Environmental Impact Assessment of Buildings based on Building Information Modelling

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Abstract

Buildings require a great amount of energy and carbon-intensive materials in the construction process. This causes a growing amount of CO_2 emissions over its life cycle. In addition, the building industry produces a large amount of waste in the construction and deconstruction stages. With respect to such a significant impact on the environment, the demand for sustainable building approaches is increasing. Responsible management of recycling and reuse of building materials and components are an essential aspect of sustainable buildings. In this study, a concept for a material and component bank is developed to reduce eco-footprint of a building by focusing on the reuse of decommissioned building components. This paper presents a framework for developing a Building Information Modelling based tool for buildings in a digitalized form of such a bank. The system includes seven sub-databases, which form the basis of an automated calculation tool for environmental impacts assessment of a design.

Keywords: Building Information Modelling, sustainability, environmental impact assessment, material and component bank

1 Introduction

The building industry is one of the largest and least efficient consumers of global raw resources and has a significantly high environmental footprint. In fact, buildings in Europe account for more than half of raw material consumption, around 42% of energy use and produce almost 35% of greenhouse gas emissions (COM, 2011). In addition, the building industry produces substantial amount of waste in the construction and deconstruction stages, which is approximately 850 million tonnes per year in Europe (Saez & Osmani, 2019). The construction and demolition (C&D) waste represents the largest waste stream in Europe, accounting for 35% of the overall waste generation. As a result, applying sustainability principles to the building industry to adopt environmentally friendly construction methods and waste management methods is a big challenge for years to come.

The European Commission (EC) identified that circular economy systems have huge benefits for sustainable development because it reduces the extracting of raw materials from finite natural resources and stops producing the waste at the other end. Hence, the EC adopted new policy initiatives such as the Circular Economy Action Plan (CEAP) to encourage policy makers, academia and industry towards sustainability (COM, 2020). In circular economy, the extensive return of building materials and components into the material cycle through recycling and reuse are the key strategies in increasing sustainability in the building industry. However, there is still no circular economy market that supports the reuse and recycling of building materials (Waldmann, 2017). This is mainly due to the lack of information on the composition and condition of the materials and components in existing buildings. Therefore, a quantitative recording and qualitative description of the building materials and components in buildings is necessary in order to promote circular economy in the building industry.

In addition, it is required to have suitable assessment methods in order to maximize their reusability and recyclability. An appropriate selection of materials in the early design phase also has a high impact on the sustainability of the building because it reduces energy consumption as well as greenhouse gas emissions, C&D waste generation and other environmental impacts over the building's life cycle (Gonzalez & Navarro, 2006; Braganca, et al., 2014).

Life Cycle Assessment (LCA) is the most widely adopted approach in the assessment of environmental burden associated with a design. Since LCA requires large amount of data, significant time and effort for implementation, this assessment is often performed at the end of the design phase when all the required information is available (Van Eldik, et al., 2020). However, many important decisions regarding the design of the building such as types and amounts of building materials are often made at the planning stage or early design stage. Therefore, it could be too late to incorporate the environmental impact of a design into the decision-making process (Basbagill, et al., 2013).

The above-mentioned aspects have been introduced into a research project of the University of Luxembourg entitled "Eco-Construction for Sustainable Development" (ECON4SD) co-funded by the European Union in partnership which is oriented to bring the circular economy in the future built environment in Luxembourg. The overall objective of this project is to develop components and design models for resource and energy-efficient buildings based on the construction materials concrete, steel and timber. Within the ECON4SD project, new architectural typologies and new sustainable solutions for timber-concrete and steel-concrete floor systems are developed considering the modularity, flexibility, adaptability and upgradability with demountable inter-structural connections (Ferreira Silva, et al., 2020). In addition, material degradation effects in concrete building components and energy efficiency of building components during whole service life are assessed (Habera & Zilian, 2019; Rakotonjanahary, et al., 2020). With an introduction of a new circular economy strategy, which is called Material and Component (M&C) bank, this project also paves the way to increase sustainability of construction by effectively managing the recycling materials and reuse of building components (Cai & Waldmann, 2019; Jayasinghe & Waldmann, 2020; Akbarieh, et al., 2020).

This study aims to continue the progress towards the assessment of recyclability and reusability of entire building components and environmental impacts of buildings. This would be undertaken thanks to a M&C bank which would make it possible to acquire all the necessary information on materials and components used in a whole building. This paper is organized as follows: Section 2 reviews the M&C bank and its interaction with Building Information Modelling (BIM), followed by a theoretical foundation for the development of BIM-based tool as digitalized M&C bank as well as a case study to demonstrate the operational steps and applicability of the tool on the environmental impact assessment of buildings. Conclusions are presented in Section 5.

