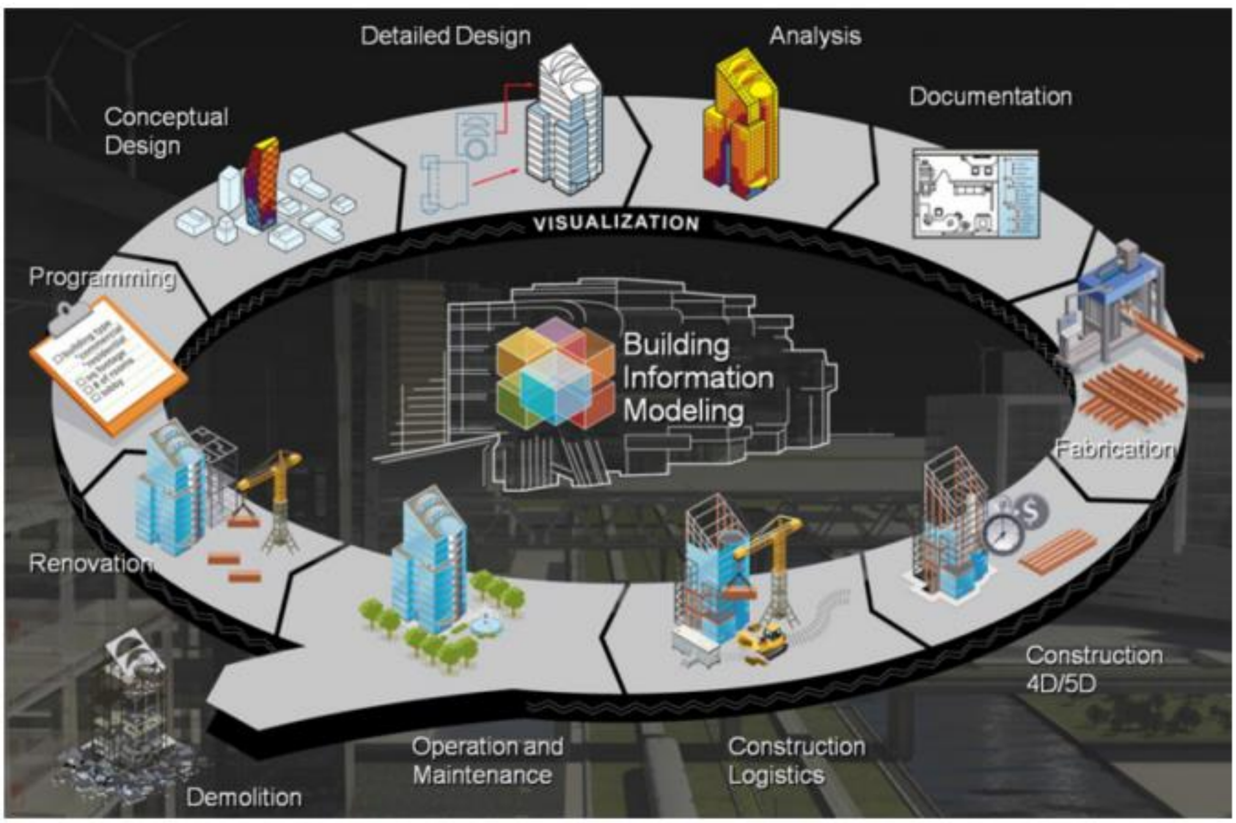

Figure 2: Application of BIM on the building life cycle (Becker et al., 2018)

In the planning and construction phase of a building BIM is used to simulate the construction project in a virtual environment. With BIM technology a building is digitally constructed and contains precise geometry and relevant data needed to support the design, procurement, fabrication and construction activities of a building (Azhar, 2011).

According to Matějka et al. (2016), the operational phase of a construction projects is considered as the most important phase of a building because it takes up most of the time of the life cycle of a building. BIM-models have the potential to make facility management more efficient and consequently reduce costs during the O&M phase (Matějka et al., 2016). According to Gao and Pishdad-Bozorgi (2019), facility managers face the problem that they do not have easily and quick access to the information they need to process work orders. BIM could be used to integrate fragmented facility management information that is spread over different building management systems and to provide an intuitive information access interface. Gao and Pishdad-Bozorgi (2019) distinguish six different fields where BIM could be useful during the operational phase: maintenance and repair, energy management, emergency management, change/relocation management, security, and facility O&M in general.

According to Akinade et al. (2017), the implementation of BIM for end-of-life scenarios of a building is not common practice but they recognize the potential that BIM could have in the end-of-life phase of a building. BIM contains information about materials in a building but should also contain information about how they could be disassembled to reduce the Construction and Demolition Waste (CDW) of the construction industry. BIM could improve the process of deconstructing a building and support the circular economy instead of disposing a building and generating CDW (Akinade et al., 2017).

When integrating the life cycle of a building into a framework, Pishdad-Bozorgi, Gao, Eastman and Self (2018) distinguish two different conditions of a building, the virtual and the physical. In figure 3 a framework is shown that shows the cooperation between the different participants in a project team and the connection to the BIM-model.

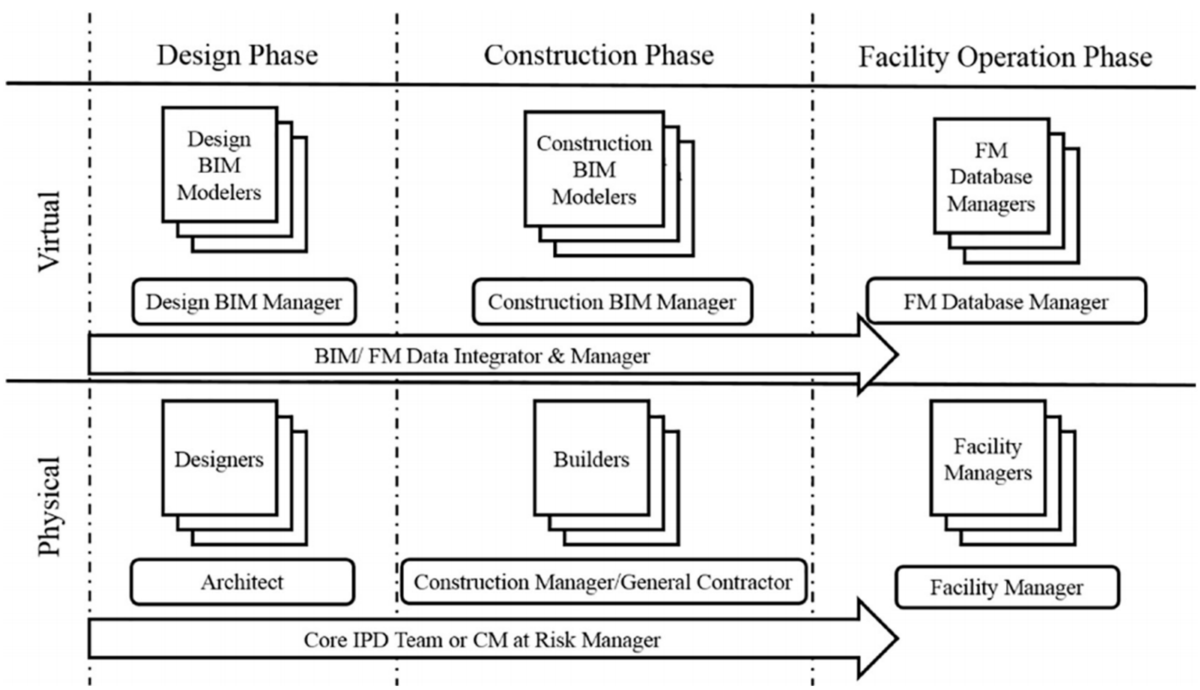

Figure 3: Framework of the different life cycle phases of a building (Pishdad-Bozorgi et al., 2018)

Pishdad-Bozorgi et al. (2018) make a difference between a Design BIM Manager, Construction BIM Manager and a FM Database Manager. Others, such as Tulke and Schumann (2018), see the BIM Manager as an independent role coordinating the implementation and application of BIM throughout different specialist areas. In this study the role of the BIM manager is seen as an independent person that coordinates the BIM-model of a building during the whole life span of a building and controls the quality of the BIM-model. Besides the BIM managers Pishdad-Bozorgi et al. (2018) distinguish a role for the architect, contractor and facility manager during the life cycle of a building and its virtual model.

2.2. Up-to-date BIM-model

Each of the four stakeholders in the life cycle of a building has his own responsibility in keeping the BIM-model accurate. When using BIM in a project the architect create a BIM-model (Aguiar, Vonk & Kamp, 2019). The contractor uses the design model as a basis to create the as-built model. According to Aguiar et al. (2019) the contractor is responsible for an accurate as-built model at the end of the construction phase. In the O&M phase of a building the facility manager and the contractor are responsible that adjustments and renovations are implemented in as-built models (Aguiar et al., 2019). According to Parhiala, Yalcinkaya and Singh (2014) one of the challenges of BIM is the fragmented nature of the construction industry. Therefore, the ownership and management of a BIM-model across the different phases is unclear for most stakeholders in the industry (Parhiala et al., 2014). To avoid potential conflicts, it is crucial to establish contracts that define the ownership, deliverables, interaction with project stakeholders and the risks (Kubba, 2012; Azhar, 2011).

Research of Zadeh, Wang, Cavka, Staub-French, and Pottinger (2017) shows that the quality of as-built BIM-models do often not meet the expected level of quality that is purposed for facility management. To ensure the quality of the models built by the stakeholders in the project team Pishdad-Bozorgi et al. (2018) say the models need to be assessed continuously to determine if the models contain the required information and formats. However, assessment of the model is not only needed in the design and construction phase of a building. Also during the O&M phase it is important that all adjustments in a building are tracked and documented accurately. According to Hungu (2013) it is a challenge to keep track of the changes made by building users during the O&M phase. Users tend to fit buildings to their activities without reporting the owner about the changes they made. However, to prevent working with wrong assumptions a model needs to be up-to-date.

2.3. BIM modeling standards

To make data exchange between different BIM software programs easier, the way of storing data is standardized. Standardization makes it possible to exchange models between different software programs. The platform BIM Loket manages several different standards, coordinates and strengthens the mutual connection between the different standards (BIM Loket, 2019). With BIM-standards BIM Loket tries to improve the BIM-process with more efficient communication, less time loss and qualitative better building objects for lower costs.

A common standardization which is used for BIM modeling with the software program Revit in the Netherlands is the standard NLRS. NLRS is accepted as a recommended standard by the Forum of standardization (BIM Loket, 2019). In the NLRS agreements are made about the application of the BIM modelling software program Revit including naming, model structure and the use of parameters in Revit. Therefore, Revit can export standardized and vendor independence IFC-files with a uniform structure which can be used and imported by other software packages (BIM Loket, 2019). The NLRS standard is very applicable to export to IFC because NLRS has as guiding principle the exchange with IFC (Revit Standard Foundation, 2019).

To support the exchange between different modeling software programs, NLRS facilitates the use of other open standards such as CB-NL, IFC and NL/SfB (BIM Loket, 2019). As default NLRS uses the NL/SfB code to classify objects. The NL/SfB classification is mapped in the parameter 'assembly code' in the properties set of an object. The parameter 'assembly code' is a parameter field where the classification of an object can be filled in. Besides NLRS delivers a complete material library with a naming system based on the 'NL/SfB table 3' classification of materials. Using the library of NRLS will result directly in a correct export of the materials to IFC (Revit Standard Foundation, 2019).

NLRS is based on the architecture and construction therefore the installation industry often uses the EMCS standard (Bureau Forum Standaardisatie, 2017). The EMCS standard is specialized for electrical and mechanical installations. EMCS is used to guarantee that Mechanical, Electrical and Plumbing (MEP) families are consistent, behave correctly in a Revit-project and contain relevant information (MEP content, 2019). EMCS has a library with MEPcontent product models which are documented according the EMCS standard (Stabiplan, 2018).

EMCS identifies different levels of information detail of a product. A MEPcontent product is documented according to the EMCS standard and will normally have an information level of 5 or 4. A level of information of 4 means that all components of a product contain a generic description and dimensions. A level of information of 5 means that the manufacturer specific properties are specified and components represent a specific product (Stabiplan, 2018).

All MEPcontent product models are classified according to a set of European and international classifications. The different European and international classification are included in the property set of an object with different parameters from which some are filled in automatically but others need to be filled in manually. As some standards contain a long list of product properties EMCS only includes the parameters that are useful during design and on delivery of a project or that are needed to uniquely identify objects (Stabiplan, 2018).

The standards NLRS and EMCS are used to standardize the naming and the use of parameters to store data. NLRS is a national standard and uses national classifications, whereas EMCS is an international standard and uses international classifications to classify an object.

2.4. Material passport

A material passport is an instrument that offers a platform and repository for storing, linking and providing relevant information on materials in buildings to the relevant actors along the value chain (Heinrich & Lang, 2019). The use of a material passport will stimulate circularity in the construction sector. As a material passport gives transparency in the materials that are used in a building it makes it easier to reuse the materials. The material passport can also be used to keep track of the value of materials in a building over time (Waal, 2018).

According to Honic et al. (2019a), a material passport should contain information about the materials composition of a building. Honic et al. (2019a) say a material passport should show the materials that are embedded in buildings but as well showing their recycling potential and the environmental impact.

Munaro, Fischer, Azevedo and Tavares (2019) proposed a building material passport as shown in figure 4. According to Munaro et al. (2019) a material passport should contain information on quality, safety, use and operation, disassembly, reuse potential, history of checks and traceability of materials. Munaro et al.

(2019) state also that it is important that the data in the material passports is obtained and constantly updated. The parties involved in a project each have a different aspects of a material passport they should obtain and constantly update.

Product tracking code: **Product name:** **Manufacturer:** — **Building Material Passport** (BMP) Last update: yyyy/mm/dd	**Sections description**
1 General data Product/commercial name; Composition/materials; Manufacturer/supplier; Use period/time; Use recommendation/restrictions; Performance characteristics; Technical data (strain/weight)	Comprises the manufacturer/supplier data, the general description of the material/system, composition, recommendations and restrictions of use, performance requirements and criteria, intended use period.
2 Security measures (dafe data sheets) Security information (warnings/recommendations); Toxicological recommendations; Handling and storage instructions; Risk identification/fire protection	Indicates safety information from material receipt to its disposal; warnings regarding the toxicological risks involved; first-aid and fire-fighting measures.
3 Sustainability Environmental declaration; Life cycle assessment (LCA); LCA boundaries and methodology; LCA results and interpretacion	Involves LCA and environmental product declarations, the methodology used, the results and interpretation.
4 Use and operation Positioning and location in the building; Assembly instructions; Connections details and requirements; Maintenance and cleaning	Indicates the positioning and location of the material in the building; assembly instructions; maintenance and cleaning; connections details and systems requirements.
5 Disassembly guide Disassembly instructions (removal/replacement of pieces); Transportation and storage instructions	Provides instructions for disassembly, removal, replacement of the pieces and components of the meterial/system. In addition, indicates best practices regarding transportation and storage.
6 Reuse potential End-of-life considerations (reuse/recycling/remodeling); Disposal options	Provides information regarding the reuse, refurbishment, recycling potential as well as disposal considerations at the end of life of the material.
7 History Use period; Latest uses/operations; Verifications made during use; Updates during operations	Covers tests and verifications carried out during the material or system life, indicating its use period, past uses/operations, as well as its current state.
8 Other information References used/standards consulted; Complementary material	Indicates sources, references and standards consulted, as well as details and descriptions of information used in the development of the passport.

Figure 4: Proposed building material passport (Munaro et al., 2019)

Comparing the material passports of Honic et al. (2019a), Munaro et al. (2019) and Waal (2018), Waal (2018) adds that a material passport should also contain information about the value of the materials. Buildings can be seen as stock markets with their own economic value that can be traded. When materials at the end of the life cycle of a building can be reused it means that they have residual value. To know which value a building has during its life cycle it is important that the materials stored in a building are documented accurately.

In a new construction project it is possible to include the availability of materials in buildings that should be demolished and could be used in the design process. Especially building materials of nearby buildings that will be demolished are interesting to keep in mind during the design process. By using locally available materials the environmental impact of a building can be reduced (Waal, 2018).

According to Honic et al. (2019b), the data needed to generate a material passport are building parts information, volumes and materials, recycling data and LCA data. The data of the building parts can easily be extracted from BIM-models because they contain most of the needed information. Figure 4 shows the methodology that Honic et al. (2019b) use to generate a material passport from a BIM-model.

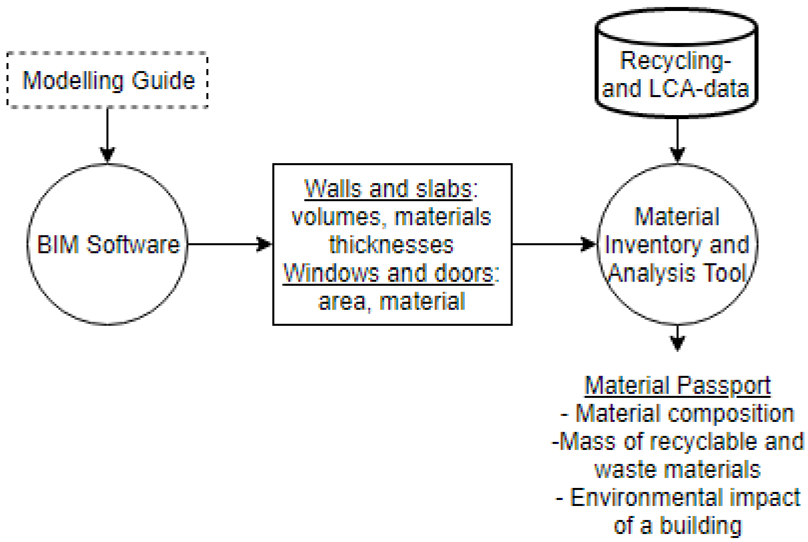

Figure 4: BIM methodology for the generation of Material Passports

Figure 4 shows that in the modelling guide the requirements on how to create the BIM-model are determined. The BIM-model modeled in a BIM software program is used to extract the data about the volumes and materials. The data about volumes and materials together with recycling and LCA-data from a database is the input data for the material inventory and analysis tool. The data of the geometry and materials together with recycling and LCA-data from a database is used by the material inventory and analysis tool to generate a material passport.

