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Development of a BIM-based web tool as Material and Component bank for a sustainable construction industry

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Abstract: The construction industry consumes an enormous amount of global resources and produces more waste than any other sector. The need to move toward sustainable development in construction requires significant changes in construction and demolition (C&D) waste management. The estimation of waste, recycling materials and reusable components could be vital in waste management, achieving huge efficiency in the construction industry. Moreover, a typical building comprises of an extensive amount of materials and components with various characteristics. This study proposes a Building Information Modelling (BIM) based system to allow the circular economy by storing information of the materials and components of buildings and by effectively managing the recycling of materials and reuse of components. A tool which serves as Material and Component (M&C) bank is developed with PHP and MYSQL by making use of a web browser able to extract the materials and component information of a building through the BIM model. This information is vital for several uses such as quantification of C&D waste and assessing for the design for deconstruction. It can also be used to obtain the information of reusable condition of the components and instructions for the reconstruction.

Keywords: Waste management; Material and Component Bank; Recycling; Reuse; Building Information Modelling; MYSQL database

1. Introduction

The construction industry is the largest consumer of global resources and energy. Recent studies have shown that more than 50% of the global raw resources are consumed in constructions, with more than 50% of global energy use [1, 2, 3, 4, 5]. On the other hand, the construction industry produces over 35% of greenhouse gases and over 50% of global waste which eventually end up in landfills, causing a significant loss of valuable metals, minerals and organic materials to future generations [6, 7, 8]. Thus, it is needed to practice waste prevention and reduction in every phase of construction.

Many researchers have been working on finding solutions to the management of construction and demolition (C&D) waste. The areas of research can be divided into two main categories. The first category of research focused on the reduction, recycling and reuse of building materials [9, 10, 11, 12]. Recycling and reuse of construction materials and structural components at the end of their first life span can be used for effective C&D waste management [13]. This will help to reduce the environmental impact of construction such as the depletion of natural resources, cost and energy use incurred by landfilling [14]. According to Chen et al. [15], the use of recycled materials can save more than 60% of the initial embodied energy of buildings. However, in the conventional building design, recyclability of the materials and the direct reuse of structural components for a new building are currently not considered at the design phase. If designed properly, the whole building or each component of the building may be usable for similar applications at the end of a first service life. Design for Deconstruction (DfD) is closely linked with the research on reducing, reuse and recycling of building materials. DfD is defined as the design of structures to facilitate future change, revitalization and removal for recovery of components and materials for reuse. Thus, DfD will increase the useful life of components of a structure by making them available as material stocks for the future. However, failure to identify components in advance and the condition of the components after disassembling as well as the certification of the remaining performance of the components are main barriers to implement this process. Thus, it is needed to keep the records of all information related to the design, materials and construction of the structure as well as of the ageing process and possible incidents which may occur during the life span of a building.

The second category of research includes developing tools for C&D waste management [16, 17]. Poon et al. [18] introduced a method called 'Waste Index' to estimate the waste generation from demolition. It was defined as the quantity of construction waste generated per Gross Floor Area (GFA). Jalali [19] introduced the 'Component Index' to estimate the amount of waste based on the type of components in a building. The main drawbacks of those methods are that they cannot separately identify the building materials used for each building and they are difficult to implement in practice. The material stocks and flow approach was suggested by Cochran and Townsend [20] to estimate the waste based on the data from industry surveys. However, the accuracy of this method depends on the accuracy of the data given by the contractors to those surveys. The quantification of C&D waste provides valuable data to make the adequate decision for C&D waste management because the lack of detailed information on the materials and components when planning for recycling will lead to a waste of time and money during demolition and renovation period [17]. Therefore, the estimation of C&D waste, reusable structural components and recycling materials are essential to achieve sustainable efficiency in the construction industry.

However, the existing tools for the estimation of C&D waste and recycling potential of building materials are not convenient enough for both contractors and recyclers [17, 21, 22]. One of the reasons for the current situation is that buildings are highly complex and durable products. On the other hand, conventional buildings are not planned to provide seamless documentation of their materials and components. There is an extensive amount of material and component related information of quality and detail with regard to their performance over the entire life cycle of the building. Thus, the contractors and recyclers have to spend too much time and effort to retrieve the material volumes to be recycled and landfilled.

In order to promote the DfD as well as recycling of materials and reuse of components, a detailed knowledge about the materials and components incorporated in buildings is required. This makes the concept of a Material and Component (M&C) bank, which acts as a manager to handle all the businesses involved in the construction industry [23]. Cai and Waldmann [23] discussed the main businesses of the proposed M&C bank including assessment, conditioning, storage and certification of materials and components obtained from the demounted structures. For that, it is needed to establish a detailed database about materials and components in buildings. The database will provide all kind of information on the materials and components in a building to allow the circular economy by effectively managing the recycling of materials and reuse of components. It can also be linked with the current method of life cycle assessment and environmental impact assessment. The role of the M&C bank during the deconstruction and reconstruction phases is shown in Figure 1 and the more details on the concept of the M&C bank is given in Cai and Waldmann [23].

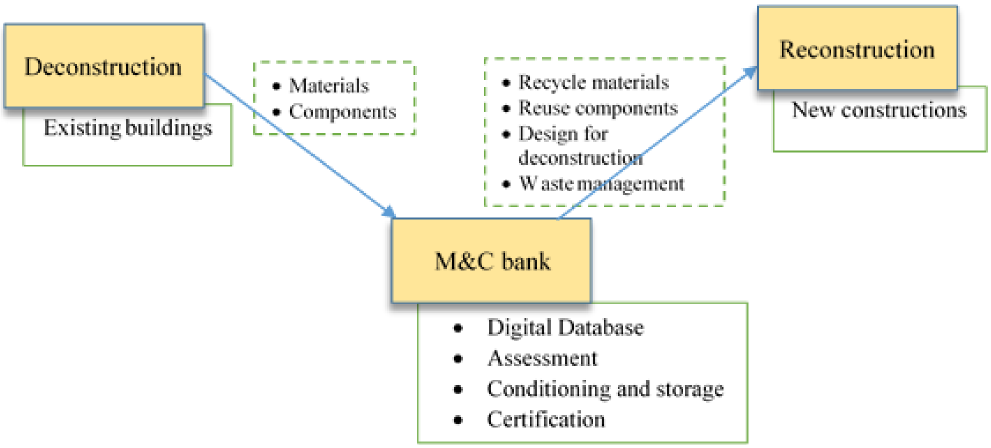


Figure 1. Role of the M&C bank.

The collection of detailed information about the building projects is a difficult task by means of the classical CAD, plan and specifications. These data must be automatically collected, checked and evaluated, which is not possible in traditional building planning without process and data flow digitalization.