2 Interaction of BIM and M&C bank

Recently, there are a few projects framing a view of buildings as material banks such as BAMB tries implementing circular strategy and tools to increase the value of building materials leading to reduce the virgin materials input and the waste generation (BAMB, 2021). The BAMB project introduced a digital platform whereby more than 300 material passports are demonstrated at three detail levels, such as product, building and component (Luscuere, et al., 2019). In the present study, a new actor in the construction supply chain called M&C bank is proposed as an alternative solution to store, manage and share building information for the implementation of buildings as material banks. M&C bank is an additional institution which organizes the transfer of materials and components extracted from demolished or deconstructed old buildings for reuse in a new structure. The deconstructed building components would be transported, stored, and repaired/improved according to their next usage and finally remounted in a new structure. A physical M&C bank can be anticipated for such purposes. In order to establish this process, the bank has to maintain a database which stores the information of extracted materials and components. However, so far, no such a centralized database has been developed which has a capacity to store the information from different projects in one location. As such, this study develops a web-based centralized database connected to BIM models of existing and new buildings to exchange the lifecycle information of building components. As illustrated in Figure 1, the other key businesses of the bank are: assess the conditions of recycling materials and reuse components, provide re-certification for reuse of structural components, provide storage facilities for decommissioned structural components, and produce new components from recycled materials, as well as tracking and monitoring of reuse components after employed in a new structure.

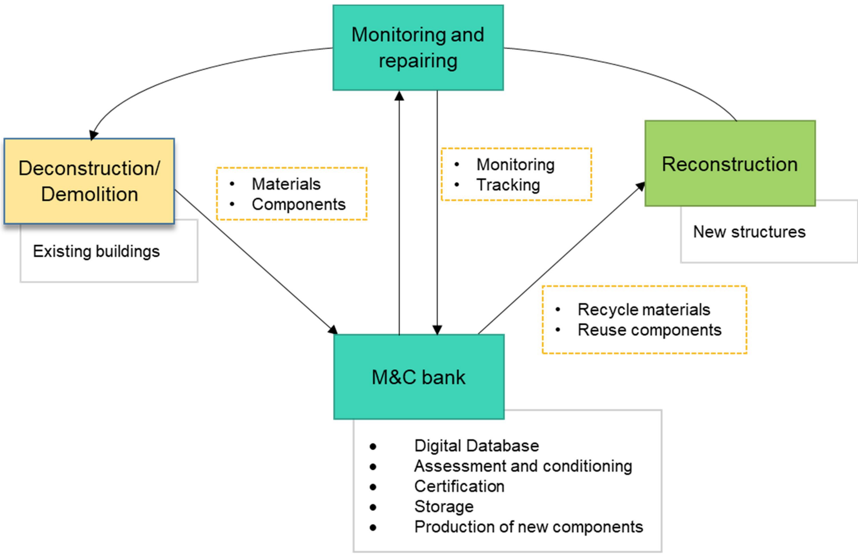


Figure 1. Role of the M&C bank. The figure is modified from (Jayasinghe & Waldmann, 2020)

The bank would get involved throughout the whole life-cycle of the building, including the design, monitoring, maintenance, deconstruction as well as reconstruction phase. In a building project, the durability of each component should be controlled, not only the durability of the whole structure. Thus, a regular update of the information concerning the components, which have to be decommissioned and reused, would be required during the lifetime of each and every building component. This exchange of information would be made thanks to the possibility of introducing different multi-disciplinary data into a single BIM model.

In the past decade, BIM has been increasingly adopted in the building industry. BIM is not only a digital representation of precise geometry but the accurately structured information about materials and components with numerous life-cycle data associated with the geometry. Since BIM facilitates the decision-making process and functions, BIM-based applications can help designers to optimize their designs and improve buildings' sustainability (Liu, et al., 2015; Volk, et al., 2014; Wang, et al., 2013). In addition, with the increasing concerns about buildings' life cycle environmental impacts, some researchers have adopted BIM as a potential solution to carry out an LCA in the early design phase of a building (Hollberg, et al., 2020). However, the BIM models should be developed with an enough level of detail and quality to perform an appropriate LCA analysis of the building.

The selection of the appropriate Level of Development (LoD) for implementation of BIM models and BIM-M&C bank interaction was one of the main problems at the start of the project. The LoD of the adopted model affects the final evaluation results. Based on literature, the building 3D models are developed in LoD 100 in its conceptual design stage. The lowest LoD which was used in BIM based facility and life cycle management is 300. In addition, the non-geometric information can be attached to the modelled elements. Thus, in this study, the building was modelled in the LoD 300.

Since the transparency and accessibility of information will be increased through BIM, having a BIM-coupled digital representation of the materials and components in a structure will expand the reusable M&C market. In addition, a BIM-based digital tool will reduce the intensive work of collecting data about building components and provide the potential to decrease the additional effort for LCA.

However, the performance and accuracy of the digital tool depend on the quality and availability of the retained information. Every BIM software has its native built-in parameters that already exist for elements to be defined. However, some additional parameters may be used depending on the needs of the project. In this study, BIM models are created in a template, in Revit, to generate information on materials and components in order to identify the recyclability of materials and the reusability of components. They should also include the information needed for the automatization of LCA calculation. Therefore, some additional information to be added in a BIM model is proposed, as shown in Figure 2. Theses parameters were mainly defined according to the BAMB material passports (Heinrich & Lang, 2019), Eurocode 2 (EN 1992-1-1, 1992) and some LCA databases. The added parameters are grouped into different categories depending on the design, structural, time-dependent, chemical, thermal and green building related material properties. The design data category provides the information that has an influence on the design from the early stage. The time-dependent material data category provides the information needed for the calculation of the remaining life of each element. The age of each element is a key factor to calculate the time-dependent material properties. The information on the chemical, thermal, and green building material data categories will provide the designers to perform LCA.