One of the challenges that Munaro et al. (2019) identify is the lack of data about product properties and specifications in BIM-models (e.g. materials, toxicological recommendations, end-of-life considerations). To identify the reuse potential of products and materials it is important that the product properties and specifications are provided by the supplier and connected to the BIM-model. Another challenge that Munaro et al. (2019) identified, is that the data in the material passport should represent the current state of the building which means that the materials and products must be tested and examined to ensure the reliability of the material passport. A building should be tested and examined to determine the condition of the products and materials and if the data is up-to-date. For a BIM based material passport it means that the BIM-model must be up-to-date and contain accurate information.

When looking at a circulair economy and sustainable built environment a material passport should be placed in a broader context. Heinrich and Lang (2019) see the material passport as part of a building's documentation. Figure 5 shows the position of a material passport in the building's documentation. Gathering the data from material passports in an open online platform makes it possible that a new market will open in building products in which buildings are a depot where materials are stored. Building owners could plan the deconstruction of a building based on the actual value of the building materials.

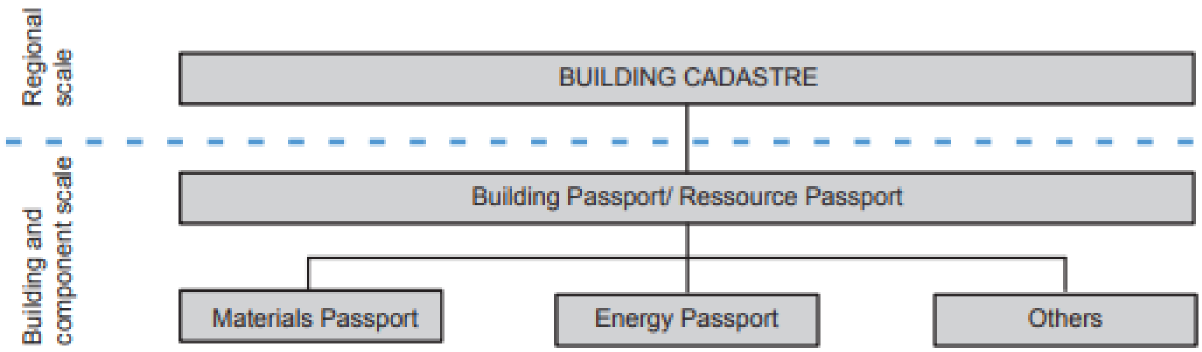

Figure 5: Classification of materials passports from a building and regional scale (Heinrich & Lang, 2019)

Figure 5 shows that a material passport together with a energy passport and other documents of a building constitute the building passport. Madaster wants to facilitate a platform where these documents can be gathered and generated.

2.5. Madaster

These material passports of buildings can be gathered and connected to a location in the Madaster online platform. The goal of Madaster is to keep materials available in all economic cycles, by facilitating the registration of the materials and thus the availability of materials at the highest possible level (Madaster Platform, 2018b). Madaster is the building cadaster that Heinrich and Lang (2019) identified where material passports and other building documents are stored.

Madaster uses two ways of structuring the data about the products used in a building. The first method is structuring the products per building layer. The building layers in Madaster are based on the shearing layers that Brand (1994) defined. Brand divides a building in six layers: Site, Structure, Skin, Services, Space plan and Stuff. The division of the layers is made based on the different lifespans of the layers. Madaster uses for the lifespan of the building layers respectively 500, 100, 20, 15, 10, 5 years (Madaster Platform, 2018b). To complete the overview of the data Madaster added a total layer and an unknown layer for materials that are not connected to a building layer as shown in figure 6.

Figure 6: Different building layers in Madaster (Rau, n.d.)

The second method of structuring the data is by dividing all the elements in material families. Madaster distinguishes six material families as is shown in figure 7. They also have a seventh category for elements that can't be assigned to a material family.

Figure 7: Different material families in Madaster (platform.madaster.com)

Madaster does not only generate material passports but also provides a systemic overview of the data and applications of the data such as the economic value and a circular indicator. Compared to the proposed material passport of Munaro et al. (2019), a material passport in Madaster only contains (1) the amount of the materials and products and (2) the circularity of materials and products. Other elements of a material passport that Munaro et al. (2019) identified (e.g. security measures, use and operation, disassembly guide) are not part of the material passport in Madaster but can be added on the online platform as separate documents related to a building. In the online platform there is also an indication of the economic value of materials as Waal (2018) suggested. The Madaster platform is structured in four different categories: Building, Building process, Circularity and Financial.

2.5.1. Madaster Building

In the building category Madaster gives insight in were all the materials and products are located in the different building layers of a building (Madaster Platform, 2018b). The total amount of the materials and products is expressed in volume, in weight and as percentage of the whole building. The data about the building is structured in a table with a vertical division in building layers and horizontal in material families. Per building layer there is a possibility to display a further refinement of the elements present in the building and the product information can be accessed. It also gives property owners the opportunity to search for the location of a specific type of material in a building.

2.5.2. Madaster Building process

The Madaster building process category defines five phases of a renovation project and shows them in an orderly manner: (1) current situation: the materials in the existing building, (2) deconstruction: the materials that are removed from the building during deconstruction, (3) casco: the remaining hull, (4) virgin materials: new or recycled materials and (5) the final situation: the situation after renovating (Madaster Platform, 2018b). For each phase, Madaster clarifies which materials are used and in which quantities (volume, weight and as a percentage of the whole). The data about the building is structured in a table with a vertical division in construction phases and horizontal in the material families.

2.5.3. Madaster Circularity

The Madaster circularity category gives insight in the circular value of a building. The Madaster Circularity indicator (CI) is based on the Material Circularity Indicator of the Ellen MacArthur Foundation (Madaster Platform, 2018d). A building can score between the 0-100% based on the data entered by the user. A building that scores 100% consists, among other things, of recycled materials, has a more than average lifespan and can be disassembled relative easily at the end of his life cycle. Besides the total indication of circularity on building level, Madaster also gives insight in the level of circularity per phase of the life cycle of a building which can be displayed for the whole building but also for the different building layers. Madaster distinguishes three different phases: the construction, O&M and end of life phase.

The Circularity indicator measures the level of circularity in the different phases. In the construction phase the CI measures what the ratio between "new" and "recycled, reused or renewable" raw materials is. In the O&M phase the CI measures what the expected lifetime of the products used compared to the average lifetime of comparable products is. In the end of life phase, the CI measures what the relationship between "waste" and "reuse or recycling" of materials and products that are released during a renovation or demolition of a building is. The building CI is corrected with two factors that include the completeness of the imported dataset in Madaster in the total score. The correction of the CI is needed because Madaster is still able to generate a material passport if not all the requirements described in section 4.1.1. are met.

The completeness of the model is the extent in which the BIM-model meets the requirements of Madaster. The correction is derived from the completeness of the model based on the percentage of the mass whose material is unknown, and the completeness of the model based on the percentage of the mass of which the NL/SfB coding is absent (Madaster Platform, 2018d).

2.5.4. Madaster Financial

The economic category in Madaster shows the residual value of a building at the end of the different lifespans of the products expressed in the material value. Besides this, Madaster shows the actual material value and the predicted development to the future. To make an accurate prediction of the end values of a building, the material values are corrected with the (1) deconstruction costs, (2) handling feedstock costs, (3) a correction for the size of the raw material flow and (4) transportation cost per kilo of material (Madaster Platform, 2018c).

The residual value of the different building layers on the various functional lifespans is calculated with the net present value of a material in a building layer towards the present. Which means this is the net present value of the residual value based on the expected functional lifespan of the materials. The functional lifespan is the expected lifespan of a building layer and differs per building layer (Madaster Platform, n.d.).

For banks, investors and other real estate owners it is important to determine what the end value of their buildings is. Firstly, it is important for them because knowledge of a building decreases the risk factor for demolition related debits. Secondly, the material value of a building can be representative for the end value of a building. This end value can result in a more positive business case when making an investment decision during construction or when purchasing a building. In this way the circular goal of Madaster is connected to the residual value of a building and therefore to money (Madaster Platform, 2018c).

2.6. Industry Foundation Classes (IFC)

The reliability and accuracy of the calculations performed in Madaster depend on the availability and accuracy of the input data. Madaster uses Industry Foundation Classes (IFC) files to import data of buildings from BIM-models (Madaster Platform, 2018b). This IFC files contain data over the location and the amount of material in volumes and weight. Madaster categorizes and sums the data from the IFC files to get a clear overview of the materials used per building layer.

The fragmentation among project disciplines (e.g. architects engineers, contracters) causes costs of billions of dollars in lost productivity, wasted materials and increased liability. The IFC data model is seen as one of the solutions to overcome the inefficiencies of the distributed and fragmented industry (Thein, 2011). IFC is an open standard for the exchange of building data models used in different software programs. According to Hitchcock and Wong (2011), IFC provides software developers and users of BIM a standard for sharing consistent, accurate building information amongst software tools used throughout a buildings life cycle. IFC is used for the coordination between models build in different software programs and cannot be used for editing models. The IFC standard is a set of agreements on how to document building elements. IFC files contain information about the 3D geometry and property data of an object. To build the IFC files in a logical way the data is organizes hierarchically in a tree structure as shown in figure 8.

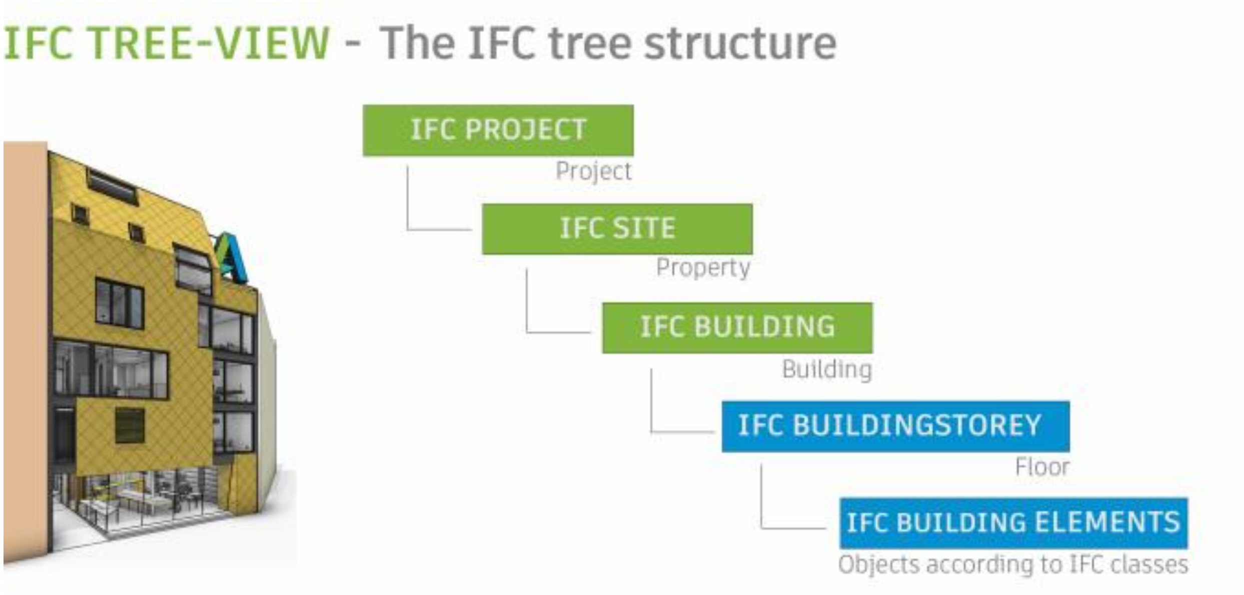

Figure 8: IFC tree structure (Autodesk, 2018)

Figure 8 shows the predefined structure that IFC uses to store data. Translating the data from the different BIM software programs to the IFC structure makes it possible to exchange data between the software programs. However translating data from a software program to a IFC structure means that the original structure or data that is lost when exporting to a IFC file cannot be returned when importing the IFC in the software program.

The data in IFC files is not only limited to the geometry but IFC files also presents the building components and enables the linking of alphanumeric information such as properties, quantities and classification to building objects and maintaining these relationships (Autodesk, 2018). Madaster uses the geometry, properties, quantities and classifications to determine the volumes and properties of the used materials in a building.

In the fragmented construction industry each discipline uses its own BIM software program with its applications. The IFC standard is the format that is used to overcome inefficiencies and therefore is commonly used in the construction industry. Connecting to IFC increases the reach of Madaster, each BIM-model that is modelled in a software program that supports IFC can be used as an input for Madaster. Due to IFC, Madaster is able to connect to all the BIM software programs that support IFC Instead of connecting to a select number of BIM software programs.

3. Research questions

This study has a main objective which will be investigated with two main questions. To answer these main questions, they are divided into sub-questions. The first objective of this research is to get insight into how data from a Revit-model connects to the requirements of Madaster to generate a material passport. The Madaster platform functions as an online library of materials in the built environment. It connects the material-identity to a location and registers this in a material passport. The main question belonging to this objective is:

To what extend can data about the quantities and properties of elements from a Revit-model be used for a BIM-based material passport in Madaster in the construction phase? (1)

To answer this question it is necessary to know what data and data formats are required to import a BIM-model into Madaster, which corresponds to the first sub-question:

What input data and data formats are needed in Madaster? (1.A)

The second sub-question will get insight in how the Revit standards connect to the data format that Madaster requires.

How do the Revit standards NLRS and EMCS used in the Revit models connect to the required data format in Madaster? (1.B)

The second objective of this research is to get insight into how a material passport can be generated and can be kept up-to-date during the operation and maintenance phase. The main question belonging to this objective is:

How can a BIM-based material passport of a building be generated and kept up-to-date during the operational and maintenance phase of a building? (2)

To find out how a BIM-based material passport could be kept up-to-date during the O&M phase it is important to know what the relation between a BIM-model and a material passport is. As a result, the first sub-question is:

How is the input BIM-model needed for Madaster to generate a BIM-based material passport created? (2.A)

After knowing the relation between a BIM-model and a material passport it is important to get insight into the process of generating a material passport from a BIM-model in which the information about a building is stored. This results in the second sub-question:

Which steps need to be taken to generate a material passport and keep it up-to-date during the operational and maintenance phase of a building? (2.B)

Since there is no legislation of the correctness of a material passport the level of detail and accuracy of a material passport is not clear. To get insight into the effect of the level of detail and accuracy on the material passport the following question will be asked:

What is the effect of the accuracy and level of detail on keeping a material passport up-to-date during the operational and maintenance phase of a building? (2.C)

The research question will be answered with the methodology discussed in chapter 4.

4. Methodology

To answer these questions, methods are chosen to collect and process data and get results. This methodology in the research process is visualized in Figure 9.

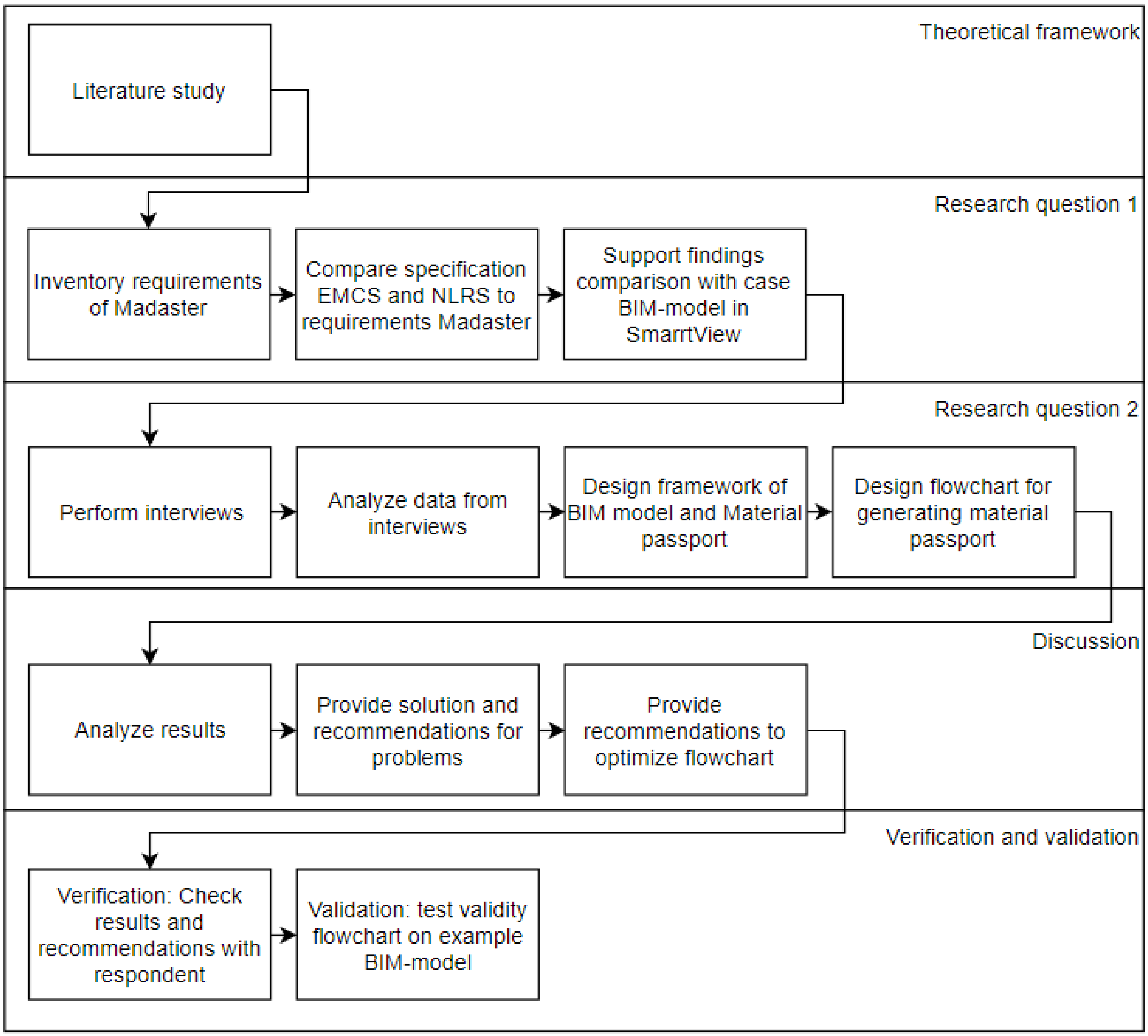

Figure 9: Methodology flowchart

A literature study was conducted to get background information about BIM, modeling standards, material passports and Madaster. Desk research was conducted to answer the first research question. During the desk research secondary data is gathered and analyzed. The data needed to answer the first research question are Madaster's requirements for the input IFC files and the specifications of the Revit standards. This research will focus on the standards because it gives the opportunity to make statements that can be generalized for all BIM-models modelled according to a standard instead of studying individual models and make statements about individual models which cannot be generalized. The research focusses on the standards NLRS and EMCS and therefore uses the specifications of NLRS 2.5.1 and of EMCS 4.0. This study focusses on the standars NLRS and EMCS because these standards are the main standards Peoplepower uses. To find out to which extend the Revit standards connect to the input of Madaster the specification of the standards are compared to the requirements for the input of Madaster. Comparing the requirements to the standards means to check whether the requirements of Madaster are included in the specifications of the standards.