Over the past few decades, the Building Information Modelling (BIM) method and the planning processes based on it have gradually been introduced, using as a basis a computer-generated information model of the building. BIM promises a solution to the digital representation of the building facility during the design phase and later during operation [24]. Compared to the conventional two-dimensional drawings, the digital building model that emerges in BIM contains all the relevant information about materials and components with numerous lifecycle-related data, such as material properties, geographic information, quantities, function, life, composition and costs [25]. In addition, the information can be expanded as required to represent the specific building requirements. There are many recent studies, which demonstrate the feasibility of using BIM for streaming life cycle performance of structures. Akinade et al. [22] studied the limitations of existing DfD tools and discussed the essential BIM functionalities that could provide effective decision-making mechanisms for DfD. Focus Group Interviews (FGIs) were conducted with professionals from UK construction companies, and then a thematic analysis was carried out to identify the key functionalities, which could be employed in BIM-based DfD tools. Elmaraghy et al. [26] investigated the possibility of extending BIM functionalities to support deconstruction processes in alignment with lean principles. Galic et al. [27] adopted a BIM-based approach to identify instabilities when deconstructing a steel structure for further reuse or relocation. Ge et al. [28] used a reconstructed 3D model with BIM to improve accuracy of the waste management system. Iacovidou et al. [13] have discussed the integration of Radio Frequency Identification (RFID) with BIM to facilitate the sustainable resource management. Marino et al. [29] introduced a software architecture and framework to be used in design for building construction. They have used Linear Algebraic Representation (LAR)-based BIM for the modelling. Honic et al. [21, 30] presented a BIM-based Material Passport (MP) as well as data- and stakeholder management framework. The MP, which acts as a optimization tool in early design stages and an inventory at the end of the life-cycle of building, was developed by coupling of a BIM-model with the material inventory and BuildingOne analysis tool. Won and Cheng [31] did a comprehensive review of C&D waste minimization and management studies in order to identify the potential BIM-based approaches for C&D waste management and minimization. In order to be able to document buildings and to simulate and optimize them, a comprehensive, complete and up-to-date information is required in every step of the planning process and also after the first life span if the structural element should be reused somewhere else. The information in BIM coming from all categories can be defined as the process of generating and mapping all information of the life-cycle phases of a building. This creates an up-to-date information database of the buildings. Thus, it is necessary to develop a BIM-coupled information model to guide and handle all the business involved in the construction industry. This information model can be used as a database for storing information on the materials and components in buildings and a platform that can be used to prompt waste estimation and planning of C&D waste.

Compared to existing literature, the current research proposes a new approach by presenting a centralized database as BIM-based web tool, which is able to store the information from different projects in one location. Thus, this study aims to develop a method for a BIM-supported system ensuring that the buildings are transformed into fully documented, secure and predictable secondary storage of material resources, with the main concerns of C&D waste management, DfD and the reuse of whole structures and components. In this paper, a study on the development of a BIM-based web tool is presented and discussed. It provides the information on the materials and components in a building to allow the circular economy by effectively managing the recycling of materials and reuse of components.

This article is structured in four sections including an Introduction. Section 2 presents the framework and the procedures of the development of BIM based web tool. In section 3, the system layout and functionalities of the developed system with a discussion are presented. A case study through a BIM model of 11-story residential building with a ground area of 390 m^2 is presented to demonstrate the features of the BIM based web tool. Eventually, the concluding remarks and future works are presented in section 4.

2. Framework and development of the BIM-based web tool as M&C bank

In a typical building, hundreds and thousands of components with different material properties and characteristics are comprised. It implies that a large amount of information needs to be stored to maintain a detailed database about materials and components, which can effectively evaluate their recycling and reuse potentials [14]. BIM has the capacity to handle a large amount of information, which is needed for the bank. Since it can define all the functional and physical characteristics that describe the behavior of the structures, it has become an essential tool for planning new constructions [32]. BIM can also facilitate the data management that is useful to identify recyclable and reusable components in advance and to identify cost and risk in the waste disposal at the deconstruction stage of a building [33, 34, 35]. However, all kind of information on the materials and components in several structures has to remain available for a long time through the whole life span of the structures in the proposed M&C bank. This can be performed by establishing a centralized database that could collect the information in BIM models developed for existing and/or new structures. This section presents the methodology of the development of a web-based application. The developed application extracts and processes the information from the BIM model. It will help designers to identify and select the reusable components for a new construction, using the information stored in the database of the application. It will also serve as a waste estimation tool before the demolition or renovation phase.

In this study, the web-based application which serves as M&C bank was developed using PHP and MYSQL. PHP belongs to the class of languages known as middleware that is needed to work with the web server. It processes the requests made from the web browser, interacts with the server to fulfil the requests and then indicates to the server exactly what to serve to the web browser. The hypertext mark-up language (HTML) was used to render the application in the web browser. MYSQL is a relational database management system, which provides a great way to store and access an enormous amount of information. The required information for the database is extracted from the BIM model using a visual programming language, Dynamo, as illustrated in Figure 2. The connection of the BIM model to the MYSQL database is further described below.

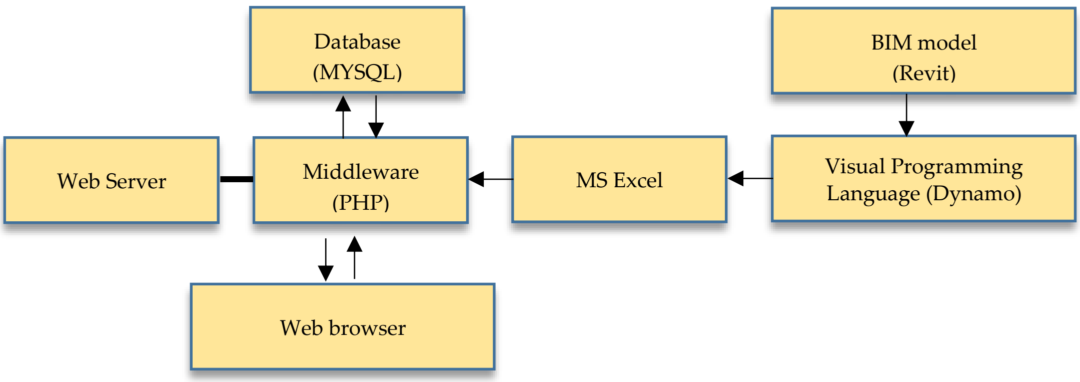


Figure 2. Architecture of the application.

Based on the preliminary studies, it was decided to keep available important information such as project details, detailed dimensions of the components, design relevant parameters, material properties, ageing and possible deteriorations in the system. The database of the system is illustrated in Figure 3. Various data on the materials and components in a building are categorized. The required information for the database is extracted from the BIM model. The information on the MYSQL database can be categorized into three groups, such as project details, components and materials. These information can be used for various purposes. For example, design properties of the components provide information on the installation, extraction and handling procedures required of a reusable component at the deconstruction and reconstruction stages. Structural properties are helpful for structural assessments to determine whether the components can be re-used in a new structure, while chemical properties and thermal properties are needed for environmental and energy assessments, respectively. The physical properties of the components are used to estimate the waste at the demolition stage. It is important to note that some parameters may not be applicable to some components in the BIM model. For example, if some components are not reusable, the attribute for reusable can be kept as *Unchecked*. Then, our developed system will not identify those components as reusable components.