Shared parameter name	Shared parameter group	Prameter group	Data type	Discipline	Instance? Y/N
MB_Data_Age	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Data_Initial Use	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Data_Design for Deconstruction	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Data_Instruction for Installation	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Data_Instruction for Handling	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Data_Instruction for Transportation	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Data_Instruction for Storage	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Data_Instruction for Extraction	MB_DATA_Design	PG_DATA	MultilineText	Common	Y
MB_Mat_Ageing & Deterioration	MB_MAT_Design	PG_DATA	MultilineText	Common	Y
MB_Mat_Density	MB_MAT_Structural	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Poissons Ratio	MB_MAT_Structural	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Compressive Strength	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Creep	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Elastic Modulus	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Shear Strength	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Shear Modulus	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Shrinkage	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Tensile Strength	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Carbonation	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Cracking	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Deformation	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Chloride Penetration	MB_MAT_Time dependent	PG_STRUCTURAL	Number	Common	Y
MB_Mat_Rebar Cover - Exterior Face	MB_MAT_Time dependent	PG_STRUCTURAL	ReinforcementCover	Common	Y
MB_Mat_Rebar Cover - Interior Face	MB_MAT_Time dependent	PG_STRUCTURAL	ReinforcementCover	Common	Y
MB_Mat_Rebar Cover - Other Faces	MB_MAT_Time dependent	PG_STRUCTURAL	ReinforcementCover	Common	Y
MB_Mat_Exposure class	MB_MAT_Chemical	PG_TEXT	Text	Common	Y
MB_Mat_Chemical Composition	MB_MAT_Chemical	PG_TEXT	Text	Common	N
MB_Mat_Corrosion Resistance	MB_MAT_Chemical	PG_TEXT	Text	Common	N
MB_Mat_Toxicity Grade	MB_MAT_Chemical	PG_TEXT	Integer	Common	N
MB_Mat_Fire Resistance	MB_MAT_Thermal	PG_TEXT	Number	Common	N
MB_Mat_Specific Heat	MB_MAT_Thermal	PG_TEXT	Number	Common	N
MB_Mat_Thermal Expansion Coefficient	MB_MAT_Thermal	PG_TEXT	Number	Common	N
MB_Mat_Thermal Conductivity	MB_MAT_Thermal	PG_TEXT	Number	Common	N
MB_Mat_GBP Unit	MB_MAT_Green Building	PG_GREEN_BUILDING	Text	Common	N
MB_Mat_ADP	MB_MAT_Green Building	PG_GREEN_BUILDING	Number	Common	N
MB_Mat_GWP	MB_MAT_Green Building	PG_GREEN_BUILDING	Number	Common	N
MB_Mat_PEern	MB_MAT_Green Building	PG_GREEN_BUILDING	Number	Common	N
MB_Mat_PEnern	MB_MAT_Green Building	PG_GREEN_BUILDING	Number	Common	N
MB_Mat_Treated	MB_MAT_Green Building	PG_GREEN_BUILDING	YesNo	Common	Y
MB_Mat_Treated comment	MB_MAT_Green Building	PG_GREEN_BUILDING	MultilineText	Common	Y
MB_Mat_Reusability	MB_MAT_Green Building	PG_GREEN_BUILDING	YesNo	Common	Y
MB_Mat_Recyclability Grade	MB_MAT_Green Building	PG_GREEN_BUILDING	Integer	Common	Y
MB_Mat_Disminatling Grade	MB_MAT_Green Building	PG_GREEN_BUILDING	Integer	Common	Y

Figure 2. Added parameters in Revit

Namely, the Global Warming Potential (GWP), Abiotic Depletion Potential (ADP), the renewable Primary Energy (PEern), and the non-renewable Primary Energy (PEnern) are used for LCA in this study. The values per unit for these parameters are taken from a material directory database with LCA data for building materials. If the LCA data for a material is given per volume (per m^3) in the material directory database, the respective volume of the material in m^3 is then multiplied with this value to calculate the total value for the corresponding parameter. The same principle applies for the unit values given in per m^2 and per kg. The added parameter "MB_Mat_GBP Unit" allows the user to know which quantity (area, volume or mass) has to be multiplied with the corresponding values of those added shared parameters in green building material data group.

These additional parameters can be defined and added in Revit as shared parameters to extend the built-in parameters. The shared parameters enable the sharing of the data between linked models, loadable families and other Revit projects. In addition, they can also be exported to other BIM software if aligned with IFC property sets (Heaton, et al., 2019). In this study, the additional parameters were added as shared parameters in a Revit model by using a DYNAMO script, as shown in Figure 3.