In addition, a single case study was performed with the Revit BIM-model. The BIM-model was provided by PeoplePower that initiated the research. The building in the BIM-model was an educational building with a laboratory, built in Revit version 2019. The BIM-model consisted of detailed architectural, structural, electrical and plumbing models. A single case study was performed because all BIM-models of PeoplePower are modelled according to the standards NLRS and EMCS which means the data and data formats in different models would be the same. Performing a multiple case study would not change the result. With a SmartView the documentation of the elements in the Revit model was analyzed and visualized. Analyze the documentation meant to check, with the help of the visualization in the Smartview, which elements did not meet the requirements of Madaster and find out the cause.

A SmartView is a visualization that highlights elements based on a criteria. The SmartView is used because a visualization gives a better overview of the quantity of elements that meet the requirements of Madaster. The used SmartView checks if certain criteria from the requirements are met. A SmartView is not able to check all the criteria but can check whether a parameter is defined or undefined and if a parameter is equal to a certain value. There are multiple software programs in which a SmartView can be created (e.g. Navisworks, Solibri model checker and BIMCollabZoom). In this research BIMCollabZoom is used because it is available for free and has a predefined SmartView for the requirements of Madaster.

To answer the second research question interviews were conducted. The interviews were inductive to discover new sights on how to generate and keep a material passport up to date during the O&M phase of a building. According to Steckler et al. (1992), interviews generate rich, detailed, valid process data that usually leave the study participants' perspectives intact. The interviewees were experts working at business partners involved in the life cycle of a building who were experienced with Madaster. Since interviews generate subjective data it is important for this study to interview not only employees of Madaster but also partners in the lifecycle of a building who had experience with a material passport. In this study a BIM-manager of a contractor and a circular advisor were interviewed to gather knowledge about their experience with generating material passports in Madaster. Besides an employee of Madaster was interviewed to get insight from the viewpoint of Madaster. In appendix A a list of the interviewees and their functions is given.

The data that was generated by the interviews is primary data and was gathered through semi-structured interviews. According to Bradford and Cullen (2013), semi-structured interviews allow to gather information about a similar subject, whilst also acknowledging the potential contradictions or differences between opinions and experiences of respondents. As the employee of Madaster and the other interviewees, who use Madaster, all had different stakes, they had different opinions on how a material passport should be generated and kept up to date. The interviews consisted of descriptive and structural questions. According to Harrell and Bradley (2009), descriptive questions are asked to let people describe things and may let to new insights and structural questions help to get insight in how things are related and how to categorize things.

The aim of the interview with Madaster was to find out how a material passport can be generated, what it means to keep a material passport up to date and what information is needed during the O&M phase of a building. The aim of the interviews with the other respondents was to get insight into the steps that need to be taken to generate a material passport and what it means to keep a material passport up to date during the O&M phase of a building. Besides, the aim of the interviews was to get insight in what the effect of accuracy and level of detail is. The information about the interviews was coded and analyzed. The data from the interviews was coded in four themes: (1) establishment of a BIM-model and a material passport (2) the process of generating a material passport from a BIM-model, (3) the accuracy and level of detail of a material passport, (4) a material passport during the O&M phase. Analyzing the responses of the interviews meant to compare the opinions of the respondents with each other. As a result, from the analysis of the interviews a flowchart was designed on how to generate a material passport in Madaster. The flowchart describes the decisions that need to be made and processes that need to be performed to generate a material passport.

In the discussion the results of the desk research and interviews are critically assessed and compared to the discussed literature in the theoretical framework. Based on the problems and opportunities identified in the discussion solutions and recommendations are given. To ensure the quality of the results a member check is used to verify the flowchart. The validity of the flowchart is tested with a case BIM-model. The BIM-model used for the validation is not very complex and contained some basic elements of a building. Using a less complicated BIM-model with less elements makes it possible to check where problems occur and the documentation is incorrect. In section 5 the results of the described methodology will be presented.

5. Results

In this chapter the results of the desk research and the interviews are presented. In section 5.1 the results of the desk research to answer research question 1 are shown and in section 5.2 the results of the interviews to answer research question 2 are shown.

5.1. BIM (Revit) to material passport in Madaster

This section discusses to what extend the data from a Revit-model can be used for a material passport in Madaster. Section 5.1.1. elaborates on the requirements of the input that Madaster needs to generate a material passport and to calculate the circular an economic value of a building, whereas section 5.1.2. presents the results of the comparison between the Madaster input and the Revit output.

5.1.1. Requirements Madaster

To make sure the IFC files contain enough data for Madaster to perform accurate and reliable calculations Madaster formulated a set of requirements. The following guidelines for setting up a BIM and then exporting it to an IFC file are given by Madaster (Madaster Platform, 2018a):

- Ensure that the project zero point is related to the RD coordinate anywhere in the world;
- Prevent the use of the IFC entity "Building element proxy" and "Building element part";
- Every Globally Unique IDentifier (GUID) must be unique;
- All elements assign a material;
- All elements classified by NL / SfB (4 digits);
- Enter the "IFC-Type" correctly, for each element as completely as possible;
- Always export the "Base Quantities"
- Export the "Renovation status" or "Phasing" in the Property set of the same name; use the English name if created by yourself: Existing / Demolish / New
- Use the "2x3" export setting, or a possible "Madaster export" setting

If the data does not meet these requirements the result in Madaster will be inaccurate and unreliable. To improve the accuracy and reliability of Madaster, Madaster has the possibility to enrich the data manually. However, modifications in Madaster are not implemented in the source files but only applied in the online platform of Madaster. Therefore it is important that the source files meet the requirements of Madaster. In the sections below the requirements of Madaster are described and in section 5.1.2 the requirements are discussed further and compared to the specifications of NLRS and EMCS.

Project zero point related to RD coordinates

The first requirement of Madaster for an IFC file is that its project zero point relates to the 'Rijksdriehoek' (RD) coordinates. RD coordinates are used to determine the geographical location of an object. The geographical location is needed by Madaster to place a project in the cadaster. To place a project on the right location the project zero point needs to be connected to the corresponding RD coordinates.

IFC entity "Building element proxy" and "Building element part"

"Building element proxy" and "Building element part" are unidentified elements which means the elements have no defined meaning of a special type of building element they represent. When elements are not identified Madaster cannot recognize them and place the element in the corresponding building layer and connect the element with the database of Madaster. "Building element proxy" and "Building element part" should only be used to exchange building elements for which there is no semantic definition provided (BuildingSmart, 2019).

Unique GUID

A GUID provides a unique ID for everything within a BIM-model. GUIDs are used for precise tracking of information. The aim of a GUID is to give each element a unique code so it can be identified and followed through his life cycle. A GUID can in the future be used to track the history of an object throughout its life cycle from cradle to grave. GUIDs do not need a central database for issuing and tracking IDs because the likelihood of finding two identical numbers is very small. This IDs can be unique because a GUID consist of a 128-bit number (BIMToolbox, n.d.). To import a model into Madaster all GUIDs must be unique to ensure that all the information about an element is connected to the corresponding element.

Element material

To get insight in the materials that are used in a building all the elements need to be assigned a material. A material is a homogeneous or inhomogeneous substance that can be used to form elements (BuildingSmart, 2019). To generate a material passport Madaster must know which materials are used in a building. When elements are not assigned a material, Madaster cannot list the materials from which the elements are made. The materials should be named and associated with material properties according to the classification of a standard.

IFC-Type

The type of an element needs to be defined as completely as possible. A complete IFC-Type describes not only the type of element but also the object type for example an element type is a roof and the object type is roof tiles. The definition of the element type needs to be as specific as possible so it could also contain information about the specific product name or code.

NL / SfB classification

To import a IFC file into Madaster the elements must be classified according to the standard classification NL/SfB. The NL/SfB classification consists of 4 codes (see Figure 10). The first code exists of the coding for the environment to be built and the spaces to be created. The second code is de coding for the functional components of the facility to be built. The third code consists of the coding of the construction method to be used and the coding of the construction material to be used. The last code exists of the code for the preparation and construction process to be organized, the characteristics and properties of a building, spaces and (building) materials and the characteristics of the activities of (future) users (BNA, 2005). The coding for the 4 codes is documented in 5 tables with the third and fourth table describing the third code.

Figure 10: NL/SfB classification (BNA, 2005)

A common problem of the NL/SfB-classification is that it is limited usable for the classification of technical installations. It is often unclear how modern installation systems can be accommodated in the "classical" NL / SfB classification (BIM Loket, n.d.).

Base Quantities

BuildingSmart (2019) defines base quantities as quantity definitions that are independent of a method of measurement. The IFC base quantities provide information about the gross and net values of an element provided by measurements of the geometric shape representation of an element. The base quantities differ for each element in appendix B an example of the base quantities that are used for some basic elements is shown. Madaster uses the base quantities to sum the volume and weights of the materials and products in a building (Madaster, 2018a).

"Renovation status" or "Phasing" in the Property set

The "Renovation status" or "Phasing" is used by Madaster to keep track of the changes that are made in a building during its lifecycle. The "Renovation status" or "Phasing" is optional but for the completeness of a material passport especially during the O&M phase of a building it is recommended to use phasing in a BIM project. The "Renovation status" or "Phasing" gives insight in which elements are demolished and newly built during the renovation of a building. All the elements in a BIM-model should be labeled with either Existing, Deconstructed or New so Madaster can keep track of what happened during a renovation project.

"2x3" export setting

As models can't be edited in IFC files they are exported from other BIM-software programs. When exporting models to an IFC file they should be exported with the "2x3" export setting. The "2x3" export setting is optimized for the exchange of BIM-models between partners in the building industry. The export setting determines the geometrically representation of a 3D object in a model.

5.1.2. Revit to IFC for Madaster

The requirements of Madaster do not only include requirements about the coding, naming and classification of elements which is modelled according to standards but also about the coordination and the export settings. To meet the requirements of Madaster the export settings of Revit must be modified. Madaster requires the 2x3 export settings but these export settings must be modified to include a GUID for each object and to export the base quantities. In the modify setup tab the export settings can be changed and the setting produce GUID and export base quantities can be selected.

When exporting IFC files, Revit uses a mapping table to define the IFC class type and the IFC type. If a Revit category in the mapping table does not match any IFC class type, the IFC class type parameter is defined as ifcBuildingElementProxy when it is exported to IFC (see Figure 11). IFC does not have an IFC class type for every element in Revit and therefore uses the IFC class type parameter ifcBuildingElementProxy to name all elements that cannot be semantic classified.

Lighting Devices	IfcBuildingElementProxy
Afdekplaat	IfcBuildingElementProxy
Afdekraam	IfcBuildingElementProxy

Figure 11: Example IFC export mapping table

The location coordinates should be set when starting a project in Revit. Revit has three coordination points, the origin zero point, the survey point and the project base point (Autodesk, 2018). The survey point is the point that indicates where the building is located on the earth's surface and should be assigned with the RD coordinate system. The project base point is used to determine the position of objects relative to a specific point near the model. The origin zero point and the survey point must always overlap. If a project has one building model the project base point must also be equal to the survey point and the zero point.

In the theoretical framework was found that the elements that are imported from the NLRS library are classified according to the NL/SfB classification. However, products that are used from the MEPcontent library are documented according the EMCS standard which does not include a classification according to NL/SfB. As mentioned in the theoretical framework the MEP content documented according to EMCS has a parameter for the NL/SfB classification but it is not filled in automatically. As a result, not all installations are classified according to NL/SfB. When comparing the different building layers to the extend in which they have a NL/SfB classification it can be concluded that almost all elements in the structure have a NL/SfB classification. Most of the elements in the skin are classified according to the NL/SfB classification but in the service layer barely any element has an NL/SfB classification because the NL/SfB classification for technical installations is limited, as has been mentioned above.

For each element the type is defined because all products from the NLRS or EMCS library are assigned an IFC Type. As all elements in the library have a description the IFC type is known for each element. To import an IFC file into Madaster it is also required that all elements are assigned a material. For the NLRS library content only elements that have a material that is documented by NLRS are assigned a material (Ham et al., 2016). Stabiplan (2018) says the EMCS standard gives two different options on how to use the material parameters. The material parameter can be used to define a material with all its properties but also to show realistic, manufacturer-specific colors to represent a material in a model. According to Stabiplan (2018), the material must be assigned to an element in Revit when loading MEPcontent products into a project. Which means the material has to be filled in manually when modelling a building.

Phasing is not part of standards yet but NLRS has included phasing already in the template and is working on documenting the phasing (Ham, De Riet, Tas, & Wieringa, 2016). EMCS has no parameter for phasing. As a result, in the case model can be seen that the different AEC partners included different coding for the phasing of the project as is shown in figure 12.

Architectural model

	Name
1	bestaand
2	sloop
3	nieuw

MEP model

	Name
1	1. Bestaande situatie
2	2. Sloop
3	3. Nieuwbouw
4	4. Plan over 10 jaar

Structural model

	Name
1	Existing
2	New Construction

Figure 12: Documentation of phasing in case model

Figure 13 shows the level of documentation of the elements regarding the requirements of Madaster over the classification and identification of elements and materials. With the help of a SmartView all elements of the case model that do not meet the requirements of Madaster in terms of the NL/SfB classification, IFC type, material identification and element identification are highlighted in red.

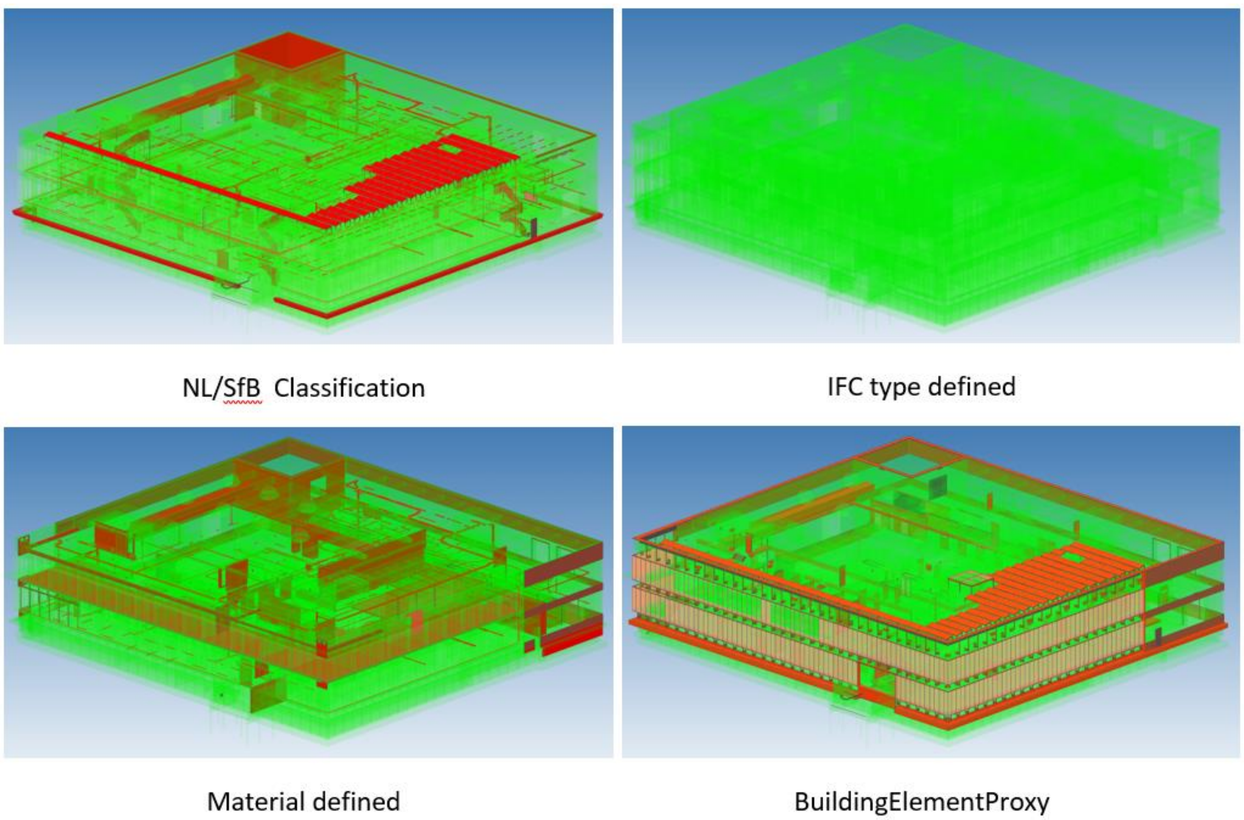

Figure 13: SmartView requirements Madaster

Figure 13 shows the requirements that can be checked with a SmartView. The SmartView checks whether the parameter for the NL/SfB classification, IFC type and material is defined and the parameter IFC class type is equal to BuildingElementProxy. In section 6.1 the results of the desk research and Smartview are discussed.