To demonstrate the creation of a link between the MYSQL database and BIM model, Autodesk Revit software was chosen in this study. One of the advantages of using Revit is that any customized information can be added by designers. As the developed system will be used to assess the recyclability of materials, reusability of components and waste generation in a building, in Figure 3 a certain number of new parameters are proposed to be added in the BIM model. Those customized parameters can be defined and added in Revit as *Shared and Instance parameters* to extend the built-in parameters. Therefore, according to the specific characteristics of each structural element, their properties can be edited. Figure 4 shows the custom parameters implemented for a column in the ground floor.

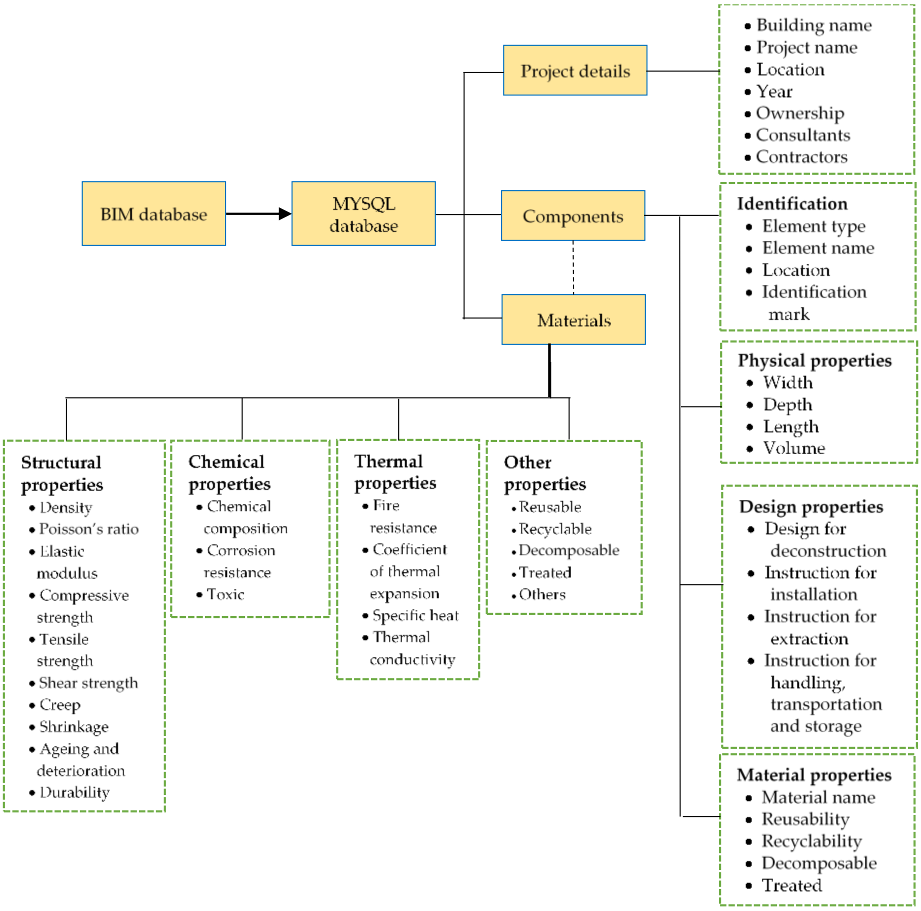


Figure 3. Illustration of the database.

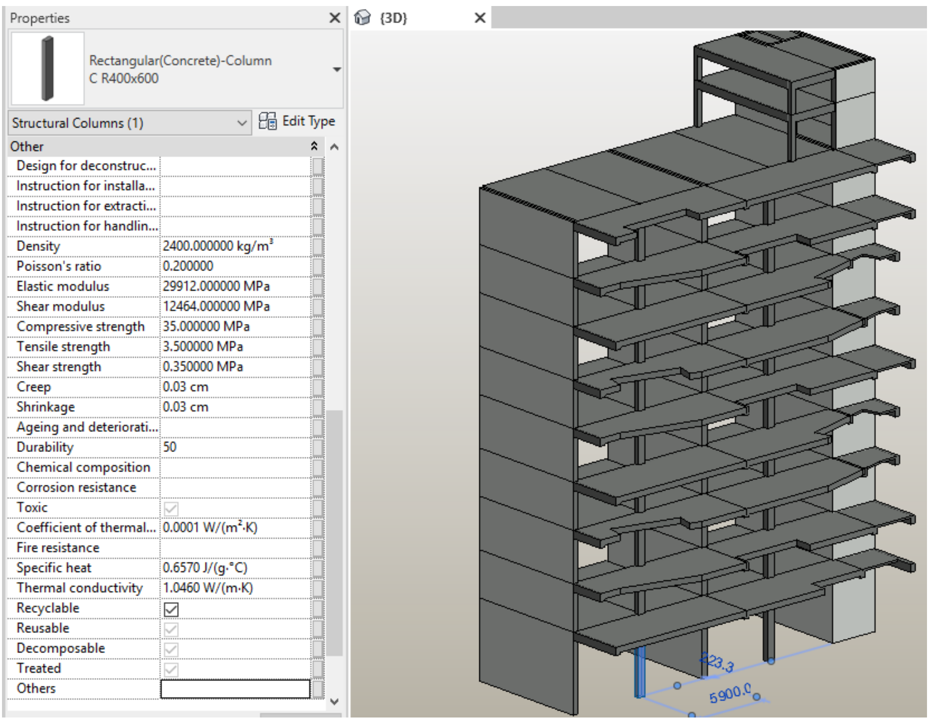


Figure 4. Custom parameters implemented in Revit for a given building.

The data flow from the Revit BIM model to the database was achieved by developing a script using Dynamo, which is a visual programming language for Revit, so that it can access the data structure in the Revit BIM model and obtain information from it, and then insert it into an Excel sheet. A whole script implemented in Dynamo for Revit to send the data from the BIM model to an Excel sheet is shown in Figure A1 in the Appendix A. It consists of different nodes connected with wires that transport data from one node to another. Nodes are the objects placed to form a visual program. Some nodes contain the data and some nodes represent the operations like math functions. Each node has several ports, and they are only connected to other ports of another node if the output type matches to the input type. For the developed system, the Dynamo script works not only as the medium to transfer the data to the system, but as the calculation tool itself. The dynamo script can be divided into 4 parts that have different functionalities such as element take-off, database reading, calculation and export data to excel as shown in Figures A2 to A5, respectively, in the Appendix A. This study was limited to keep the information of structural elements only. Thus, the element take-off gets all the structural elements depending on whether they are modelled as columns, structural framing (beams), floors (slabs), walls and foundations. Then, all the relevant geometrical and material parameters are extracted from the Revit BIM database, and the results are sorted out into appropriate lists. After that, the calculation takes under consideration the material and element type. Finally, the results generated from reading the database are automatically imported into an Excel sheet.