Figure 3. DYNAMO script to add additional parameters in Revit

3 Development of BIM-based digital M&C bank

The digital M&C bank performs the role of a database to store and manage detailed information on recyclable materials and reusable components extracted from existing buildings (Jayasinghe & Waldmann, 2020). Due to the complexity in managing the vast quantity of data to perform LCA, the tool adopts BIM to accurately estimate the amount and composition of materials and components in a building. The developed system for the digitalized bank consists of a database, a server, and a web application, as illustrated in Figure 4.

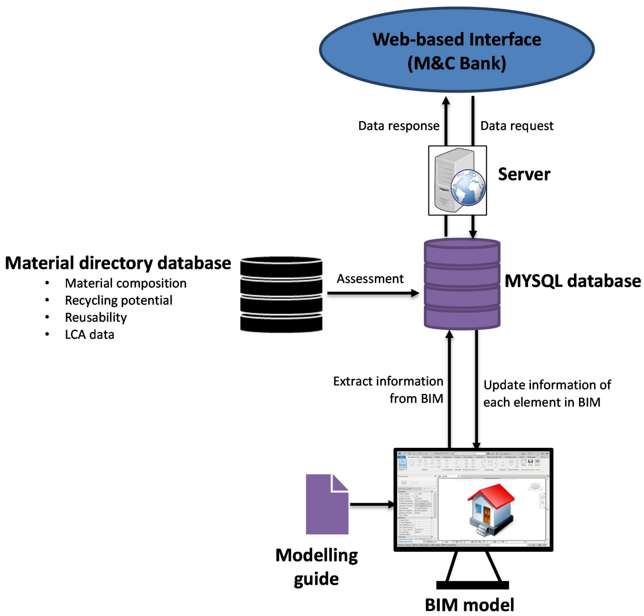


Figure 4. Conceptual model for developing BIM-based M&C bank tool

The web-based application which serves as M&C bank tool was developed using PHP and MYSQL. The database management system was created using a SQL server and MYSQL is used for the database connection. The MYSQL database is composed of seven sub-databases, such as

Project database, Material database, Component database, Recycling materials database, Reuse components database, Waste material database and Environmental impact assessment database.

The project database is composed of general information about the building such as project name, building type, location, constructed year, ownership, consultants and contractors. For each added project, an ID is automatically assigned. The project database has one-to-many relationships with all the other sub-databases. The material database is composed of all important information on the materials used in each project. The materials in the material database are linked to the material directory databases with LCA data for building materials. The component database provides the geometrical, material and design properties of all the components in a building. Indeed, it has a direct link with the material database and it provides the bill of quantities for waste volume calculation and LCA analysis. Recycling materials and Reuse components databases are composed of information about the identified recycling materials and reusable components, respectively. Indeed, the Reuse components database lists all the reusable components and their properties so that designers can search the available components for reuse in their future designs. Waste material database is composed of the quantity of demolished materials in each project. Due to the unavailability of the demolition data in Luxembourg, relevant data from literature were used in developing the database. In the Environmental impact assessment database, calculated results for LCA of each project are stored. This database has a one-to-one relationship with the LCA databases.

The required information for the database, such as basic information about the project and building, location, geometrical and material properties of components as well as material quantities of different types of materials that are used in various components are extracted from the data entered by designers in BIM models. As mentioned above, the additional parameters which are needed to made direct link between the database and the BIM model are defined in a modelling guide. A permanent link between the database and BIM model is kept by providing a unique ID for the element for each element in the database and the BIM model. The data flow from the BIM model to the database was achieved by developing a script using a visual programming language DYNAMO, as described in Section 4.1.

4 Case study: Application of the M&C bank concept on Slab Building

In ECON4SD project, three types of new architectural typologies were proposed, particularly a Slab Building, a Tower Building and a Demountable Building, considering the modularity, flexibility, and disassembling to address the increasing demands for multi-use, re-usable and resource-efficient constructions. (Ferreira Silva, et al., 2020). Among them, the 11-storey modular building called the Slab Building which is designed as a shelf structured, where wooden housing modules can be plugged in and out, was chosen to apply the M&C bank concept in this study. More architectural design details on the building can be found in (Ferreira Silva, et al., 2020).

4.1 BIM model

A BIM model of the building was created in Revit, as shown in Figure 5. The custom parameters for the building materials and components were created according to the required data for the automating of the assessment process as described above.