5.2. Generating a material passport

In sections 5.2.1. until 5.2.4. the results of the interviews are shown. See Appendix A for the list of respondents. Section 5.2.1 discusses the formation of an BIM-model and a material passport and in section

5.2.2 the process of generating a material passport from a BIM-model is described. Section 5.2.3. discusses the effect of accuracy and level of detail and in section 5.2.4 is discussed how a material passport can be kept up to date during the O&M phase of a building.

5.2.1. Relation between a BIM-model and a material passport

Central in this research is the BIM-based material passport. This means the material passport is generated based on a BIM-model. However, the use of BIM-models in the construction phase of a building is not common practice yet. As mentioned by the respondents the use of BIM needs to be initiated by the owner of a building. Respondent 2 argued that in the BIM process during the construction phase a BIM-model is developed according to the 'hamburger model'. This means that architects, constructors and installation advisors develop a BIM-model to a design level. This design BIM-model describes the performances a building should have. The next step is that suppliers and subcontractors improve the performance model. Based on the supplier models, called production models, the production is managed (Koomen, 2017). Respondent 2 also discussed that an as-built model is created from the production models and for the parts that are not elaborated in the production models the design models are used. The production models are often more detailed than the design models but they often contain less information in the parameters. For a material passport the consideration needs to be made to use the less detailed design models which already contain the correct parameters or use the more detailed production models where parameters need to be added. From the as-built model the facility management models can be created.

Respondents 1 and 3 argued that the as-built model should be the input of the material passport. According to respondent 1, only a list of materials used in a building is not enough to change to a circular economy. To make the connection between Madaster and a marketplace the information that Madaster requires is not enough. To make products tradeable the product specification needs to be known. For facility management it is also interresting to add guarantee certificates and lease contracts. Respondent 1 discussed that an owner of a property should include the use of BIM and the deliverable of an as-built BIM-model which is suitable for an import in Madaster in the tender contract. Respondent 2 argued that the material passport itself is part of the commissioning when that is determined in the contract.

To make the as-built model suitable for import in Madaster it should meet the requirements mentioned in section 5.1.1. To ensure the quality of the as-built model the design and production BIM-models need to be checked during a construction project. According to respondent 2, the role of a BIM-manager is to guide the BIM-process and check the quality of the design and production models delivered by the sub-contractors and suppliers. Checking the quality means to see if the models meet all the requirements which were determined at the start of a project. Comparing the framework of Pishdad-bozorgi (2018) shown in figure 3 with the data of the interview resulted in a framework that can be seen in figure 14.

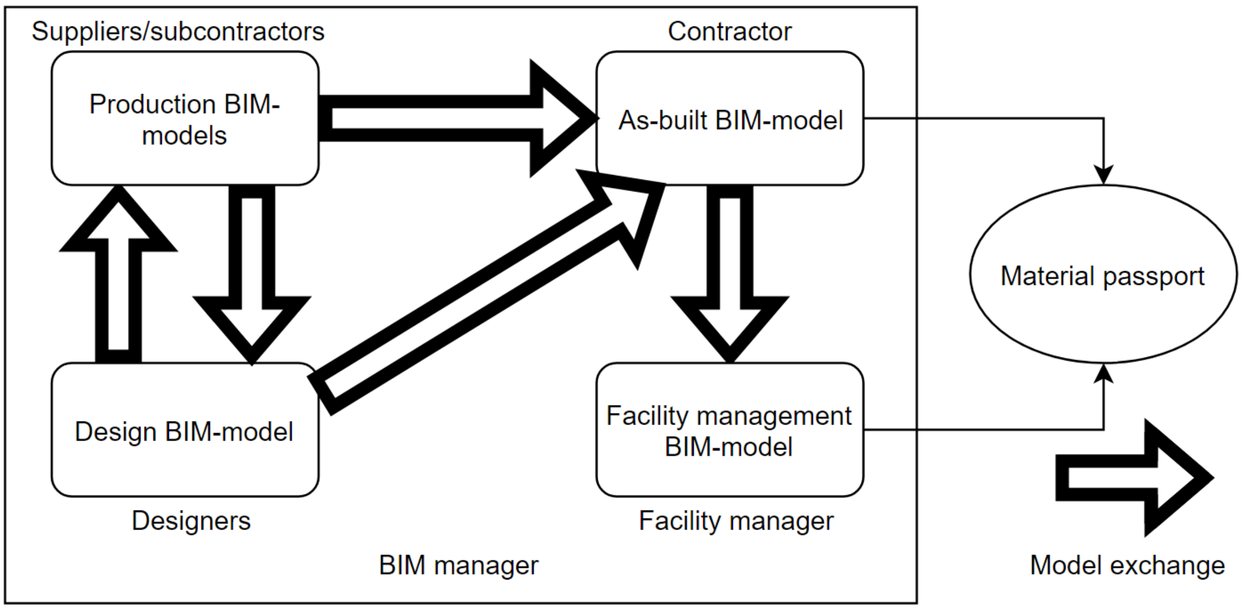

Figure 14: Life cycle of a BIM-model

The ‘hamburger model’ described by respondent 2 is derived from the General AEC Reference Model (GARM) discussed by Gielingh (1988). The design BIM-model and the production BIM-model in figure 14 are derived from the ‘hamburger model’. In theory for every part of the building there should be a design BIM-model and a production BIM-model. However according to respondent 2 in practice there is not for every part in a building a production model so to create an as-built BIM-model the design BIM-model is used for these parts that are not included in the production BIM-models. As described by Pishdad-bozorgi (2018) in figure 3 the BIM-models from the construction phase are used for the facility management BIM-model. During the O&M phase the facility management BIM-model should be used to generate a material passport.

5.2.2. Process of generating a material passport

Madaster developed a platform that generates a material passport based on an input BIM-model in IFC format and a database as shown in figure 15. According to respondent 3 the Madaster platform is built to automatically read IFC files and connect the BIM-models to the database to generate a material passport. However, respondent 3 acknowledged a challenge in the mapping between the BIM-model and the database due to inconsistent naming of materials and products. Contradictory, respondent 2 argued that it connecting the systems is not that simple and there are still some steps that need to be taken manually.

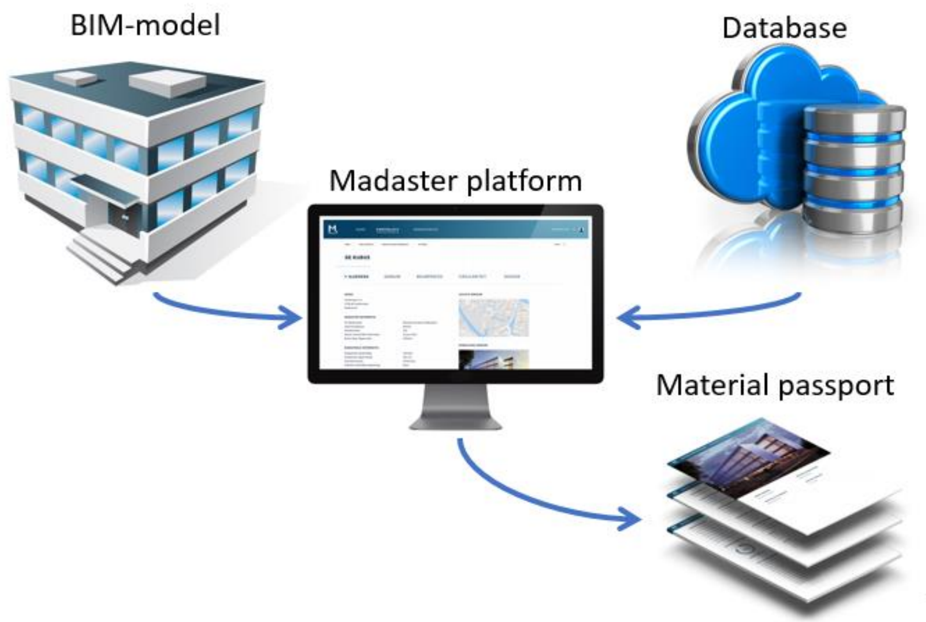

Figure 15: Process of generating a material passport

The database shown in figure 15 represent the entire database in Madaster. This includes the personal customized database but also the public available databases in Madaster from the different BIM software programs, Madaster and the NMD database. The information in the database about the materials and products is shown in appendix C.

Respondent 3 described the process of generating a material passport in Madaster in a few steps. The first step is to make an export of the BIM-model that meets the requirements of Madaster. The second step is to upload the IFC files to Madaster which checks automatically if the requirements are met. Madaster matches the IFC files to the products and materials in the database. If the matching is not complete the third step is to enrich the mapping manually in Madaster. Respondent 2 distinguished some more steps and said the process starts with an inventory of what to document as a material or product. The second step is to create all the materials and products in Madaster because the materials in the Madaster database are 'virgin' materials and have poor sustainable properties. In appendix C the interface for creating a material or product in the database is shown. Another step that respondent 2 added is that the IFC files should be improved so all the parameters are documented according to the requirements of Madaster. The main difference between the respondents is that respondent 3 assumed that the BIM-model already met the requirements of Madaster whereas respondent 2 assumed the BIM-models need to be improved. Another difference is that respondent 3 assumed that all the materials and products are included in the database whereas respondent 2 thought the products and materials in the Madaster database are not realistic and do not cover all the products and materials in a building. Combining the respondents' views on the process of generating a material passport in Madaster the flowchart in figure 16 was designed.

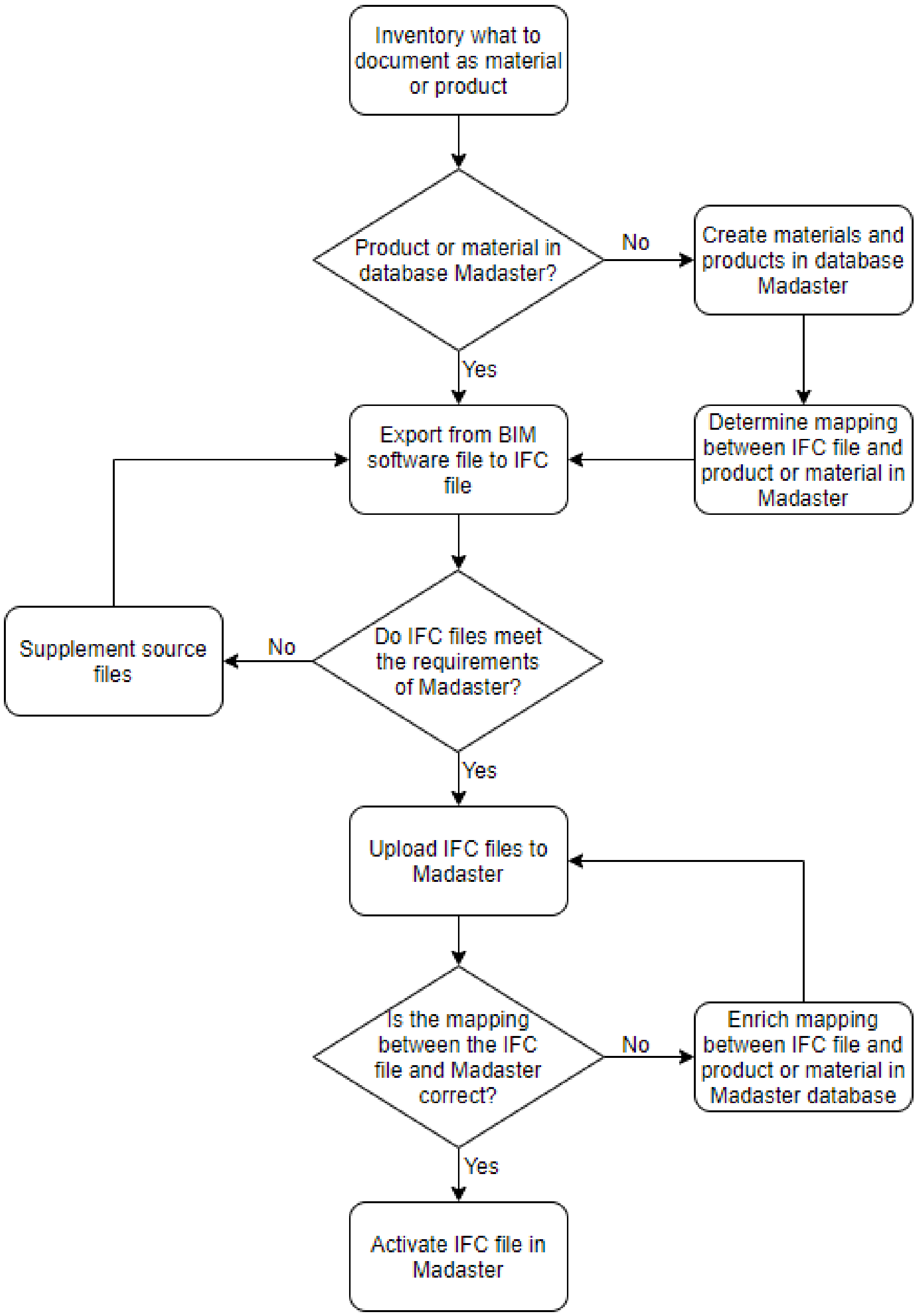

Figure 16: Flowchart of generating a material passport in Madaster from a BIM-model

The flowchart in figure 16 is the result of the responses of the interviews. All steps that the respondents mentioned are included in the flowchart. A few elements of the flowchart are not in line with what the respondents suggested. First, respondent 2 argued that the IFC files needed to be checked on the requirements of Madaster manually before uploading the IFC files to the Madaster platform. Respondent 3 argued that Madaster automatically checks if the requirements are met. Second, respondent 3 did not assume the need to create materials and products in Madaster whereas respondent 2 assumed all products and materials needed to be created manually. Therefore, the decision box ‘product or material in database Madaster?' is added to check whether a product or material is already part of the database of Madaster or if there is a need to create a new product or material in Madaster. In section 6 the flowchart is discusses and recommendations for optimization are given.

5.2.3. Accuracy and level of detail of a material passport

When looking at the building layers of Brand (1994) the respondents acknowledged that all of the layers are interesting to document in Madaster. The construction is interesting because it contains most of the mass of a building. According to respondent 1 and 2 the interior and the space plan is especially interesting because they are changed more often and have the highest potential in recycling. The products in the interior and space plan are easier to demount and have a low risk of failure because the quality can be checked easily and there is no safety risk in reusing these products. According to respondent 1, at the moment the installation in a building is mostly outdated at the end of the lifecycle. Therefore, these materials are recycled which results in a low residual value. Respondent 1 argues that, generally speaking, currently it could be said that (1) steel provides money, (2) the disposal of concrete costs money and the (3) other parts in a building are even.

To ensure the quality of the material passport the accuracy and level of detail need to be determined. The respondents did not give a clear answer about the accuracy and level of detail a material passport should have. Currently it is the choice of the owner what elements are included in the material passport. According to respondent 3, it is to the owner to decide how much time he will put in finding all the information. The owner needs to find a balance between the time and the expected result. In practice this balance often means to invest 20 percent of the time in getting 80 percent of the information instead of investing also the last 80 percent of the time in getting 20 percent of the information. However, respondent 2 thinks information is worthless if you don't know whether it is accurate and up-to-date because you cannot rely on the information if you don't know what parts are updated and accurate.

Incomplete documentation of building elements results in invalid and unreliable results in Madaster. As Madaster divides the information in building layers there is a possibility to generate valid and reliable results for a specific building layer. However, the results for building as a whole will not be valid when layers are not considered. If elements or building layers are not included in a BIM-model it is also possible to add an Excel file in the Madaster format to the Madaster platform to add additional information on elements not included in the BIM-model.

According to respondent 3 a certification is needed to check the quality of a material passport. The certification of a material passport means that the correctness of the material passport is checked with the actual building. This certification is still in development in the whole market. From a financial point of view the certification of a material passport is important because it is unlikely that a not-certified material passport will result in tax deduction or better financing conditions. However, from the sustainability point of view the certification of the material passport matters less. As the respondents mentioned, a material passport will make the owner of a building aware anyway that a building consists of materials that can be reused and not only of waste.

5.2.4. Material passport during the O&M phase

To generate an up to date material passport the BIM-model should be up to date. This means that all changes in the building need to be implemented in the BIM-model. According to respondent 3, Madaster has the possibility to update the material passport by uploading a new IFC file, renewed IFC file or Excel spreadsheet. The Madaster platform displays the building processes which shows the current situation, and during a transformation the casco and the end situation. According to respondent 2, there are some difficulties with updating the BIM-models. As the as-built model consists of different production and design models it is possible that the models are modelled in different software. That would mean the owner must have acces to all the different software to implement changes or go back to the suppliers to let them implement changes and update the production BIM-models.