After that, the web-based tool serving as M&C bank is developed to upload the excel file (in CSV format) so that the data will be automatically added to the database of the developed system. Finally, the developed M&C bank includes the information on the project, components and their type, component profile, materials and the parameters, total waste at the demolition, recyclability of materials and reusability of components etc.

3. System layout and discussion

As described above, a web-based tool serving as M&C bank was developed in this study. This section provides a detailed introduction of the layout and functions of the different parts of the developed tool. In addition, a case study of an 11-story residential building was developed with a ground area of 390 m^2. This building was proposed as a recyclable architectural conceptual typology during the ECON4SD project at the University of Luxembourg. In this building, the structure is designed as a reinforced concrete (RC) structure to provide stable slabs serving as framework for the introduction of prefabricated wooden housing modules, Figure 5. Those modules are foreseen to be added or removed during the whole life span of the RC structure. In this study, a BIM model for RC structure was developed in Revit to demonstrate the system. The developed BIM model is shown in Figure 4. 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. Based on Literature, the building 3D models are developed in LoD 100 in its conceptual design stage. The lowest LoD that was used in BIM based facility and life cycle management is 300. In addition, the non-geometric information can be attached to the model elements [36, 30]. Thus, in this study, the building was modelled in the LoD 300.

Figure 5. The proposed slab building under ECON4SD project [37] .

The main page of the developed M&C bank tool appears, as shown in Figure 6. The users must be registered to access the developed system, and the username will be displayed after logging into the system. The users can then visit each page (i.e. Projects, Materials, Components and Assessment) by clicking on the buttons.

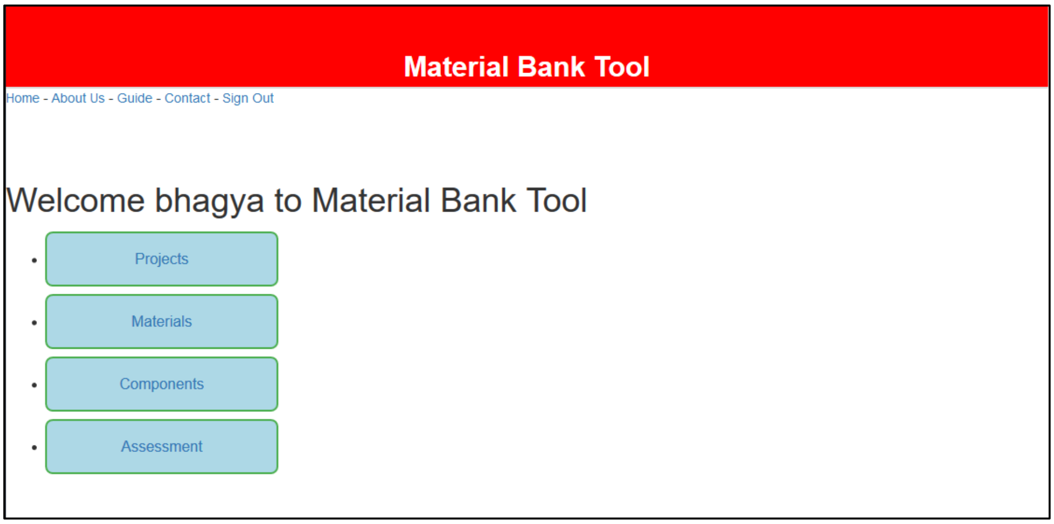


Figure 6. Main page of the system.

In the Projects page, users can view a list of projects and their corresponding information that is saved in the database, as shown in Figure 7. Users are also able to add a new project into the database automatically by uploading a CSV file (generated using the Dynamo script as described in Section 2) or even manually for buildings without any available BIM model. All the relevant data from various constructions in Luxembourg and Europe will be collected in collaboration with the project collaborators. This page also allows users to update any project listed in the database by using the "Update" button in each row. If the "Update" button is selected, then the project data of the respective project can be updated in the database by uploading an updated CSV file, if available. In addition, all the project data of any project can be removed from the database by selecting the "Delete" button.

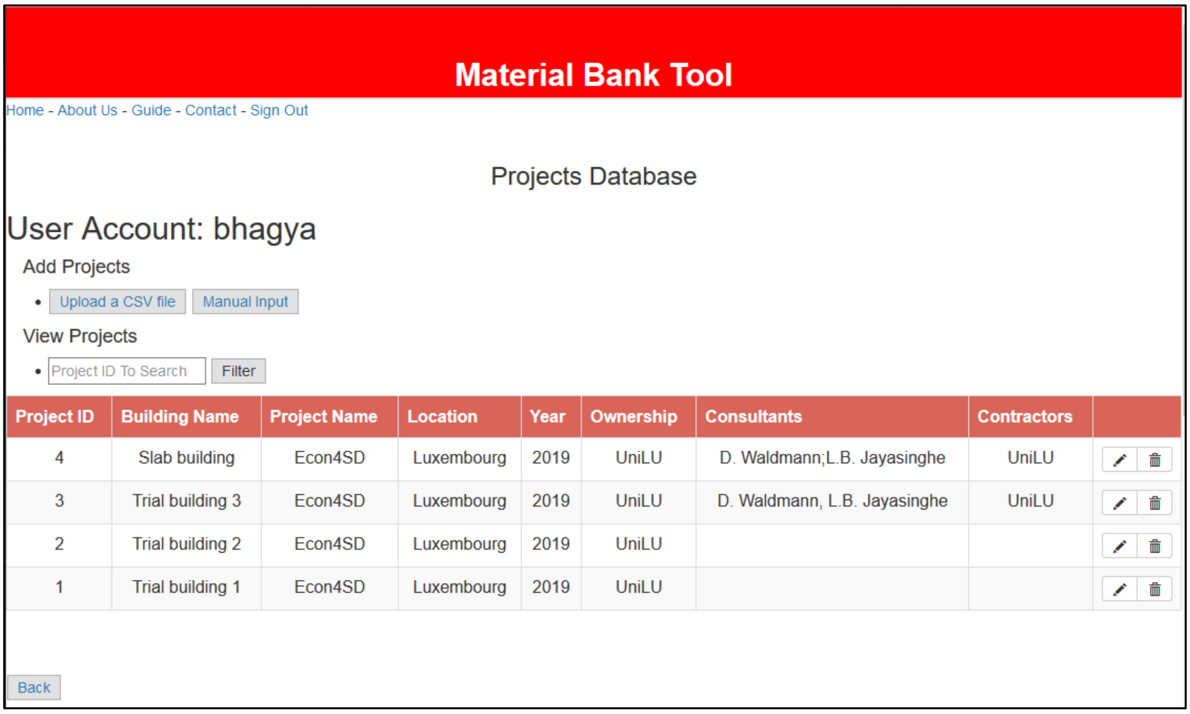
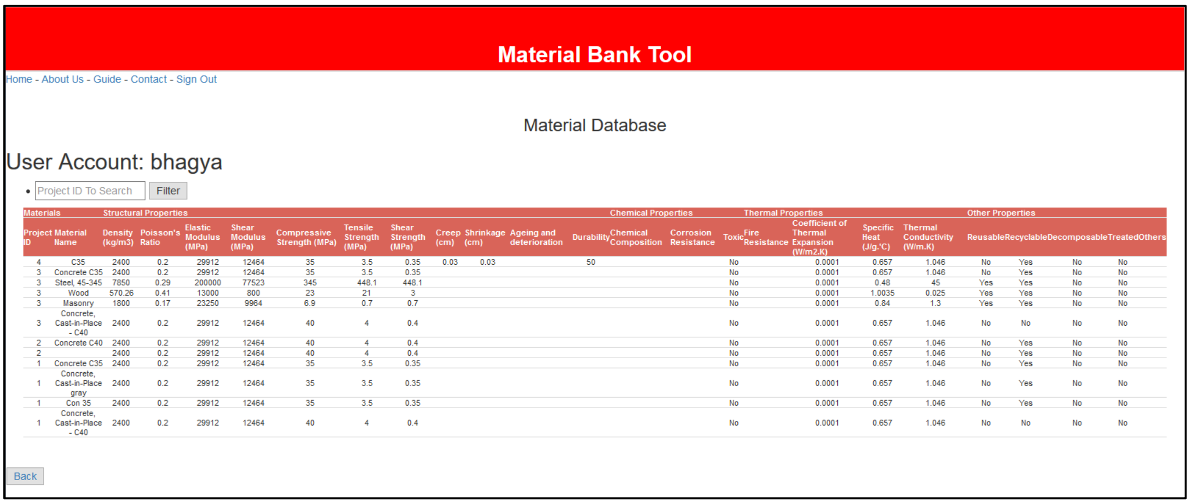