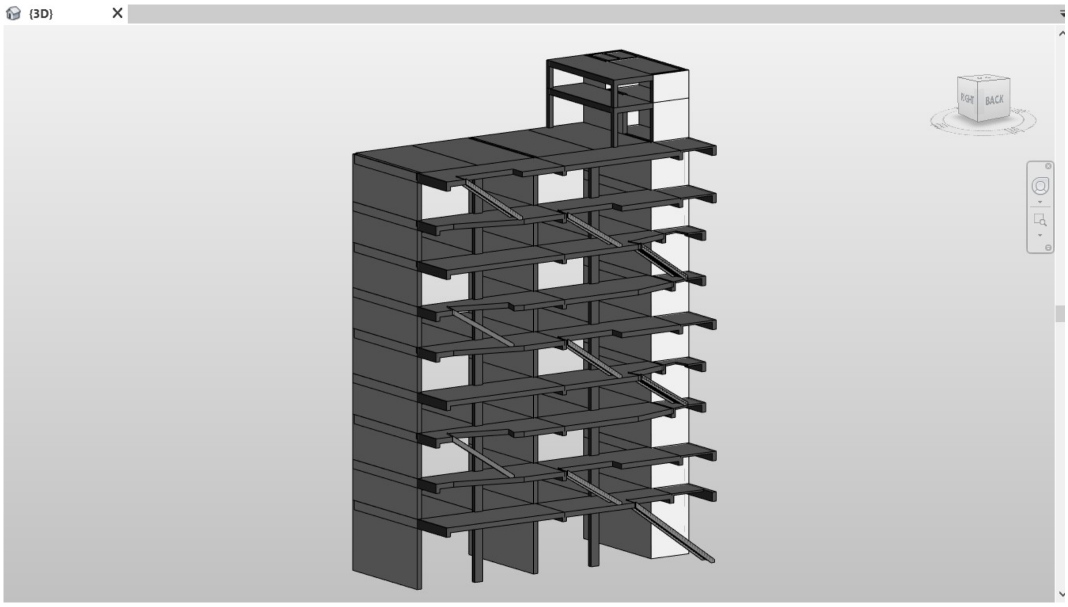


Figure 5. Revit model

The calculated impact according to the LCA approach categories, such as GWP, ADP, PEern, and PEnern are added to the shared parameters linked to the materials. However, it has to be noticed that these values are not constants. Therefore, these shared parameters have to be linked to a library with LCA data for building materials when creating the BIM model. For this study, the data are taken from the LCA database “Ökobaudat”. A script developed in DYNAMO was used to implement the values for those LCA parameters in the material library in Revit, as shown in Figure 6.

Once all the parameters were included in the Revit model, the next step was to use DYNAMO to create an automatized data take-off from the BIM model. A DYNAMO script was used to access and extract all the important information of building materials and components from the Revit model to an Excel sheet which can then be implemented in the main database, as shown in Figure 7. The script can be divided into several groups, such as analyzed elements, element data take-off, material data take-off, database reading, calculation, export to Excel, and update Revit, according to their functionalities and the linked groups. Through the analyzed elements sub-group, it is possible to take elements of their corresponding categories with the creation of a list to have them all aligned for the extraction afterward. The element data take-off gets all geometrical and project information parameters related to the structural elements depending on whether they are modelled as columns, structural framing, floors, walls, and foundations. The material data take-off gets all the material linked structural, thermal, chemical, and green building parameters already defined in Revit. Then, all the required component and material data are stored in appropriate lists for the extraction. The calculations take under consideration the material type and element type to identify the recyclable materials and reusable components as well as for automating the LCA process. Then, the results generated from reading the database are automatically exported into an Excel sheet. Nevertheless, the script can be used to update the Revit model with the changes made in Excel. The Excel file that contains the information of building materials and components from the BIM model of the assessed building is then imported into the M&C bank tool to automatically add the information into the main database of the bank. In addition, the user may input some additional information of the building using the M&C bank tool.