Respondent 3 argues that it is the responsibility of the owner to decide whether things are updated or not. To let owners keep track of changes and document all the changes a mind shift is needed. Respondent 3 sees that legislation is needed often to accomplish a mind shift. In order to make legislation of a material passport possible the quality of a material passport must be measureable. Together with its partners, Madaster is working on a certification of the material passport to enable implementation of quality measures. When a material passport is confirmed to be correct, this improves changes to get a tax deduction and better financing conditions because of environmental friendly measurements. According to respondent 3, most propably a visual inspection is needed to ensure the correctness and quality of a material passport. Respondent 3 discussed that Madaster is exploring how condition measurements can be connected to Madaster because for a condition measurements visual inspections are already needed. Besides the condition of a product also influences the reuse potential and the financial value of products and materials. Madaster wants to connect to existing processes such as condition measurements according to NEN 2767 to reduce the effort to generate a correct and certified material passport. A condition measurement is a checklist whereby the technical state of a building or building part is measured (NEN, n.d.). Based on the condition scores often a maintenance plan is established. However, certification and the connection to condition measurements is a system that is still in development in the market.

6. Discussion

In this chapter the results are discussed. In section 6.1 the findings of the desk research about the connection between Revit and Madaster are discussed and compared to the literature from the theoretical framework. In section 6.2 the process of generating a material passport is reviewed. In section 6.3 the findings of the interviews about the process of generating a material passport are applied to the O&M phase. Lastly, in section 6.4 recommendations for a optimization strategy are given.

6.1. Export from Revit to IFC

In accordance with the desk research and the literature review, the experiment with the case BIM-model showed that the Revit standards NLRS and especially EMCS do not cover all of the requirements of Madaster. The results of this study show that all elements have been assigned a type but not all elements are identified, classified according to NL/SfB and have assigned a material. Several types of elements are more likely to lack information.

First, the desk research and the experiment showed that most of the MEPcontent products are not assigned a material or have a color as material assigned. Elements are given a color according to a standard to give a uniform representation of the MEPcontent so the elements that belong to a system can easily be identified (Stabiplan, 2018). However, the color representation gives no indication about the material an element is made from. In the NLRS library content instead, all elements have a material assigned except from elements that consist of materials that are not available in the NLRS material list. The NLRS library consists of the most frequently used and best-known materials so the basic elements all have assigned a material. Only elements that consist of a less common material have no material assigned. As a result, the materials in the structure layer are mostly known but in the other layers a lot of less common elements have not assigned a material.

Secondly, from the desk research followed that all elements that are modelled according to NLRS should contain a NL/SfB classification. However, the Smartview in figure 13 shows that not all elements besides the technical installations have a NL/SfB classification. The difference between the NLRS and EMCS standard is that the EMCS standard is an international standard and the NLRS standard is a national standard. The classification problems of the EMCS standard are due the fact that EMCS is an international standard for MEP content while NL/SfB is a national classification. On the national level BIM Loket manages the connection between different standards. On international level the European Committee for Standardization is working to develop European norms for BIM in CEN/TC 442. To solve standardization problems between national and international levels there should be an international classification and standardization that is accepted an implemented on national levels. As Madaster is internationalizing and developing their service it should extend its database to other international classifications.

Between models, inconsistent use of phasing parameters has been detected. The desk research showed that Madaster uses the parameters ‘Demolish’, ‘Existing’ and ‘New’ for phasing. However, from the desk research and the experiment also appears that the use of phasing parameters is not standardized. As a result, every model uses different ways to identify the phasing. To improve the exchange of data about the phasing between different BIM software programs the phasing should be included in the different standards. If the phasing is standardized Madaster should use the standardization to display the building process during the life cycle of a building.

Another issue arises when IFC classes are generated. Many elements in the model cannot be identified when exporting to IFC and are given the IFC class type ifcBuildingElementProxy. To improve the IFC export from Revit the mapping table of the IFC class types should be improved. Revit users could also use the parameter ifcExportAs to manually give elements a semantic classified IFC class type instead of the IFC class type ifcBuildingElementProxy.

As can be seen in figure 13 there is a lot of overlap in elements that are not defined, classified or a material assigned. The basic elements in a building are documented according to the standard NLRS and contain all the information that Madaster needs. However, less common elements are not that well documented and therefore often do not meet the requirements of Madaster on more than a single parameter. Elements that are not documented according to the requirements are not included in the calculation of the CI and the financial value of a building. The CI is corrected when elements are not documented well enough but the financial value of elements that are not documented is not considered. Therefore, the financial value of the building will be inaccurate if elements are not documented sufficiently. Madaster provides the possibility to manually enrich the information in the platform but adjustments and enrichments of the information must be made in the source files to keep information structured and accurate.

When reviewing the results for each of the different building layers of Brand (1994) that were introduced in the theoretical framework, it can be concluded that the connection between Revit and Madaster is better for the structure than for the other building layers. For the other building layers, the requirements of Madaster are not met and the documentation of elements in Revit needs to be improved to make them suitable for importation into Madaster. The difference in suitability between the building layers is caused by the fact that the structure is built of basic elements whereas the other building layers consist of less common elements.

6.2. Process of generating a material passport

The decision of what to document as a product or material effects the calculation of the economic value of a building. As respondent 1 said, products have a completely different value than materials. The value that Madaster calculates is based on the material value but products that are in proper condition have a higher value than solely the materials they are made from. So, to get the most accurate result it is better to document elements as products instead of materials.

When more buildings are documented in Madaster the database with products and materials will grow. Especially, when the same products and materials are used in several buildings, the need to create products and materials will decrease. However, this requires that the owners of buildings and of product and material databases that were created manually are willing to share the databases so others can benefit from it. Another challenge with regards to using databases of others is the mapping critera which could possibly not connect to the IFC file of another user due to different naming of products and materials. For that reason it is important that the naming of products and materials is consistent in the BIM-models of different users.

Especially when using databases of others it is important that the mapping is checked. Checking the mapping between the IFC files and the databases means that manually needs to be checked if an element is documented correct as a product or material. Besides needs to be checked if an element is matched with the correct product or material in the database. When a change is needed in the mapping it is important that the mapping criteria is changed or extended instead of matching an element manually to a product or material in the database.

As was described in section 5.1.2 and discussed in section 6.1 the BIM-models modelled according to the standard EMCS do not meet the requirements of Madaster. Consequently, the BIM-models must be supplemented to get complete overviews and results in Madaster. This challange is already identified by Munaro et al. (2019) who said that BIM-models often lack data about product properties and specifications.

In the ideal situation there is no need to supplement the source files, create any materials in the database or change the mapping. As a result the process of generating a material passport will go automatically. To make a BIM-model suitable for a material passport in the early stages of setting up a BIM-model the requirements for a material passport need to be considered. To ensure the IFC files contain the needed information in the parameters it should be included in the BIM-protocol of a project.

6.3. Material passport during the O&M phase

When implementing the flowchart in figure 16 in the O&M phase as described in section 5.2.4. it is important that changes in parameters are made in the source files. If changes would not be implemented in the source files, problems in the transition from the BIM-model to Madaster will occur every time a new IFC file is uploaded. The starting level of a material passport in the construction phase influences the process of keeping the material passport up-to-date during the O&M phase. Every manually enrichment will need to be executed again every time a new IFC file is uploaded. To prevent these extra tasks, only new materials that are not part of the database available in Madaster should be created manually and the mapping criteria should be changed in Madaster. Other enrichments should be made in the source files. When the source files meet the requirements of Madaster and the mapping criteria between the IFC files and the Madaster database are correct, updating the material passport is fairly easy. Only new elements need to be documented according to the requirements of Madaster and supplemented when uploading to Madaster.

To keep all information in Madaster, demolished elements should not be deleted in the BIM-models. Instead, the parameter building phase of these elements should be changed. Otherwise Madaster cannot keep track of the materials that have been demolished.. However, when all demolished elements stay in the BIM-model the workability of the model could become a problem.

As mentioned by respondent 2 the use of different modelling software programs could be a problem when keeping a material passport up-to-date. Applying changes in all of the source files would mean that access to all the used software programs is necessary. As a result, it will be more difficult to implement small revisions in different software than big renovations where the partners with the different software programs are involved.

The Dutch government added a material passport to the environmental list of 2019 which include all environmental friendly investments which are qualified for tax deductions such as MIA and VAMIL (RVO, 2019). The MIA and VAMIL tax deductions on investments do not give a motivation to keep a material passport up-to-date. To motivate property owners to keep a material passport up-to-date there should be a continuous motivation such as a reduction on property tax. However not only the owner of a building needs to be motivated to keep the material passport up-to-date. The contractors and technicians also need to be motivated to document everything that is changed. As mentioned by respondent 3 there is a mind shift needed that everything needs to be documented.

6.4. Optimization strategies generating a material passport

The process of generating a material passport can be optimized in three steps. Optimizing the process means reducing the amount of manual work needed to generate a material passport. Firstly, the manual work in creating products and materials in the database of Madaster needs to be reduced. Secondly, the manual work in supplementing the BIM-model needs to be reduced. Thirdly, the manual work in checking and enriching the mapping needs to be reduced. In the sections 6.4.1 till 6.4.3 the three different strategies to optimize the process will be discussed.

6.4.1. Creating products and materials

The first step is that Madaster should reduce the input parameters for creating a material or product in the database and add the parameters to the BIM-model or use an existing parameter in the BIM-model. Adding the parameters to the BIM-model will reduce the need to create materials and products in the database which are the same but only differ on a parameter. For example, when a material with multiple applications and different recycled content exists in a building, for each different recycled content a new material needs to be created in the database in Madaster. In addition, the matching needs to be correct so in the material name of an element in the BIM-model a distinction needs to be made between the recycled content. To optimize this process the parameters for circularity needed to calculate the Material Circularity Indicator of the Ellen MacArthur Foundation (e.g. lifespan, recycled content, reusability) and general information, such as the supplier, should be extracted from the BIM-model.

In Madaster elements can be matched with materials or products from the database. When matching an element with a material it is possible to add the circularity parameters in the property set of a material or in the property set of an element. However, when matching an element with a product the parameters should be included in the property set of an element.

This recommendation will reduce the manual work because there is less need to create a material or product in the database and change the naming of materials to correctly match to the database. For example there are three types of plastic tables as shown in table 1. Each of the table is made from plastic but has a different amount of recycled content. In the current situation in Madaster three different kind of plastic need to be created with a different value for the recycled content. Besides the matching criteria need to be defined so the element is matched with the correct material with the corresponding recycled content in the database. All the material names in the BIM-model on which is matched with the database are the same and therefore need to be changed so the difference in recycled content is also clear in the material name (e.g. Plastic20, Plastic30, Plastic40).

Table 1: Example tables with different recycled content

Naming	Material	Recycled content
Table A	Plastic	20%
Table B	Plastic	30%
Table C	Plastic	40%

When adding the parameter to the BIM-model there is no need to make a distinction in the matching criteria and the material names to express the different recycled content. In the example this means that only the material plastic needs to be part of the database of Madaster with the matching criteria 'Plastic' and the parameters for recycled content need to be added to the BIM-model.

To export the parameters correctly from Revit to IFC a user defined property set for Madaster can be used. Adding a parameter for the circularity in the BIM-model could also make the designers think about the environmental impact of the product or material choice they make. As a result designers might reconsider the use of a product or material because of the environmental impact of a product or material. The next step to optimize this process is to include the parameters for circularity in the modelling standards.

6.4.2. Supplementing the BIM-models

The second step is to improve the connection between a BIM-model and the database the BIM-model should be modelled according to a standard. For Madaster it is important to use standards for the naming of elements and assign an element a material from a standardized library (e.g. NLRS material library). To ensure that the BIM-model is built according to a standard supported by Madaster the use of a standard should be included in the BIM-protocol, as well as other requirements of Madaster. In the BIM-protocol should also be included that multiple materials for an element can only be used in layers or only the dominant material needs to be assigned. To improve the standards EMCS it is recommended to include a parameter for the volume of the material. The standard NLRS can be improved by adding a standardization for the phasing.

Besides to improve the connection between the BIM-model and Madaster it is recommended that Madaster should support multiple standards and classifications. If the elements in a BIM-model are classified with a different classification than Madaster supports all elements in the BIM-model need to be supplemented manually with a classification Madaster supports. Madaster should support multiple classifications as for example the uniformat classification and the NL/Sfb with NEN 2631 classification. Besides in the BIM-protocol should be include which classification should be used.

6.4.3. Checking and enriching the mapping

The third step is to optimize the matching between the BIM-model and the database in Madaster. It is recommended to get more guidance in the automatic matching process. To get more guidance it should be possible to prioritize the matching with certain materials and products. To make that possible each building should have a separate project database that includes all the products and materials that need to be prioritized in the matching.

The project database is different for each building and should contain only products or materials that are matched with a previous upload of the BIM-model or need to be prioritized based on a criteria for example the source (e.g. Madaster, Revit, Archicad, NMD). The general database contains all the materials and products in Madaster and is for each building the same. The general database includes the customized materials and products and the materials and products from the different sources: Madaster, Revit, Archicad and NMD.

For example when uploading a renewed IFC file during the O&M phase each time the mapping has to be checked, because the matching could be changed due to changes in the general database. Over the time the general database can grow and elements can be matched to the wrong materials or products in the general database because the matching criteria of a new added material or product in the general database is corresponding better. To prevent such problems it is recommended that Madaster makes a distinction between the project database and the general database for each building.

To improve the usability of the project database it should also be possible to add or remove materials or products manually from the project database and the general database. For example when a plastic table is matched to the material ´plastic A´ in the general database however it has to be matched with ´plastic B´. Adding ´plastic B´ to the project database ensures that ´plastic B´ is prioritized over ´plastic A´. To optimize the matching there should be more guidance in the matching by prioritization of materials and products in the project database.

7. Verification and validation

To improve the trustworthiness of the research the result is confirmed with a member check. In appendix D the format used for the member check is shown. The participant of the member check, an employee of Madaster, did not have any addition that needed to be made to the flowchart in figure 16. The employee of Madaster rated the flowchart as an excellent representations of the process of generating a material passport. The accuracy and usability for optimization of the flowchart were rated as good. According to Madaster the usability of the recommendations for optimization are high and they have potential to reduce the manual work and optimize the process. As comment Madaster added that to optimize the process it is important that all partners are involved and willing to cooperate. To improve the use of a material passport not only Madaster needs to improve its process but it is also important that the construction industry develops so a material passport becomes common use.

Validation is needed to ensure that the results fulfill its intended purpose. The intended purpose of the results was to give insight in how a BIM-based material passport in Madaster could be generated. The process of generating a BIM-based material passport is presented in the flowchart in section 5.2.2. The validity of the flowchart is tested with the use of the example BIM-models shown in appendix F. The validation consists of a test of generating a material passport from the BIM-model according to the flowchart. The process of generating the material passport from the BIM-model in appendix F according the flowchart is described in appendix E. Which resulted in the material passport shown in appendix G. As the total process of generating a material passport according the flowchart designed in section 5.2.2 did not lead to major problems there could be concluded that the flowchart is valid. However it only describes the main steps and does not include all technical aspects.

8. Conclusion

In this research with desk research and interviews is studied to what extend BIM-model modelled according to the standards NLRS and EMCS connect to the requirements of Madaster. Besides is studied how a material passport can be generated and kept up-to-date during the O&M phase of a building.

From the results appeared that the BIM-models modelled according to the standards NLRS and EMCS are not satisfying the requirements of Madaster. The standard NLRS does not provide a systemic documentation of the phasing. Elements modelled according to the EMCS standard do often not provide a material and classification automatically.

To generate a material passport from a BIM-model it needs to meet the requirements of Madaster mentioned in section 5.1.1. In the construction phase the as-built BIM-model and in the O&M phase the facility management BIM-model can be used as input to generate a material passport in Madaster. From the result of the interviews a flow chart (see figure 16) is created that describes the process of generating a material passport. This process should go automatically however there are still manual operations in the process. The owner of a building has to decide on the accuracy and level of detail of a material passport. A common rule in the decision of what to document is the 80-20 principle. Documenting 80 percent with spending 20 percent of the time. Currently there is no motivation to keep a material passport up to date after generating a material passport. In the future legislation and certification of the material passport in Madaster could result in a motivation to keep a material passport up to date.

While processing the result the reader should bear in mind that the study on the connection between the Revit standards NLRS and EMCS is based on specifications of EMCS 4.0 and NLRS 2.5.1. Updates of the standards could result in a different documentation and mapping of parameters. Madaster is also continuously improving the online platform and the connection to BIM software so findings in this study might not be valid for future versions of Madaster. Besides it is beyond the scope of this study to examine the quality of the case model and if there are elements that do not meet the requirements of the NLRS 2.5.1 or EMCS 4.0 standard. Because of the model being built in the past it could contain products that are documented according to older versions of the standards.

This research is limited to a BIM-based material passport in Madaster and does not include other ways of generating a material passport. In Madaster it is only possible to import Excel or IFC files. When a BIM software does not support IFC it is not possible to generate a material passport from the BIM-model in Madaster directly. This researched is limited to the BIM-based material passport in Madaster and does not include the Excel format for generating a material passport in Madaster. This research is also conducted with the modelling software Revit as principle. As a result, solutions or recommendation might be partial or not applicable to other software programs.

To optimize the process of generating a material passport it is firstly recommended to reduce the number of parameters that need to be filled in to create a material in the Madaster database. Secondly it is recommended to model according to standards and use content and materials from a standard. Thirdly it is recommended to add a project database in Madaster to guide the matching.

Hallowell & Gambatese (2009) say that a qualitative study cannot be generalized because it is based on a particular situation or on a small group but it could be used to identify elements that can be transferred to other situations. Further research should be conducted to make an generalization possible and prove the reliability of this study. The reliably of the result can also be increased by performing a multiple case study. Other recommendations for areas of further research are (1) the update and maintenance of information in BIM, (2) the certification and legislation of a material passport, (3) optimizations for generating a BIM-based material passport and (4) the technical implementation of the optimizations recommended in section 5.5.