Figure 7. Projects information.

On the Materials page, all information on the materials used in each project is listed as illustrated in Figure 8. The user can search the database by Project ID to obtain the information of the different materials used in a given building. Material properties are grouped according to structural properties, chemical properties, thermal properties and other properties to provide contractors and designers with more detailed information on the materials. Some of these data will be required for several uses, such as structural and environmental assessments. For example, the structural properties of the materials are essential for maintenance and repairing analysis. Knowing the chemical properties of the material, the origin of the hazardous waste can be identified and removed from the C&D waste. Thus, it is important for environmental and human risk assessments. For the reuse/recycle materials and components, information categorized under other properties are required. Then, the contractors and designers can calculate the amount of C&D waste and separate the reusable/recyclable materials and components for a new structure promoting a high level of sustainability in the construction industry.

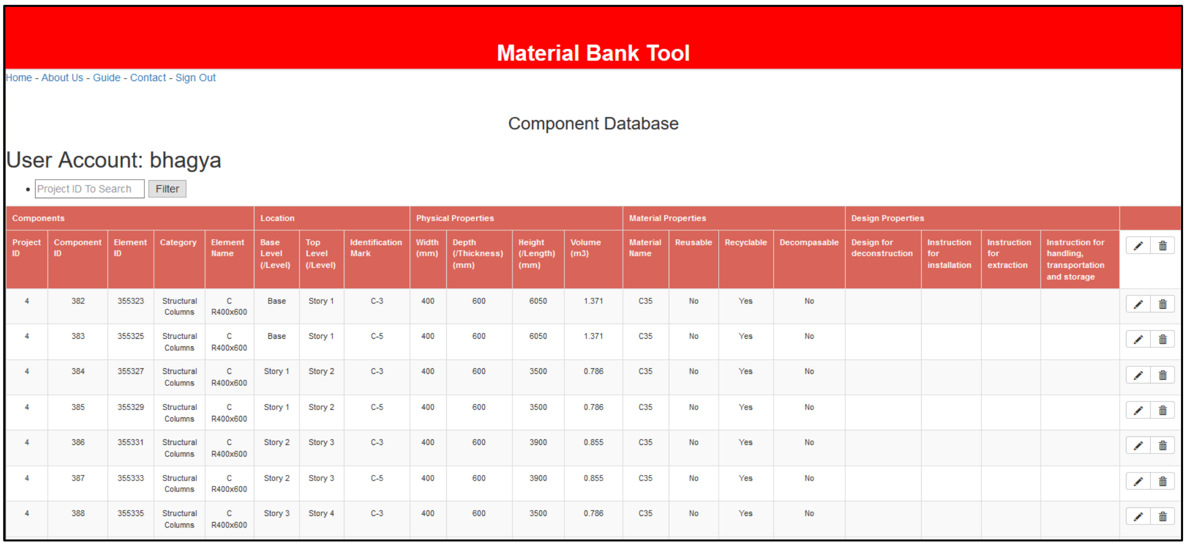


Materials		Structural Properties											Chemical Properties			Thermal Properties				Other Properties				
Project ID	Material Name	Density (kg/m3)	Poisson's Ratio	Elastic Modulus (MPa)	Shear Modulus (MPa)	Compressive Strength (MPa)	Tensile Strength (MPa)	Shear Strength (MPa)	Creep (cm)	Shrinkage (cm)	Ageing and deterioration	Durability	Chemical Composition	Corrosion Resistance	Toxic	Fire Resistance	Coefficient of Thermal Expansion (W/m2.K)	Specific Heat (J/g.'C)	Thermal Conductivity (W/m.K)	Reusable	Recyclable	Decomposable	Treated	Others
4	C35	2400	0.2	29912	12464	35	3.5	0.35	0.03	0.03		50			No		0.0001	0.657	1.046	No	Yes	No	No	
3	Concrete C35	2400	0.2	29912	12464	35	3.5	0.35							No		0.0001	0.657	1.046	No	Yes	No	No	
3	Steel, 45-345	7850	0.29	200000	77523	345	448.1	448.1							No		0.0001	0.48	45	Yes	Yes	No	No	
3	Wood	570.26	0.41	13000	800	23	21	3							No		0.0001	1.0035	0.025	Yes	Yes	No	No	
3	Masonry	1800	0.17	23250	9964	6.9	0.7	0.7							No		0.0001	0.84	1.3	Yes	Yes	No	No	
3	Concrete, Cast-in-Place - C40	2400	0.2	29912	12464	40	4	0.4							No		0.0001	0.657	1.046	No	No	No	No	
2	Concrete C40	2400	0.2	29912	12464	40	4	0.4							No		0.0001	0.657	1.046	No	Yes	No	No	
2		2400	0.2	29912	12464	40	4	0.4							No		0.0001	0.657	1.046	No	Yes	No	No	
1	Concrete C35	2400	0.2	29912	12464	35	3.5	0.35							No		0.0001	0.657	1.046	No	Yes	No	No	
1	Concrete, Cast-in-Place gray	2400	0.2	29912	12464	35	3.5	0.35							No		0.0001	0.657	1.046	No	Yes	No	No	
1	Con 35	2400	0.2	29912	12464	35	3.5	0.35							No		0.0001	0.657	1.046	No	Yes	No	No	
1	Concrete, Cast-in-Place - C40	2400	0.2	29912	12464	40	4	0.4							No		0.0001	0.657	1.046	No	No	No	No	

Figure 8. Materials information.