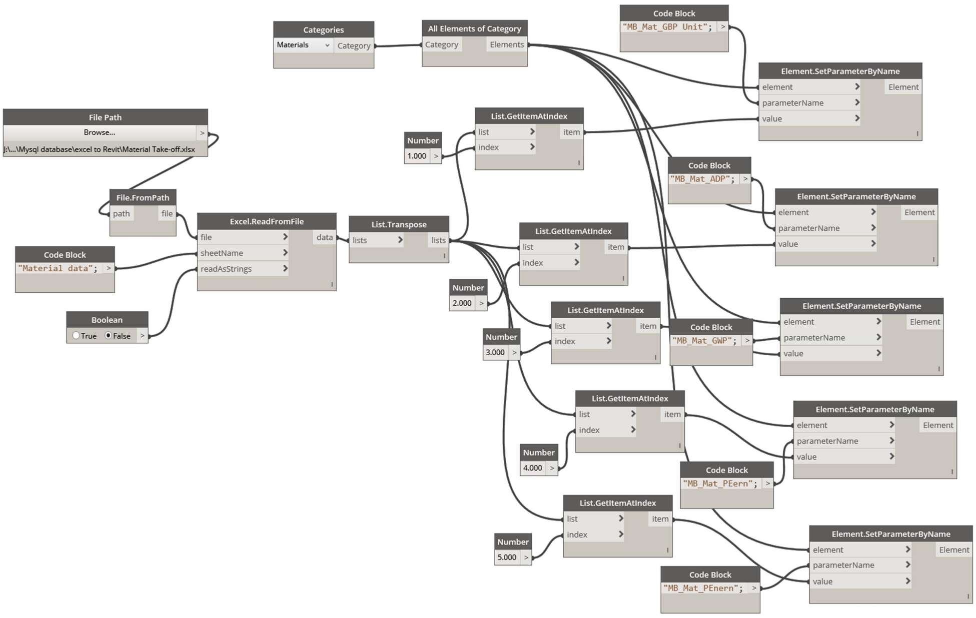


Figure 6. DYANMO script for the implementation of material library in Revit

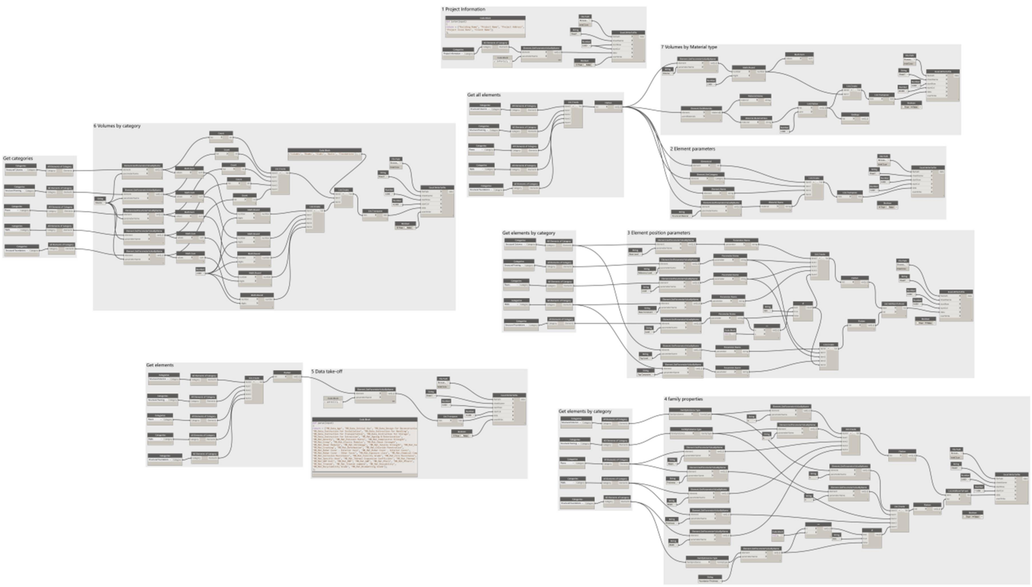


Figure 7. DYANMO script for data extraction from BIM model

4.2 BIM-based M&C bank tool

The developed preliminary M&C bank tool has been described in (Jayasinghe & Waldmann, 2020). The initial design was composed of four sub-databases, such as project, material, component, and waste material volume. In this study, it was further developed by adding a recyclable material database, a reusable component database and an environmental impact assessment database into the main database. This paper focuses only on the assessment of the environmental impacts of a design using the developed tool.

After completion of the data uploaded into the main database, the assessment page of the web-application (Figure 8) can be used to estimate the volumes of different types of demolition waste as well as the environmental impact of the building.

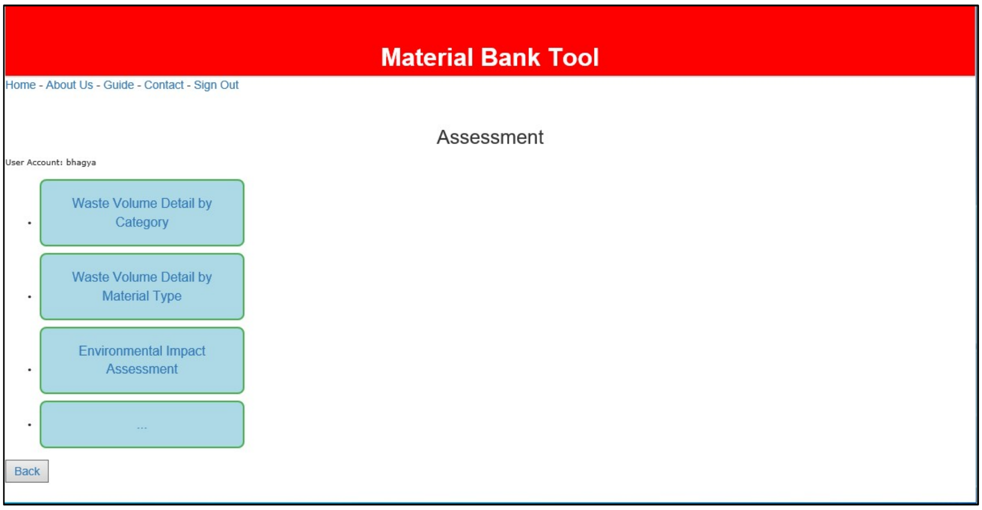


Figure 8. Assessment page of the developed tool

In the assessment page, the waste volume can be calculated according to the element type (Figure 9) or to the material type (Figure 10). For each component in the BIM model, the Dynamo script is used to automatically extract the volume data of all constituent materials. Then, the tool calculates the total volume under each category. Since the materials will become looser after demolition activities, the volumes of waste will be larger than the original volume of the building materials. Thus, the final waste volume is calculated by multiplying the volume quantities extracted from BIM by the volume expansion coefficients given in (Llatas, 2011). The values of the volume expansion coefficient for different waste types are listed in Table 1. The tool uses these coefficients as default values to calculate the actual waste volume. However, the tool allows users to enter customized values according to their experience to re-calculate the final waste volume.