Acknowledgements

This report is written as part of the author's graduation for the study Civil Engineering at the University of Twente. To write this report the author did an internship at PeoplePower. The author wants to express his sincere gratitude to the supervisors at the University of Twente, Silu Bhochhibhoya and Armin Kassemi Langroodi and the supervisor at PeoplePower, Johan Kats for the support and feedback they provided before and during the internship.

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Appendix A: List of interviewees

Interviews

Table 2: respondents interviews

Interviewee	Position	Date of interview
Respondent 1	Circular advisor	5-6-2019
Respondent 2	BIM-director	7-6-2019
Respondent 3	Madaster	12-6-2019

Appendix B: Example base quantities

IfcSite	**Zone (IfcSpace)**	**IfcWall**	**IfcCurtainWall**	**IfcBeam**
GrossArea	Height	Length	Width	Length
GrossPerimeter	FinishCeilingHeight	Height	Length	Width (rectangle profile only)
	FinishFloorHeight	Width	Height	Depth (rectangle profile only)
IfcBuilding	GrossFloorArea	GrossFootprintArea	GrossSideArea	CrossSectionArea
GrossFloorArea	NetFloorArea	NetFootprintArea	NetSideArea	OuterSurfaceArea
	GrossCeilingArea	GrossSideArea		GrossSurfaceArea
Story (IfcBuildingStorey)	NetCeilingArea	NetSideArea	**IfcDoor/ IfcWindow/ IfcOpening**	TotalSurfaceArea
Height	GrossWallArea	GrossVolume	Height	GrossVolume
NetHeight	NetWallArea	NetVolume	Width	NetVolume
GrossHeight	GrossPerimeter		Area	NetSurfaceArea ExrudedSide
GrossFloorArea	NetPerimeter	**IfcSlab**	Depth	
	GrossVolume	Width	Volume	**IfcColumn/ IfcMember**
	NetVolume	Perimeter	Perimeter	Length
	SpaceNetFloorArea BOMA	GrossArea		Width (rectangle profile only)
	SpaceUsableFloor AreaBOMA	NetArea		Depth (rectangle profile only)
		GrossVolume		CrossSectionArea
		NetVolume		OuterSurfaceArea
				TotalSurfaceArea
				GrossVolume
				NetVolume

Figure 17: IFC base quantities (Graphisoft, 2019)

Appendix C: Madaster Database

The database in Madaster contains all kind of materials and products. The materials and products in the database originate from different sources. The sources of the products and materials in the database are BIM software program libraries, Madaster, National environment database and there is a possibility to create your own materials and products. In figure 18 the interface of the database of materials and products in Madaster is shown.

Figure 18: interface material and product database (Madaster Platform, 2018f)

In figure 18 the interface for creating a new material in the database of Madaster is shown. The input data is organized in four categories: (1) material information, (2) feedstock sources, (3) end of life scenario and (4) efficiency of recycling process. In the first category general information about a material needs to be added. Categories 2, 3 and 4 contain information about the sustainability of a material and are used for the calculation of the CI.

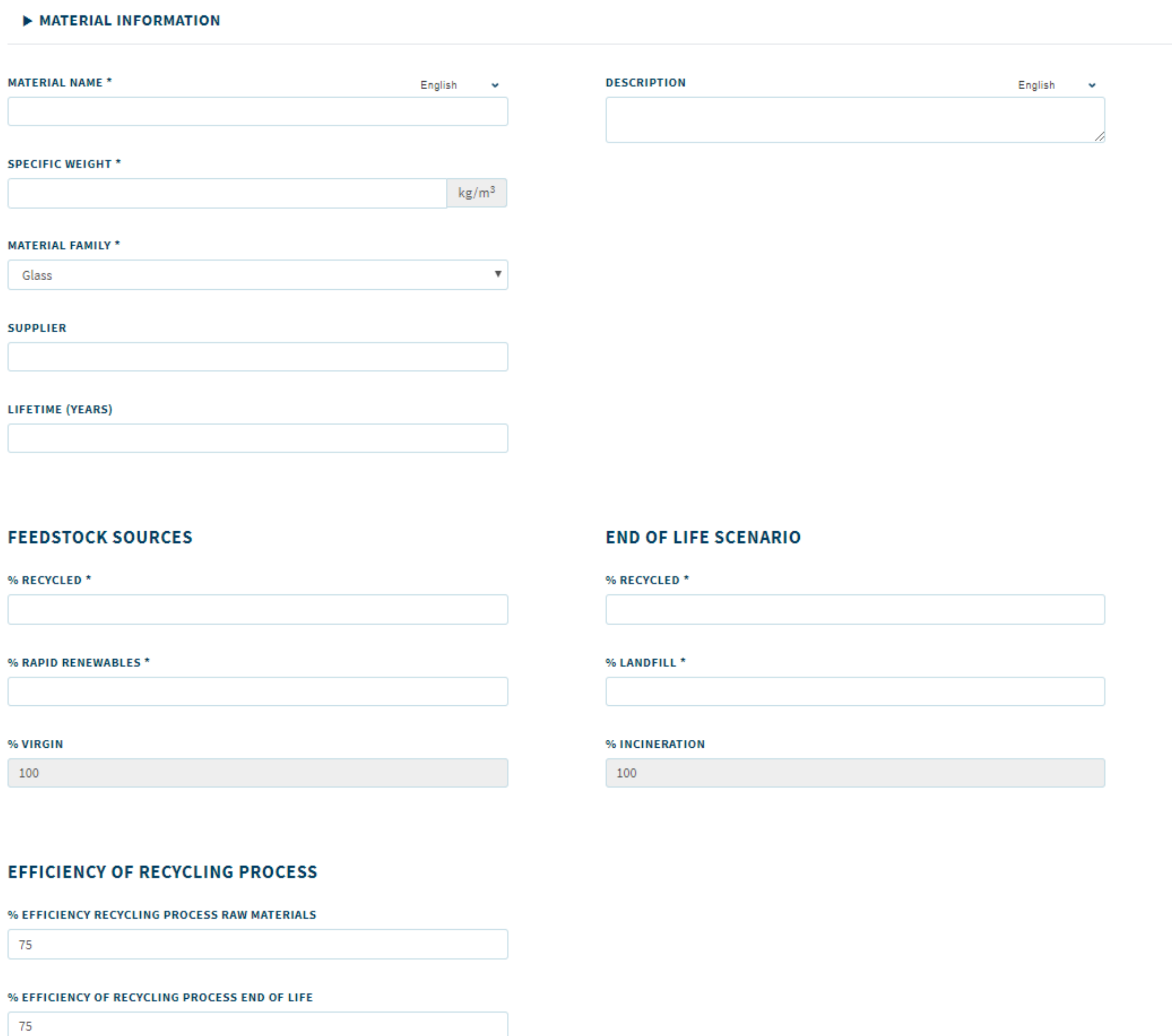

Figure 19: interface for creating a material in the Madaster database (Madaster Platform, 2018f)

In figure 20 and 21 the interface for creating a new product in the database of Madaster is shown. A new product has the same categorizing as a material. The only difference is that a product has some extra parameters such as the checklist of reusability, a functional and technical lifespan and a type to define whether a product is a volume, length, area or quantity product.

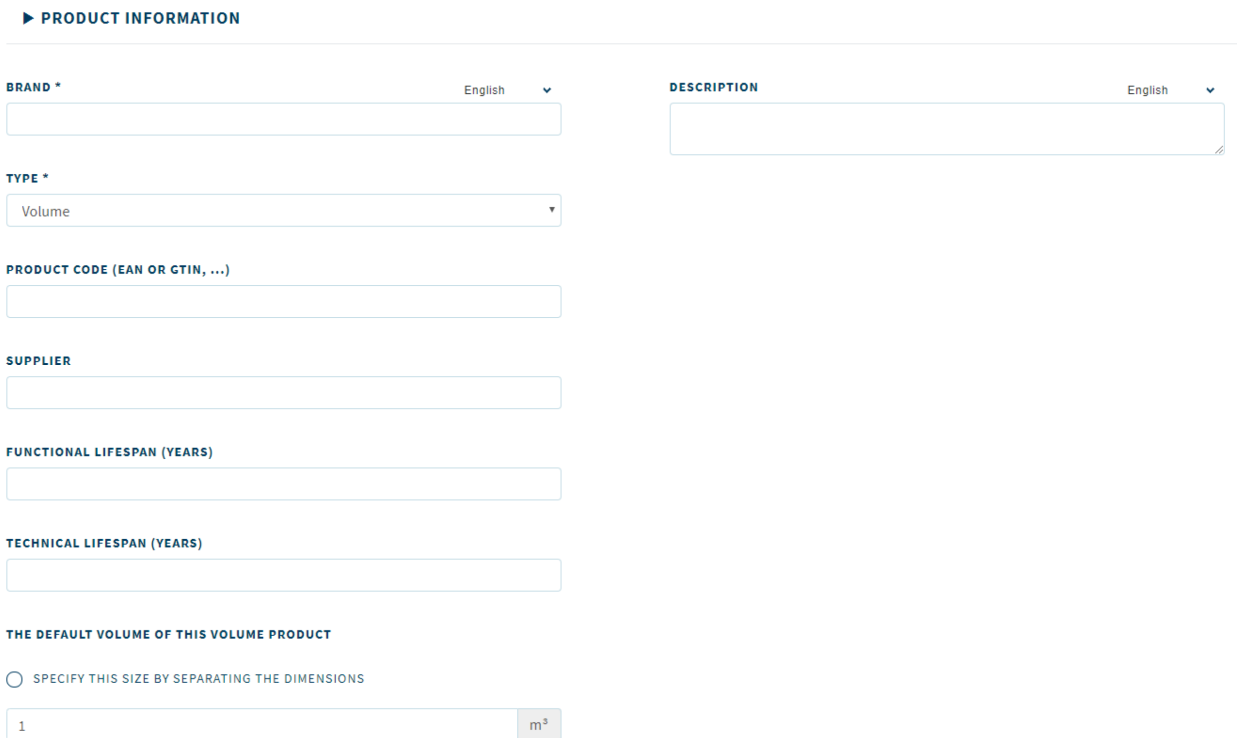

Figure 20: interface for creating a product in the Madaster database part 1 (Madaster Platform, 2018f)

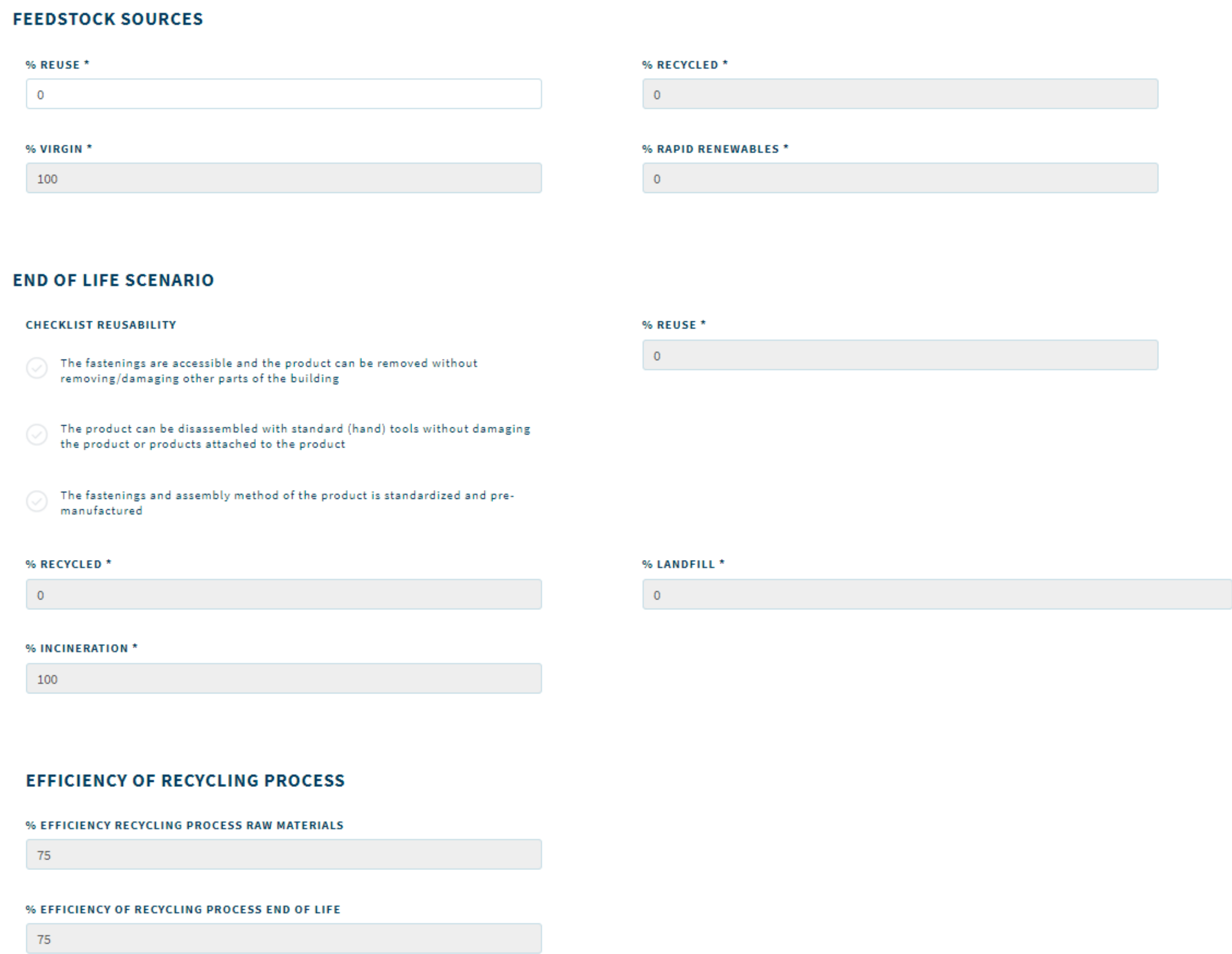

Figure 21: interface for creating a product in the Madaster database part 2 (Madaster Platform, 2018f)

In figure 22 an example of the matching criteria of a material is shown. Madaster allows for four different matching types: (1) Contains, (2) Equals, (3) Starts with and (4) Ends with. If an element matches to more than one material or product the match with the most corresponding characters will be applied (Madaster Platform, 2018e).

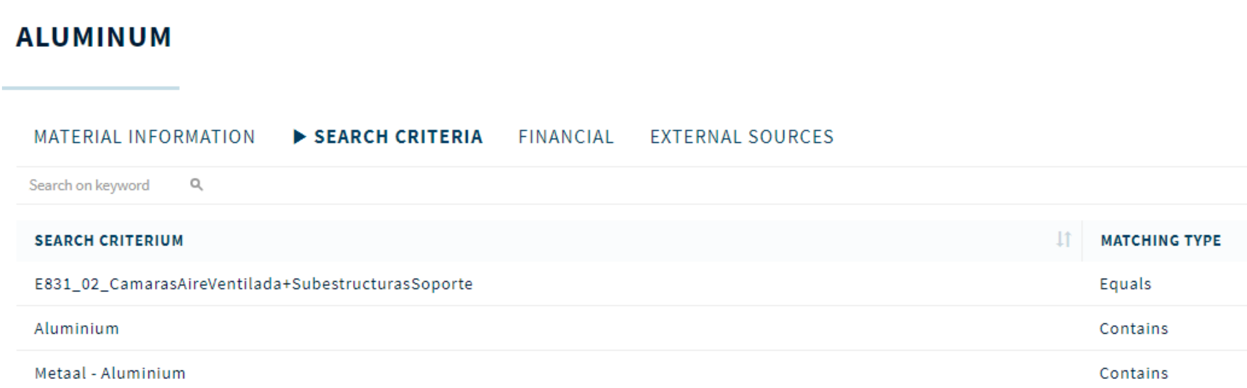

Figure 22: interface for the matching criteria in the Madaster database (Madaster Platform, 2018f)

Appendix D: Verification scheme

Table 3: Quality results

	Poor	Fair	Neutral	Good	Excellent
Correctness of the representation of the process of generating a material passport					x
Accuracy of the representation of the process of generating a material passport				x	
Usability for system optimization				x	

Comments:

Table 4: Quality recommendations

	Poor	Fair	Neutral	Good	Excellent
Usability of the recommendations					x
Potential of the recommendations in reducing the manual work				x	
Potential of the recommendations in optimizing the process				x	

Comments:

Table 5: Overall quality

	Poor	Fair	Neutral	Good	Excellent
The overall usability of the results and recommendations					x

Comments:

Appendix E: Validation flowchart

Validation of the flowchart in section 5.2.2 by testing the flowchart on a case model shown in appendix F.

The first step of the flowchart is to determine if the elements will be documented as materials or products. Most of the elements in the validation BIM-model as shown in appendix E will be documented as materials in Madaster because most elements are assigned a material from the NLRS material library. The materials of the NLRS material library are part of the Madaster database and not a lot of products are included in the database, especially from the services. To reduce the manual work the choice is made to document most elements as materials and not as products. Only pipes are documented as products because the only dimensional data in a pipe element is the length. As a result only the pipes need to be created as products in the database of Madaster. The output dimensions of the pipes in the BIM-model is a length so the pipes in Madaster need to be created with the type length and a material from the database of Madaster.