On the Components page, as illustrated in Figure 9, physical, material and design properties of the components in buildings are provided. To achieve a permanent link between the developed system and BIM model, the same element ID is employed in the database and BIM model. The developed system was limited to import and save the information of structural elements only. However, the bank can be extended to keep the records for structural and non-structural members separately. The users can update the properties of each components and materials by selecting the row to edit and then, using the update button in each row.

Usually, due to the high number of elements in a BIM model, the data management is a challenge. If the important information of each element is summarized in an appropriate list, then the users can easily check properties of all the elements. The contractors and designers can use the developed system to obtain an overview of the building components. It can also be used to obtain the information of reuse and recycling condition of the components and the instructions for the reconstruction. Thus, contractors can identify the locations of the reusable and recyclable components and then, can decide on the most suitable methods for the demolition of the buildings.



Components					Location			Physical Properties				Material Properties				Design Properties			
Project ID	Component ID	Element ID	Category	Element Name	Base Level (/Level)	Top Level (/Level)	Identification Mark	Width (mm)	Depth (/Thickness) (mm)	Height (/Length) (mm)	Volume (m3)	Material Name	Reusable	Recyclable	Decompasable	Design for deconstruction	Instruction for installation	Instruction for extraction	Instruction for handling, transportation and storage
4	382	355323	Structural Columns	C R400x600	Base	Story 1	C-3	400	600	6050	1.371	C35	No	Yes	No				
4	383	355325	Structural Columns	C R400x600	Base	Story 1	C-5	400	600	6050	1.371	C35	No	Yes	No				
4	384	355327	Structural Columns	C R400x600	Story 1	Story 2	C-3	400	600	3500	0.786	C35	No	Yes	No				
4	385	355329	Structural Columns	C R400x600	Story 1	Story 2	C-5	400	600	3500	0.786	C35	No	Yes	No				
4	386	355331	Structural Columns	C R400x600	Story 2	Story 3	C-3	400	600	3900	0.855	C35	No	Yes	No				
4	387	355333	Structural Columns	C R400x600	Story 2	Story 3	C-5	400	600	3900	0.855	C35	No	Yes	No				
4	388	355335	Structural Columns	C R400x600	Story 3	Story 4	C-3	400	600	3500	0.786	C35	No	Yes	No				

Figure 9. Components information.

In the Assessment page, the amount of C&D waste and recyclable and reusable materials and components can be calculated promptly. The building components are categorized according to their functions in a building such as columns, beams, floors, walls and foundations. The total volume and number of components in each category are given in this page, as illustrated in Figure 10. In the presented slab building, the BIM model consists of 281 structural components. For each component in the BIM model, the Dynamo script is used to automatically obtain the volume data of all constituent materials. Then, the tool calculates the total volume under each category. In the present study, Recyclable and Reusable attributes are proposed to add into the BIM model to automatically calculate the recyclable and reusable volumes in the system. If the attributes are checked, the system will tag it as "Yes". If the component is tagged as recyclable, that is when the Recyclability attribute is checked, the recyclable volume is calculated using a predefined data library of the construction materials with recycling and reuse potentials, listed in Table 1. The data library will be updated when the data for material composition of building materials in Luxembourg are available. The reusability of a component is also determined in the same manner. However, the system allows users to adjust the reusable volume depending on the users input in the other attributes under design properties (i.e. Design for deconstruction, instruction for installation, instruction for extraction, and instruction for handling, transportation and storage), the remaining service life and the structural properties such as strength values. The remaining service life is calculated by subtracting the elapsed service period from the durability of the component. If the remaining service life of a component is greater than the service life of the new design, the designers can select the component for their design. Thus, this page allows also users to enter customized values for the recycling and reuse volumes for the sake of calculation adjustments. Then, the waste amount to be disposed will be calculated in the system by subtracting the material volumes which can be reused and recycled from the total volume of components.

A typical building is comprised of different material types. The developed tool identifies Concrete, Metal, Masonry and Wood as main material types. Other types of materials are currently grouped as Unassigned in our system. In future, the system will be further developed to identify additional material types used in the BIM model. The slab building which was developed in Revit (Figure 4) comprised two material types, Concrete and Metal. Figure 11 shows the volume details by material type to provide more detailed information on the waste. This information will help contractors to calculate waste disposal fee and decision-makers to make adequate decisions for minimization and sustainable management of C&D waste.

Table 1. Reusable and Recyclable percentages of building materials

Material	% Recycle	% Reuse
Concrete [38]	50	0
Rebar (in concrete sub-structure or foundations) [39]	95	2
Rebar (in concrete superstructures) [39]	98	0
Structural steel sections [39]	93	7
Bricks [38, 40]	20	66.5
Cement blocks [40]	73	20
Wood	70	0

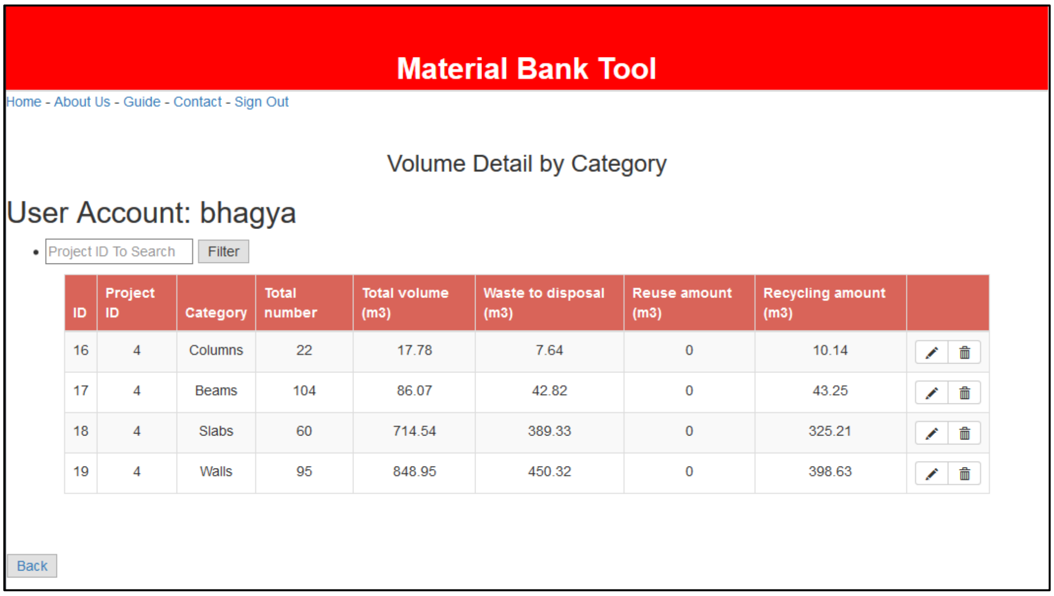


Figure 10. Material volume detail by category.