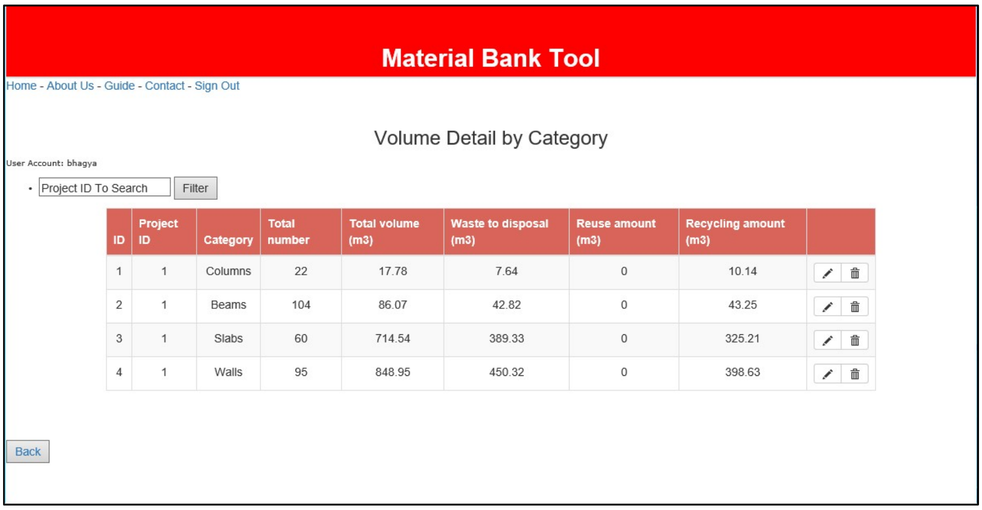
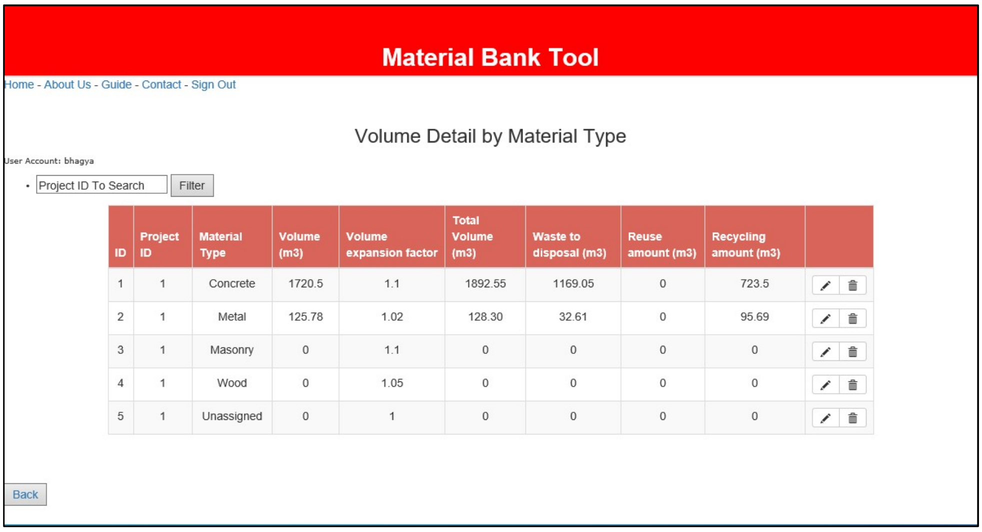


Figure 9. Material volume detail by category



ID	Project ID	Material Type	Volume (m3)	Volume expansion factor	Total Volume (m3)	Waste to disposal (m3)	Reuse amount (m3)	Recycling amount (m3)
1	1	Concrete	1720.5	1.1	1892.55	1169.05	0	723.5
2	1	Metal	125.78	1.02	128.30	32.61	0	95.69
3	1	Masonry	0	1.1	0	0	0	0
4	1	Wood	0	1.05	0	0	0	0
5	1	Unassigned	0	1	0	0	0	0

Figure 10. Material volume detail by material type

Table 1. Waste volume expansion coefficients (Llatas, 2011)

Material	Volume expansion coefficient
Concrete	1.1
Steel	1.02
Masonry	1.1
Wood	1.05

Three added parameters called Toxicity Grade, Recyclability Grade, and Dismantling Grade are essential to automatically calculate the recyclable and reusable volumes in the system. In this study, the grades for these parameters are defined as given in Tables 2 to 4. The designers have to add the corresponding value for these parameters to perform waste volume calculations accurately. If the component is tagged as recyclable, that is when the Recyclability Grade is equal to 2 and Toxicity Grade is equal to 1; the recyclable volume is calculated using a predefined data library of the construction materials with recycling and reuse rates, listed in Table 5. The reusability of a component is also determined in the same manner. If the Recyclability and Toxicity Grades are equal to 1, and Dismantling Grade is equal to 1 or 3, the component will be tagged as reusable. Indeed, the reusability of a component depends on its time-dependent material properties and given design parameters.