The next steps are to export to IFC from the BIM source software program and to check if the requirements of Madaster as mentioned in section 5.1.1 are met. In this case the model is built in Revit and export settings of Madaster are used to export to IFC. After exporting to IFC the BIM-models are checked for the requirements of Madaster with a SmartView in BIMcollabZOOM. As the model is built for Madaster, during the modeling the requirements of Madaster are kept in mind so all the requirements are met and there is no need to supplement the source files. However to get the BIM-model on a level it was suitable for import in Madaster there where some challenges. The main challenges were the classification and the materials assigned. The default classification of Revit is 'Uniformat classification' so to give all element an NL/SfB classification all the families needed to be assigned a NL/Sfb classification manually. The challenge regarding the material allocation was that not all of the imported elements were assigned a material from the NLRS material library so each family that was not assigned a material from the NLRS library needed to be changed manually. Another challenge with the material allocation was that some element were assigned multiple materials without different layers. As Madaster can only read one material from an element or element layer all elements need to be assigned only the dominant material.

For the mechanical example model shown in Appendix F it is challenging to meet the requirements of Madaster because Madaster cannot read the material of the pipes because it is located in the mechanical property set as shown in figure 23. Madaster reads the Pset_Madaster and Materials and finally the property set to find a material. To solve that challenge a user defined property set export setting as shown in figure 23 is used to assign the material to the Pset_Madaster property set in the IFC export.

Summary | Location | Constraints | **Mechanical**

Property	Value
Area	1,33 m^2
Connection Type	Generic
Diameter	160 mm
Invert Elevation	-75 mm
Material	S4R_PVC
Pipe Segment	S4R_PVC - DykaSono PVC Binne...
Roughness	0 mm
Schedule/Type	Pipe Schedule Types: DykaSono...
Section	1
Segment Description	
Segment Description	
System Abbreviation	M531
System Classification	Domestic Cold Water
System Name	M531 1
System Type	Piping System: W5310_Drinkwater

Figure 23: Mechanical property set

The pipes are also not assigned a volume automatically. To assign a volume to the pipes a new project parameter needs to be created and the volume should be calculated with the given inner and outer diameter of the pipe. To ensure that the export to IFC is correct and Madaster can read the parameters a user defined property set can be used. To export a pipe the user defined property set Pset_Madaster as shown in figure 24 is created.

```
#
PropertySet:    Pset_Madaster   T       IfcFlowSegment
        MaterialOrProductName   Text    Material
        Volume                  Volume
        Width                   Length
        Height                  Length
        Dept                    Length
        Weight                  Mass
        Classification          Text
        Phase                   Text
PropertySet:    Pset_Madaster   T       IfcFlowFitting
        MaterialOrProductName   Text    Material
        Volume                  Volume
        Width                   Length
        Height                  Length
        Dept                    Length
        Weight                  Mass
        Classification          Text
        Phase                   Text
#
```

Figure 24: Export IFC UserDefinedParameterSets

The mechanical example BIM-model did not only consist of pipes but also of fittings. The fittings are imported from the MEPcontent library modelled according to the standard EMCS. The fittings are not assigned a material but a color as mentioned in section 5.1.2. The material is defined in the type name, as is shown in figure 25. Madaster cannot read a material from the type name so the material parameter need to be edited manually for each family. The volume of the fittings is also not defined in the parameters and therefore needs to be created and calculated manually.

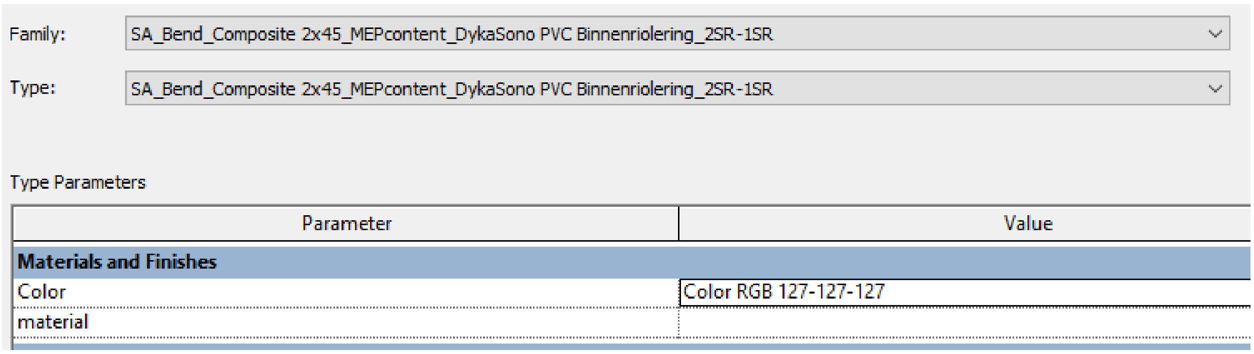

Figure 25: Materials and finishes property set

The following step is to upload the IFC model to the Madaster Platforming. After processing the uploaded BIM-model Madaster shows the quality of the BIM-model as shown in figure 26. Given that all requirements were met and the BIM-model is modelled according to NLRS with materials from the NLRS library, which are also part of the Madaster database, the quality of the source file is high.

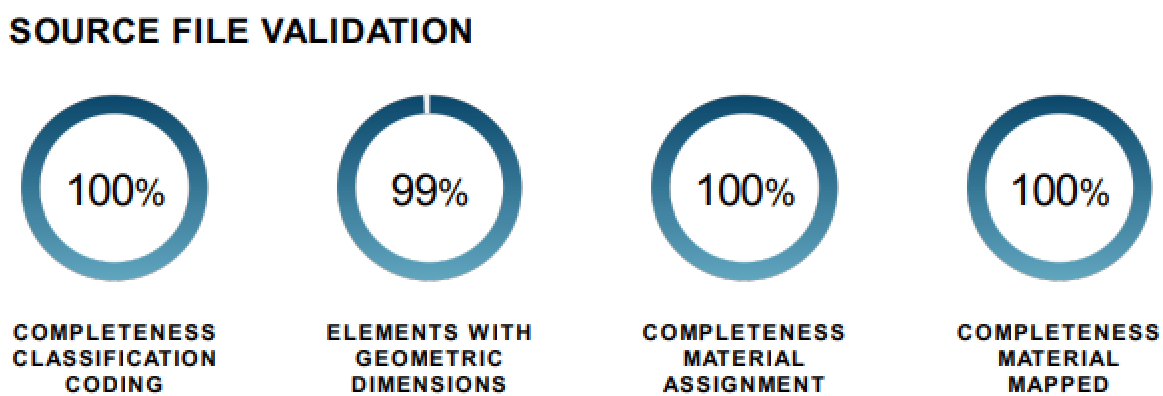

Figure 26: Quality source file

The last steps are checking the mapping and activating the BIM-model in Madaster. Checking means to manually look if the element from the BIM-model is connected to the correct material or product in Madaster. In figure 27 the interface for checking the mapping and manual enrichments is shown.

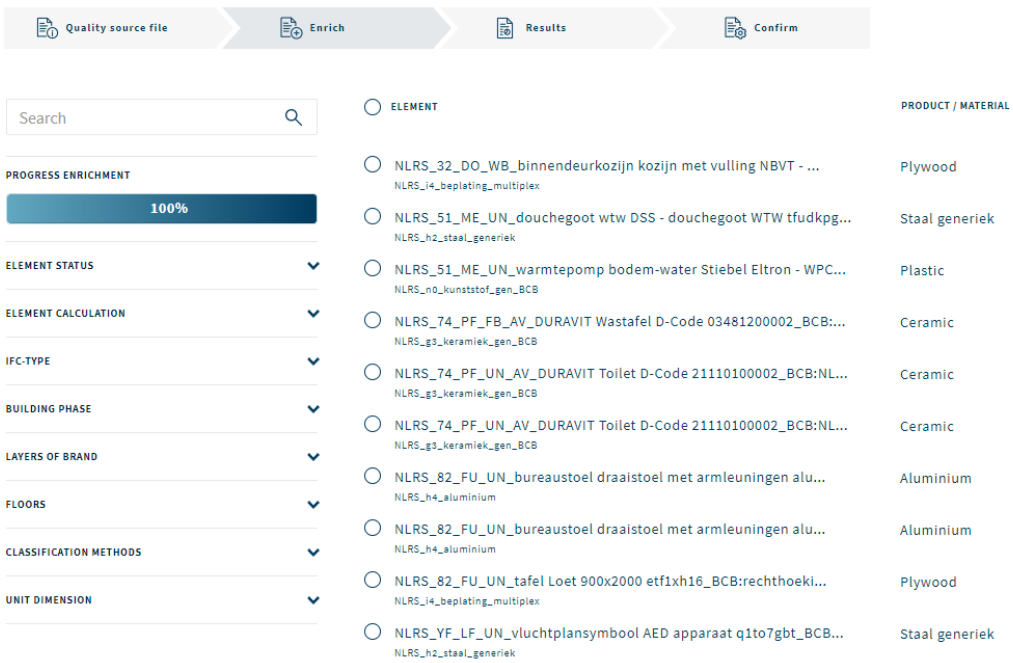

Figure 27: Enrichment interface

Appendix F: Example model validation

For the validation of this research an example BIM-model is built to test whether the research fulfilled its intended purpose. The example BIM-model consist of an architectural model and a mechanical model created in Revit. In figure 28, 29 and 30 the architectural model is shown and in figure 31 the mechanical model is shown. The architectural model is modelled according to the standard NLRS and consists of a building with three floors. The floors are connected with stairs and on the ground floor some interior and plumbing fixtures are placed. The mechanical model is created with Stabicad for Revit and contains some pipes and fittings modelled according to the EMCS standard.

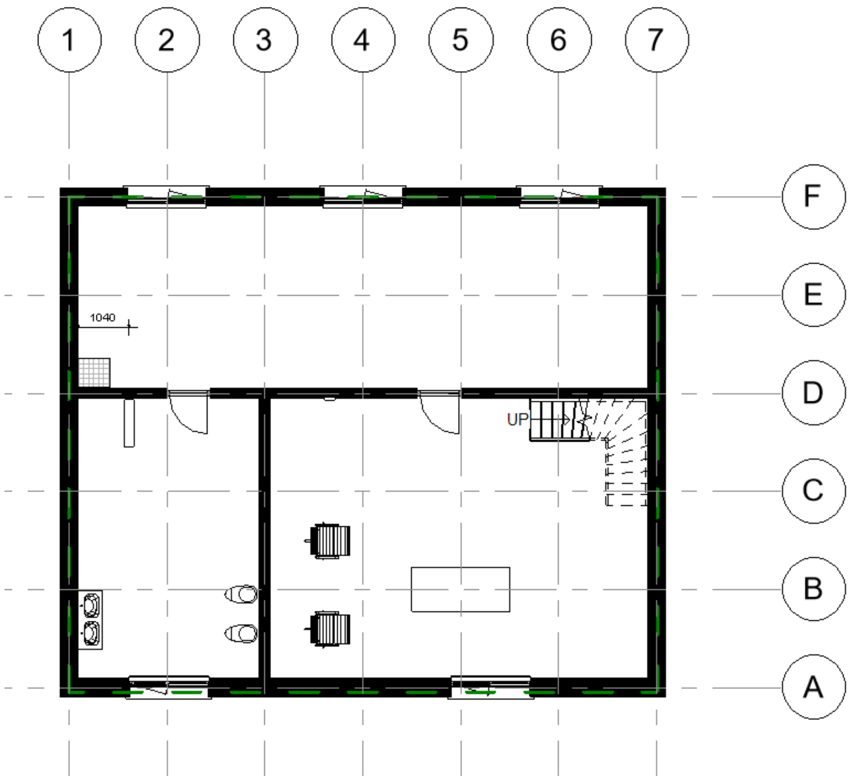

Figure 28: Level 0: Ground floor architectural BIM-model

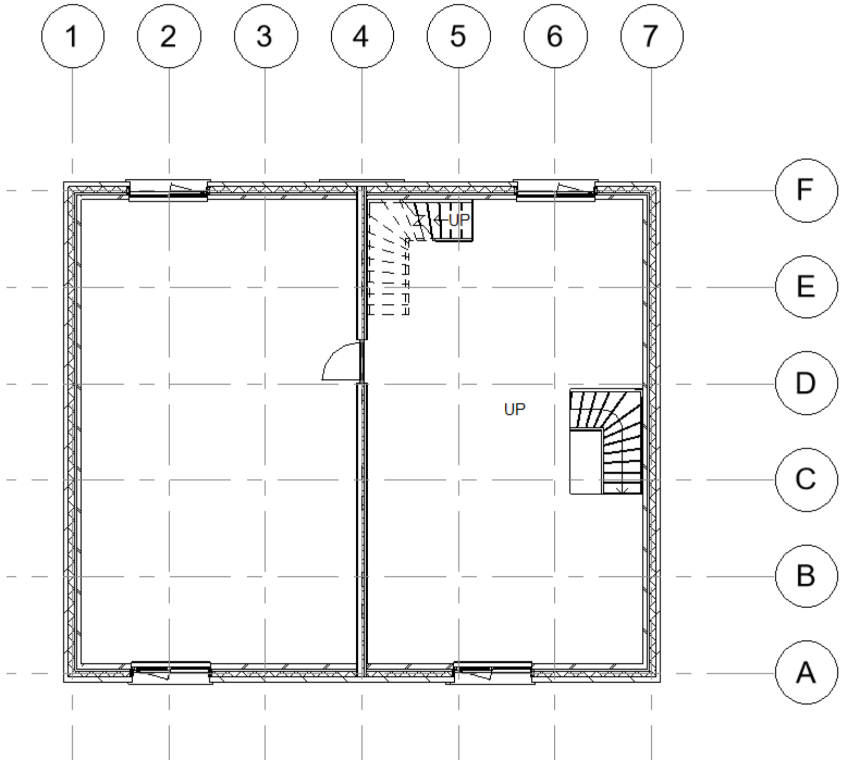

Figure 29: Level 1, First floor architectural BIM-model

Figure 30: 3D view example architectural BIM-model

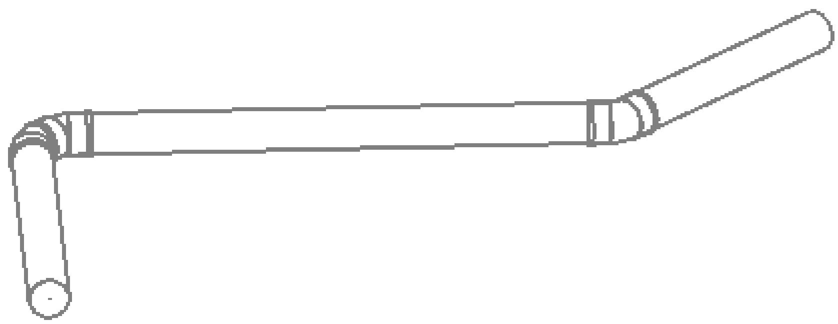

Figure 31: 3D view example mechanical BIM-model

Appendix G: Material passport from Madaster

BUILDING NAME

Validation Building

PUBLISHER

Bertus Druijff

OWNER

Bertus Druijff

PUBLISHING DATE

7/15/2019

REALIZATION

This Materials Passport was realized without any intervention by (personnel and/or employees of) Madaster Services B.V. (hereinafter referred to as: 'Madaster') and/or the Madaster Foundation, and is the sole and exclusive result of data imported by, or on behalf of the user, from the user's source files. The imported data includes data on quantities, the classification of materials into materials families, as well as the classification coding. The various representations of materials in the Materials Passport are based on this data.

Therefore, all information in the Materials Passport is based for 100% on the data contained in the source files provided and processed by the user. Consequently, the quality of the Materials Passport is fully dependent on that data being correct and complete and on the following conditions:

- The correct assignment of materials and products to all elements within the BIM model that has been exported to IFC.
- The inclusion of volume and surface attributes in the BaseQuantity properties of the BIM model that has been exported to IFC.
- The presence of a classification code for all elements within the BIM model that has been exported to IFC.
- The activated files within the platform being complementary, without any overlapping elements.

All values displayed have the accuracy specified in the validation attributes of the source files.

The user has full responsibility for the correctness and completeness of the information and data to be entered on the Madaster Platform. Consequently, Madaster cannot be held accountable in any way for the incorrect, and/or incomplete and/or injudicious entry by the user of the required information.

WHAT IS A MATERIALS PASSPORT?

This Materials Passport is a Madaster product that represents the registration of the materials and products of a building or buildings, or of part of a building. This registration is based on one or more source files from, and imported by, the user. These source files are mentioned in section [2] of this document.

The current version of the Materials Passport, version 1.0, contains views of the material and product quantities within the so-called "Building" frame. This means views of the materials and products used in the different layers of the building, based on the classification coding, and on a classification into seven "materials families".

PORTFOLIO NAME

Test

PORTFOLIO OWNER

Bertus Druijff

BUILDING NAME

Validation Building

ADDRESS DETAILS

Address:

Postal code:

CADASTRAL INFORMATION

Cadastral designation	-
Cadastral surface area	- /m^2
Lot number	-
Restriction of public law	-

MADASTER INFORMATION

Classification method	NL-SfB
Most recent BIM information	7/15/2019 1:37 PM
Building usage	Residential (Detached house)
Gross Surface Area	150 /m^2
Delivery date	6/22/2006
Last renovation date	-

LABELS

BREEAM	-
GPR-score	-
Indicative MPG score	0.65 €/m^2
LEED	-

WELL SCORE

New and Existing Buildings	-
New and Existing Interiors	-
Core and Shell	-

ENERGY

Energy label	-
Energy Performance Coefficient	-
Energy Index	-

ACTIVE SOURCE FILES

TestProject.ifc

Test-Madaster.ifc

SOURCE FILE VALIDATION

COMPLETENESS CLASSIFICATION CODING	ELEMENTS WITH GEOMETRIC DIMENSIONS	COMPLETENESS MATERIAL ASSIGNMENT	COMPLETENESS MATERIAL MAPPED

EXPLANATION SOURCE FILES

Madaster primarily uses IFC (2x3) building files to calculate the material quantities. To do this, you must include the “base quantities” of the objects in the export. The objects must be assigned a material property, as well as a classification code. Madaster does not calculate quantities: all geometric information and all quantities are imported directly from the IFC model.