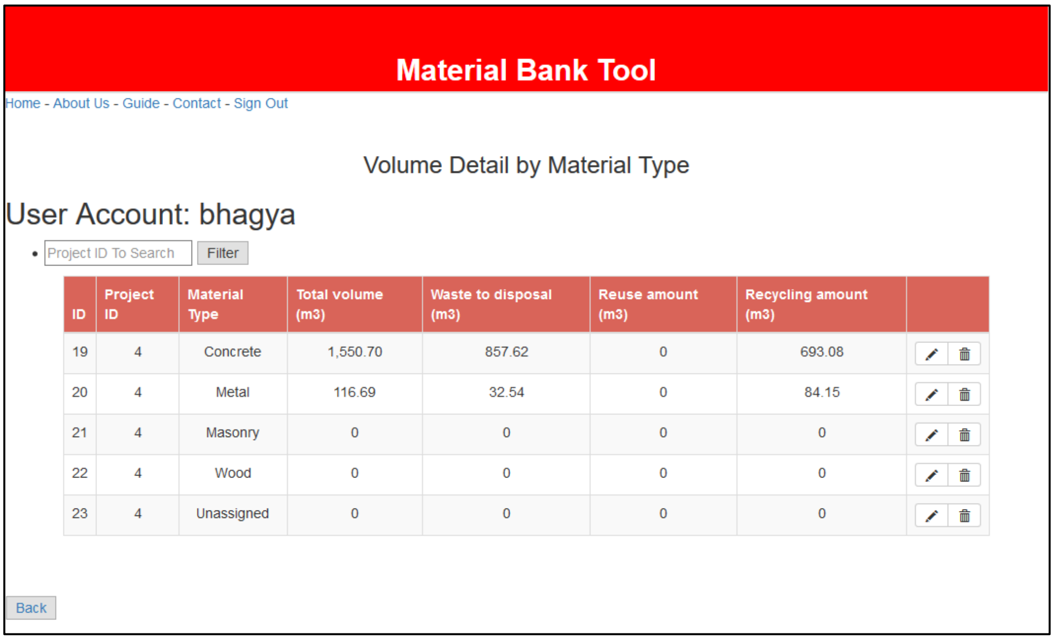


Figure 11. Material volume detail by material type.

However, the final waste volume may vary in different regions and different projects due to the different methods involved in deconstruction phase. Llatas [41] proposed waste volume change factors (Table 2) to calculate the final disposal waste volume. These factors will be adopted to the system in order to increase the accuracy of the results. However, the accuracy of the results also depends on the precision of the database, which is again depending on the precision of the BIM model and the accuracy of the data take-off. The precision of the BIM model and data take-off is related to how the geometry is modelled and the parameters assigned by the designer. Thus, it is recommended to check the BIM model using a control tool, such as Solibri Model Checker [42], in order to be error-free, before transferring the information from BIM model to the bank.

Table 2. Waste volume change factors [41]

Material	Factor
Concrete	1.1
Metal	1.02
Masonry	1.1
Wood	1.05

4. Conclusion and future work

This study was carried out to further extend the works proposed by Cai and Waldman [23]. They proposed a Material and Component bank to promote a circular economy for construction industry. The main businesses of the bank involve all main phases of a construction. In order to effectively manage all construction phases, it is needed to maintain a database which include all kind of information on the materials and components incorporated in a building. Database management systems are nowadays powerful and allow sophisticated manipulation of immense volumes of information.

This study developed a web-based tool that ensures a database for storing information on the materials and components in buildings. It was developed using PHP, HTML language and MYSQL used for the database connection. It includes the information on the project, components and their type, component profile, materials and their parameters, as well as the information on recyclability and reusability of the components. All the required information for the tool is extracted from the Revit BIM model using a Dynamo script. The unique ID for the element serves as permanent link between the M&C bank and BIM model. A case study was carried out to demonstrate the features of the developed BIM-based web tool. The accuracy of the database depends on the precision of the BIM model, the accuracy of the data take-off and the accuracy of the database.

This web-based tool will be extended in future. Further information such as the waste disposal fees and waste volume adjustment factors will be added in the tool. The system will be further developed so that it identifies different material types used in the BIM model. Moreover, all the relevant data from various constructions in Luxembourg and Europe will be collected in collaboration with the project collaborators and will update the database.