On the environmental impact assessment page of the web-application, the user can evaluate the environmental impact of a building with the recorded data in the main database. The indicators GWP, ADP, PEern and PEnern are used for environmental impact analysis. For this study, the general materials from the Ökobaudat database are used to calculate the environmental impact assessment of building. In this study, the quantities of each material are multiplied with the LCA factors are taken from the Ökobaudat database. The evaluated environmental impact of the building according to the Ökobaudat database is shown in Figure 11. In the future, this tool will be further developed by linking more than one LCA database (such as INIES, KBOB and ecoinvent) for the environmental impact assessment of a design. Then, the user can choose multiple LCA databases to compare the values for LCA indicators of different schemes.

Table 2. Toxicity grades

Grade	Description
1	Healthy
2	Very low emissivity
3	Low emissivity
4	Emissive
5	Very emissive
6	Without evaluation

Table 3. Recyclability grades

Grade	Description
1	Reuse
2	Recycling
3	Down cycling
4	Energy recovery
5	Thermal elimination
6	Without evaluation

Table 4. Dismantling grades

Grade	Description
1	Dismountable without deconstruction - Easy
2	Dismountable without deconstruction - Hard
3	Dismountable with deconstruction - Easy
4	Dismountable with deconstruction - Hard
5	Without evaluation

Table 5. Recycling and reuse rates

Material	% Recycle	% Reuse
Concrete (Huang, et al., 2002)	50	0
Rebar (in concrete substructures) (SteelConstruction.info,)	95	2
Rebar (in concrete superstructures) (SteelConstruction.info,)	98	0
Structural steel sections (SteelConstruction.info,)	93	7
Bricks (Emmanuel, 2004)	20	66.5
Cement blocks (Emmanuel, 2004)	73	20
Wood	70	0

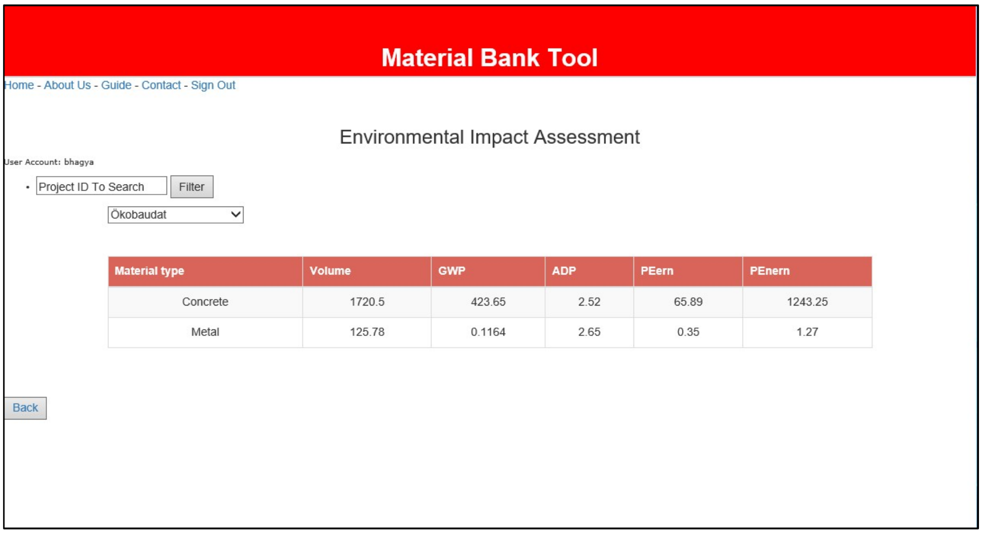


Figure 11. Environmental impact assessment module of the tool

5 Conclusions

This research work elaborated an M&C bank to manage effectively the reuse and recycling of construction materials or even of whole components of old structures within the context of a sustainable building industry. This paper presented a framework for developing BIM-based tool for buildings in a digitalized form of such a bank. M&C bank provides information on recyclable materials and reusable components based on the initial inputs provided by BIM models. The M&C bank tool is developed using PHP programming language, which is integrated with a MYSQL database management system. The database is linked to an existing LCA database using also relevant data from previous research, which are needed to perform environmental impact assessment. The tool can automatically identify and separate recyclable and reusable materials from the C&D waste.

The applicability of the developed tool was evaluated by a case study of a multi-storey building. A BIM model for the building was developed in Revit, and a DYNMO script was used to extract all the required information for the tool from the Revit BIM model. Environmental impacts were assessed using different indicators such as the GWP, ADP, PEern and PEnern. It provides the designers and decision-makers to identify the low-carbon building materials by comparing alternative building materials. In addition, the developed tool can be used to quantify C&D waste. The study was based on data obtained from international databases and literature due to the current unavailability of LCA data for Luxembourg. It was one of the main challenges in conducting this study. It is expected that such databases for Luxembourg will be developed in the future to facilitate more accurate LCA analysis studies.

Acknowledgements

This research is in the framework of the project Eco-construction for Sustainable Developments (ECON4SD), supported by the program *"Investissement pour la croissance et l'emploi"*—European Regional Development Fund (2014–2020) (Grant agreement: 2017-02-015-15).

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