On the Madaster Platform, the quality of the source files is displayed under “SOURCE FILE VALIDATION”. All calculations on the Madaster Platform are made within these frameworks. Consequently, any missing and/or incomplete and/or incorrect information in the source files immediately results in inaccurate results. Therefore, Madaster cannot warrant the quality of these results.

As a secondary source of information, a Microsoft Excel file (based on a Madaster Excel template) can be imported containing geometric information about the building, information on the building parts and/or components, materials, as well as classification codes.

TOTAL OVERVIEW

Madaster uses the "Shearing Layers" model (onion layers model) [Duffy, Brand, 1994] to organize the materials and products buildings consist of. Based on this model, a structure is proposed to classify the building. In this model each layer has a distinctive functional cycle.

The "Total" of the building is the sum total of all layers, i.e.: Site, Structure, Skin, Services, Space Plan, and Stuff. The percentage is a representation of the volume of the elements in the specific building layer.

100%
3902.85 m3
4027.35 t

TOTAL

41%
1606.13 m3
3588.25 t

STONE

0%
0.66 m3
1.65 t

GLASS

0%
9.86 m3
7.7 t

WOOD

58%
2273.07 m3
421.84 t

PLASTIC

0%
0 m3
0 t

ORGANIC

0%
1.04 m3
7.89 t

METAL

0%
12.09 m3
0.02 t

UNKNOWN

SITE

In the Madaster taxonomy the SITE layer is the sum total of the materials and products, as they are used on the premises, or lot. On the premises, the pavement, structures, fences, technical installations, as well as miscellaneous loose premise structures located between the facade and the lot limits can be distinguished. The percentage is a representation of the volume of the elements in this building layer.

TOTAL	STONE	GLASS	WOOD
0%	0%	0%	0%
0 m3	0 m3	0 m3	0 m3
0 t	0 t	0 t	0 t

PLASTIC	ORGANIC	METAL	UNKNOWN
0%	0%	0%	0%
0 m3	0 m3	0 m3	0 m3
0 t	0 t	0 t	0 t

STRUCTURE

The Structure of the building applies to all building components that are part of the foundations and the shell of the building, which are described by the classification method as structural components. Therefore, components described by the classification method as non-structural and/or undefined components, are not included in the construction layer. The percentage is a representation of the volume of the elements in this building layer.

100%	79%	0%	0%
97.37 m3	76.6 m3	0 m3	0 m3
184.35 t	176.18 t	0 t	0 t
TOTAL	**STONE**	**GLASS**	**WOOD**

20%	0%	1%	0%
19.8 m3	0 m3	0.97 m3	0 m3
0.59 t	0 t	7.58 t	0 t
PLASTIC	**ORGANIC**	**METAL**	**UNKNOWN**

GROUND, SUBSTRUCTURE (1-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
13.21 (VLOEREN OP GRONDSLAG; CONSTRUCTIEF, BODEMAFSLUITINGEN)						
19.15 m3 44.04 t	0 m3 0 t	0 m3 0 t	19.80 m3 0.59 t	0 m3 0 t	0.65 m3 5.10 t	0 m3 0 t

STRUCTURE PRIMARY ELEMENTS (2-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
23.20 (VLOEREN; CONSTRUCTIEF, ALGEMEEN (VERZAMELNIVEAU))						
57.45 m3 132.13 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0.32 m3 2.48 t	0 m3 0 t

SKIN

The Skin layer refers to building components, such as facades and roofs, that separate the outer space from the inner space (climate technology perspective). Additionally, the Building Envelope includes the facades between the building components, such as atria, or the building components of spaces located inside other inner spaces. The percentage is a representation of the volume of the elements in this building layer.

100%
3788.68 m3
3833.05 t

TOTAL

40%
1525.12 m3
3410.58 t

STONE

0%
0.66 m3
1.65 t

GLASS

0%
1.08 m3
0.84 t

WOOD

59%
2252.49 m3
419.93 t

PLASTIC

0%
0 m3
0 t

ORGANIC

0%
0.01 m3
0.04 t

METAL

0%
9.33 m3
0.01 t

UNKNOWN

STRUCTURE PRIMARY ELEMENTS (2-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
21.12 (BUITENWANDEN; NIET CONSTRUCTIEF, SPOUWWANDEN)						
76.96 m3 79.85 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	9.33 m3 0.01 t
27 (ROOFS)						
1448.03 m3 3330.46 t	0 m3 0 t	0 m3 0 t	2252.49 m3 419.93 t	0 m3 0 t	0 m3 0 t	0 m3 0 t

SECONDARY ELEMENTS (3-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
31 (EXTERNAL WALL OPENINGS)						
0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0.00 m3 0.03 t	0 m3 0 t
31.20 (BUITENWANDOPENINGEN; GEVULD MET RAMEN, ALGEMEEN (VERZAMELNIVEAU))						
0.13 m3 0.26 t	0.66 m3 1.65 t	1.08 m3 0.84 t	0 m3 0 t	0 m3 0 t	0.00 m3 0.01 t	0 m3 0 t

SERVICES

The Services consist of all the mechanical and electrotechnical installations. In the source files, many of the materials used are only included at product level. This is displayed in the list of “Products” in the Materials Passport. To cover the actual materials present would involve including the bills of materials of the individual Services, as well. At present, this falls outside the scope of the Madaster platform. The percentage is a representation of the volume of the elements in this building layer.

TOTAL	STONE	GLASS	WOOD
100%	0%	0%	0%
0.8 m3	0 m3	0 m3	0 m3
1.5 t	0 t	0 t	0 t

PLASTIC	ORGANIC	METAL	UNKNOWN
97%	0%	3%	0%
0.78 m3	0 m3	0.02 m3	0 m3
1.32 t	0 t	0.18 t	0 t

SERVICES, MAINLY MECHANICAL (5-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
51.46 (WARMTE-OPWEKKING; WARMTE-KRACHTKOPPELING, GECOMBINEERDE TAPWATER VERWARMING)						
0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0.02 m3 0.17 t	0 m3 0 t
51.51 (WARMTE-OPWEKKING; BIJZONDER, WARMTEPOMP)						
0 m3 0 t	0 m3 0 t	0 m3 0 t	0.76 m3 1.30 t	0 m3 0 t	0 m3 0 t	0 m3 0 t
52.30 (AFVOEREN; AFVALWATER, ALGEMEEN (VERZAMELNIVEAU))						
0 m3 0 t	0 m3 0 t	0 m3 0 t	0.02 m3 0.02 t	0 m3 0 t	0 m3 0 t	0 m3 0 t

SERVICES, MAINLY ELECTRICAL (6-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
OTHER						
0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0.00 m3 0.02 t	0 m3 0 t

SPACE PLAN

All architectural and all fixed components of a building that are not included in the Stucture, Skin, and Services layers, belong to the Space Plan layer. This varies from non-structural components like floors and inner walls, to stair cases and balustrades, floor covering and ceiling panelling, to fixed traffic, user, kitchen and sanitary facilities. The percentage is a representation of the volume of the elements in this building layer.

100% 15.74 m3 8.19 t	28% 4.42 m3 1.5 t	0% 0 m3 0 t	54% 8.56 m3 6.69 t
TOTAL	**STONE**	**GLASS**	**WOOD**
0% 0 m3 0 t	0% 0 m3 0 t	0% 0 m3 0 t	18% 2.76 m3 0 t
PLASTIC	**ORGANIC**	**METAL**	**UNKNOWN**

STRUCTURE PRIMARY ELEMENTS (2-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
22.13 (BINNENWANDEN; NIET CONSTRUCTIEF, SYSTEEMWANDEN; VAST)						
4.28 m3 1.27 t	0 m3 0 t	8.28 m3 6.49 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	2.76 m3 0.00 t

SECONDARY ELEMENTS (3-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
32.30 (BINNENWANDOPENINGEN; GEVULD MET DEUREN, ALGEMEEN (VERZAMELNIVEAU))						
0 m3 0 t	0 m3 0 t	0.28 m3 0.21 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t

FACILITIES (7-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
74.11 (VASTE SANITAIRE VOORZIENINGEN; STANDAARD, SANITAIRE TOESTELLEN; NORMAAL)						
0.14 m3 0.22 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t	0 m3 0 t

STUFF

The Stuff consists of all loose inventory items inside a building. This includes furniture, loose (non-attached) traffic, user, kitchen, sanitary, cleaning and storage inventory. In other words, this refers to the moveable property that is part of the building. The percentage is a representation of the volume of the elements in this building layer.

100%	0.25 m3	0.26 t	TOTAL
0%	0 m3	0 t	STONE
0%	0 m3	0 t	GLASS
87%	0.22 m3	0.16 t	WOOD
0%	0 m3	0 t	PLASTIC
0%	0 m3	0 t	ORGANIC
13%	0.03 m3	0.09 t	METAL
0%	0 m3	0 t	UNKNOWN

FITTINGS (8-)

STONE	GLASS	WOOD	PLASTIC	ORGANIC	METAL	UNKNOWN
82.11 (LOSSE GEBRUIKERSINVENTARIS; STANDAARD, MEUBILERING)						
0 m3 0 t	0 m3 0 t	0.22 m3 0.16 t	0 m3 0 t	0 m3 0 t	0.03 m3 0.09 t	0 m3 0 t

UNKNOWN

?

All elements in the sourcefile without a linked classification code will be placed in the column 'Unknown'. If you enrich the elements in the sourcefile by adding classification codes, the materials and products will be placed in the right layer of the building. The percentage is a representation of the volume of the elements in this building layer.

TOTAL	STONE	GLASS	WOOD
0%	0%	0%	0%
0 m3	0 m3	0 m3	0 m3
0 t	0 t	0 t	0 t

PLASTIC	ORGANIC	METAL	UNKNOWN
0%	0%	0%	0%
0 m3	0 m3	0 m3	0 m3
0 t	0 t	0 t	0 t

INTRODUCTION

Madaster uses the “Shearing Layers” model (onion layers model) [Duffy, Brand, 1994] to organize the materials and products buildings consist of. Based on this model, a structure is proposed to classify the building. In this model each layer has a distinctive functional cycle.

Below you will find, if available, the products per layer.

SITE

In the Madaster taxonomy the SITE layer is the sum total of the materials and products, as they are used on the premises, or lot. On the premises, the pavement, structures, fences, technical installations, as well as miscellaneous loose premise structures located between the facade and the lot limits can be distinguished. The percentage is a representation of the volume of the elements in this building layer.

No products are present in this layer.

STRUCTURE

The Structure of the building applies to all building components that are part of the foundations and the shell of the building, which are described by the classification method as structural components. Therefore, components described by the classification method as non-structural and/or undefined components, are not included in the construction layer. The percentage is a representation of the volume of the elements in this building layer.

GROUND, SUBSTRUCTURE (1-)

PRODUCT NAME	AMOUNT	QUANTITY	SUPPLIER
13.21 (VLOEREN OP GRONDSLAG; CONSTRUCTIEF, BODEMAFSLUITINGEN)			
Reinforced concrete (75kg steel/m3)	2	19.8 m^3	

STRUCTURE PRIMARY ELEMENTS (2-)

PRODUCT NAME	AMOUNT	QUANTITY	SUPPLIER
23.20 (VLOEREN; CONSTRUCTIEF, ALGEMEEN (VERZAMELNIVEAU))			
Reinforced concrete (75kg steel/m3)	2	9.63 m^3	

SKIN

The Skin layer refers to building components, such as facades and roofs, that separate the outer space from the inner space (climate technology perspective). Additionally, the Building Envelope includes the facades between the building components, such as atria, or the building components of spaces located inside other inner spaces. The percentage is a representation of the volume of the elements in this building layer.

SECONDARY ELEMENTS (3-)

PRODUCT NAME	AMOUNT	QUANTITY	SUPPLIER
31.20 (BUITENWANDOPENINGEN; GEVULD MET RAMEN, ALGEMEEN (VERZAMELNIVEAU))			
Frame wood (Generic)	64	1.08 m³	

SERVICES

The Services consist of all the mechanical and electrotechnical installations. In the source files, many of the materials used are only included at product level. This is displayed in the list of “Products” in the Materials Passport. To cover the actual materials present would involve including the bills of materials of the individual Services, as well. At present, this falls outside the scope of the Madaster platform. The percentage is a representation of the volume of the elements in this building layer.

No products are present in this layer.

SPACE PLAN

All architectural and all fixed components of a building that are not included in the Stucture, Skin, and Services layers, belong to the Space Plan layer. This varies from non-structural components like floors and inner walls, to stair cases and balustrades, floor covering and ceiling panelling, to fixed traffic, user, kitchen and sanitary facilities. The percentage is a representation of the volume of the elements in this building layer.

No products are present in this layer.

STUFF

The Stuff consists of all loose inventory items inside a building. This includes furniture, loose (non-attached) traffic, user, kitchen, sanitary, cleaning and storage inventory. In other words, this refers to the moveable property that is part of the building. The percentage is a representation of the volume of the elements in this building layer.

No products are present in this layer.

UNKNOWN

?

All elements in the sourcefile without a linked classification code will be placed in the column 'Unknown'. If you enrich the elements in the sourcefile by adding classification codes, the materials and products will be placed in the right layer of the building. The percentage is a representation of the volume of the elements in this building layer.

No products are present in this layer.

MADASTER CIRCULARITY INDICATOR (CI)

The Madaster Circularity Indicator assesses the uploaded sources files and gives the building a score between 0 and 100%.

A building is assessed on three phases: input in the construction process, the utility during the use phase and the destination of the materials at the end-of-life phase. A building with a high score is constructed with reused and recycled materials, has a higher than average utility and can be disassembled after use for easy reuse and recycling. A fully circular building has a score of 100%.

The Circularity Indicator is based on the Material Circularity Indicator that has been developed by the Ellen MacArthur Foundation. The Madaster Circularity Indicator is under development and is subject to constant change as the reliability of the data used for the calculation increases. All rights reserved.

10% × 97% × 100% = 9%

CI BUILDING SCORE

PENALTY FOR UNKNOWN MATERIALS
(% of elements with known materials)

PENALTY FOR PRODUCTS WITH AN UNKNOWN LAYER OF BRAND
(% of elements with layer of Brand)

MADASTER CI SCORE

0% & 99% & 0% = 10%

CIRCULARITY CONSTRUCTION PHASE
Non-virgin materials (goal: 100%)

CIRCULARITY USE PHASE
Utility (goal: >100%)

CIRCULARITY END OF LIFE PHASE
Recoverable content (goal: 100%)

CI BUILDING SCORE

CIRCULARITY INDICATOR (CI)

	Totals	Site	Structure	Skin	Services	Space plan	Stuff
CI building score	10%	0%	0%	10%	10%	10%	10%

CIRCULARITY CONSTRUCTION PHASE

	Totals	Site	Structure	Skin	Services	Space plan	Stuff
Non-virgin materials (goal: 100%)	0%	0%	0%	0%	0%	0%	0%
Mass of product (t)	4027.35 t	0 t	184.35 t	3833.05 t	1.5 t	8.19 t	0.26 t
Applied recycled materials (% of mass)	0%	0%	0%	0%	0%	0%	0%
Applied rapidly renewable material (% of mass)	0%	0%	0%	0%	0%	0%	0%
Applied reused components (% of mass)	0%	0%	0%	0%	0%	0%	0%
Efficiency of recycling process for construction phase (%)	75%	0%	75%	75%	75%	75%	75%
Mass of waste generated during recycling process (t)	0.01 t	0 t	0 t	0 t	0 t	0 t	0 t

CIRCULARITY USE PHASE

	Totals	Site	Structure	Skin	Services	Space plan	Stuff
Utility (goal: >100%)	99%	0%	75%	100%	100%	100%	100%
Actual average lifetime of materials (years)	22	0	75	20	15	10	5
Actual industry-average lifetime of materials (years)	75	500	100	20	15	10	5

CIRCULARITY END-OF-LIFE PHASE

	Totals	Site	Structure	Skin	Services	Space plan	Stuff
Recoverable content (goal: 100%)	0%	0%	0%	0%	0%	0%	0%
Materials for recycling which are going to be collected (% of mass)	0%	0%	0%	0%	0%	0%	0%
Components for reuse which are going to be collected (% of mass)	0%	0%	0%	0%	0%	0%	0%
Mass of potential landfill & energy incineration (t)	4027.33 t	0 t	184.35 t	3833.03 t	1.5 t	8.19 t	0.26 t
Efficiency of recycling process for end of life phase (%)	75%	0%	75%	75%	75%	75%	75%
Mass of potential landfill & energy incineration of the recycling process (t)	0 t	0 t	0 t	0 t	0 t	0 t	0 t

DISCLAIMER

This Materials Passport was created exclusively by the entry of data by the user on the Madaster Platform. In addition to the information in the Materials Passport, the general terms and conditions of Madaster apply (see: www.madaster.com) for information on the use of the Madaster Platform and on creating the Materials Passport and its contents. Madaster does not warrant the completeness and/or correctness of the contents of the Materials Passport. Also, Madaster cannot guarantee that the Materials Passport will suit the intended use or purpose of its user.

COLOPHON

This Materials Passport is an exclusive product of Madaster. This company is supervised by the Madaster Foundation.

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Madaster, 1 September 2017.

ABOUT MADASTER

MADASTER is a brand name of the Madaster Foundation.

The Madaster Foundation strives to eliminate waste and has a non-profit interest with representatives from various economic sectors. As the Madaster Foundation (the “Stichting Madaster Foundation” in full), it promotes, manages and stimulates the development of Materials Passports through the digital MADASTER platform for existing and new (additions to) buildings all over the world. This platform is managed by Madaster Services B.V.