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Appendix A

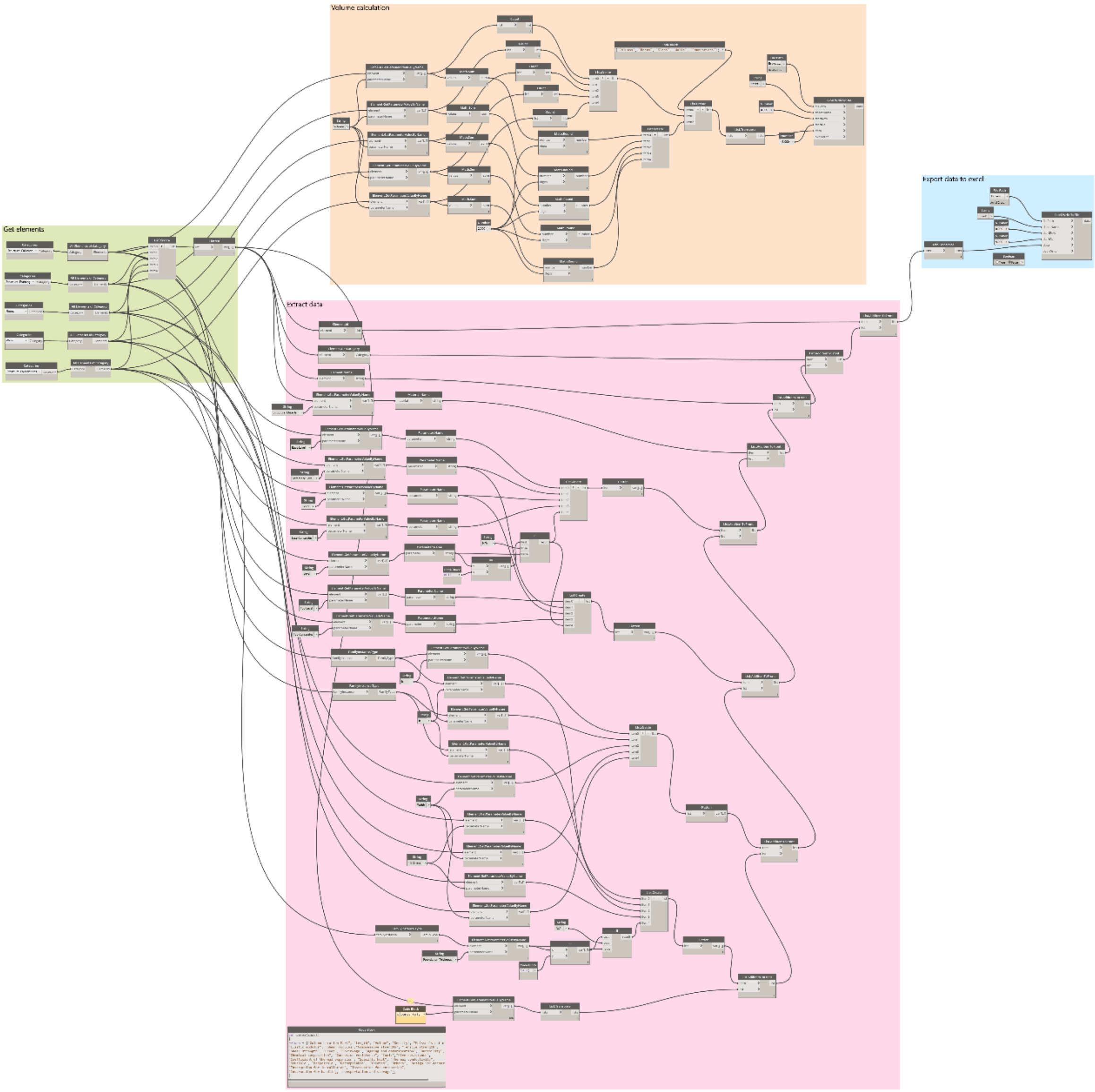

Figure A1. Whole Dynamo script overview.

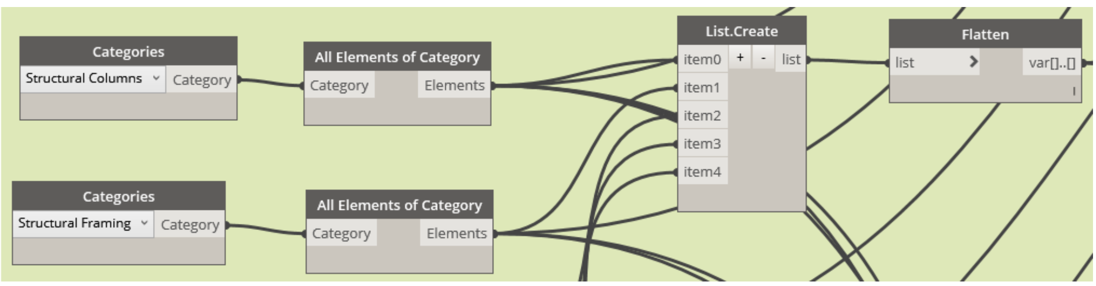

Figure A2. Detailed script for element take-off.

Figure A3. Detailed script for database reading.

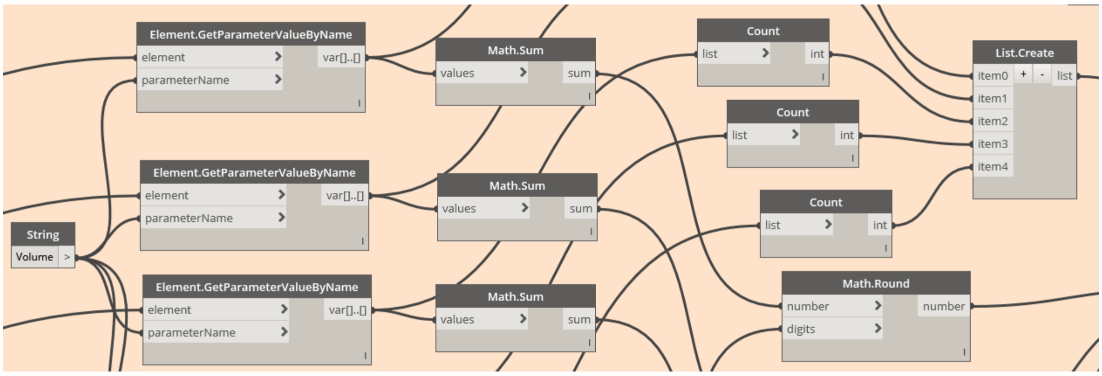

Figure A4. Detailed script for calculation.

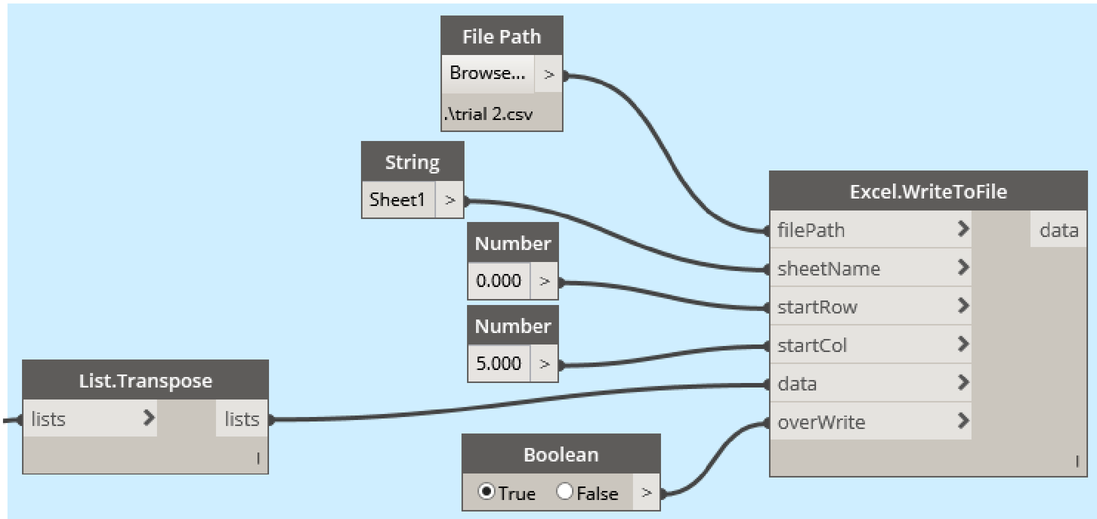

Figure A5. Detailed script for sending data to Excel.

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