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ABSTRACT

The Architecture, Engineering and Construction industry has many times been criticized for lack of control and management of its environmental impacts. In an attempt to monitor and minimize these impacts, the method of Life Cycle Assessment is being used more and more often during the design process of construction projects. Nevertheless, the whole process of performing a building's LCA is considered time consuming which sometimes prevents the design teams from using it more than once in the end of the design as a way to assess the impacts of their final design. The aim of this study is to suggest a method which will render LCA a design tool used during the whole design process. The study focuses not only in creating a tool that will be able to assess a building's environmental impacts, but will also be an analysis tool which will help the design teams make the right decisions and help them minimize their design's environmental impacts. To achieve this, this study evaluated the potential of integrating LCA into BIM, developed and proposed an Integrated Dynamic Model using Revit, Dynamo and Excel. The Integrated Dynamic model was used in case studies the results of which were compared with the respective ones from other established LCA software. The results showed that the integrated dynamic model can create results of equal quality and precision with other specialized software while demanding significantly less time. The ease of use of such an integrated dynamic model and the instant creation of results could render it a decision making tool in respect with LCA.

Keywords: Life-cycle assessment; Building Information Modelling; Design process

1. INTRODUCTION

Recent studies have shown that buildings are responsible for 30-40% of the energy consumption in Europe (Zabalza Bribián et al. 2009) and 40-50% of the greenhouse gas produced globally (Abd Rashid & Yusoff 2015). Increased awareness on the fact has led to the conduction of studies on how to reduce the environmental impacts of buildings. Life Cycle Assessment (LCA) which is one of the methods that have been developed and used to quantify the environmental impacts of a process or product (European Commission -- Joint Research Centre -- Institute for Environment and Sustainability 2010) is used in the building sector since 1990 in order to assess the

environmental impacts of buildings (Ortiz et al. 2009). On the other hand, the building industry continuously aims for cost reduction and simultaneous increase of the projects' quality (Tao & Tam 2013). Therefore methods that can lead to more sustainable design of buildings while assisting in keeping the total budget low are of high interest in the last few years.

Various tools and methods have been developed till today that can assess a building's environmental impacts (Liu et al. 2015) but few have been done to assist the architects and engineers to make the right choices in the early design stage of a building. Considering that the early stage of a building design is the stage when environmental matters are best arranged and given the fact that making good design decisions at the initial stage plays an important role in reducing a project's cost and completion time, the development of such a tool is considered necessary. The emerge of Building Information Modelling (BIM) concept, the wide use of it in the Architecture, Engineering and Construction (AEC) industry and the benefits of its use in respects with the information enrichment and visual representation of a building (Eastman 2011), dictates that such a tool should also be able to be integrated and interact with the most popular BIM software in the AEC industry.

This study aims to develop an Integrated Dynamic Model (IDM) (Negendahl 2015) that would enable design teams to assess the environmental impacts of their design from the early stages of the design through the end of it. The developed model is built to function as a design tool for the design team and offer useful feedback regarding the environmental impacts.

The IDM developed during this study consists of Revit (Autodesk 2016), Dynamo (Autodesk 2015) and an external Life Cycle Impacts(LCI) database. The results of this IDM are produced in a material level and exported in an excel sheet enabling the analysts perform hotspot analyses in a material level, construction type level or construction category level.

2. LCA IN CONSTRUCTION INDUSTRY AND BIM

The recognition of LCA as a factor of sustainability assessment of buildings has led to the increasing use of it in the construction industry. The way it is usually performed though, differs from LCAs performed for other products. The fact that buildings are not industrialized products in their majority makes a detailed LCA hard and time consuming. For this reason, in most of the cases these assessments are based on a material database that contains various generic materials' impacts per specific quantity unit. These impacts are then multiplied with the quantities of the construction's materials to give the total impacts of the construction.

The emerge of BIM concept, the wide use of it in the AEC industry and the benefits of its use in respects with the information enrichment and visual representation of a building (Eastman 2011), dictates that BIM models could be the source of all relevant information needed for a project's LCA.

The integration of projects' LCA studies in BIM will not only make LCA analysis faster but by using the graphical interface of BIM tools, the results from the LCA analysis will be communicated better among the different engineering disciplines and architects. This better communication of results could lead in more sustainable solutions for the studied buildings and projects (Jensen & Nielsen 2011)

3. PROPOSED METHOD (INTEGRATED DYNAMIC MODEL)

The proposed method consists of an Integrated Dynamic Model where the connection of Revit is used with an external material LCI database and the Visual Programming Language (VPL) Dynamo. The LCI database is the source where VPL gets the environmental impacts of the used materials from. The database consists of all common construction materials and their environmental impacts per a specific functional unit (m^2 or m^3).

The basic concept of the proposed model is that there is a permanent link between the Revit materials and the Database materials resulting to zero input from the user every time they want to perform an LCA. To achieve this permanent link, a unique material ID is employed which is the same in both the Revit material library and the LCI database.

Given the material linkage, a script developed in Dynamo is able to automatically read and understand each Revit material's environmental impacts from the LCI database. Getting the material take-off from the BIM model in the same script, it is possible to calculate the total life cycle environmental impacts. Finally, the results are formed accordingly and exported in a new excel sheet which generates all the necessary graphs and charts.

As shown in the model's overview in Figure 1, an advantage of calculations actually happening in the BIM environment itself is the graphical feedback of the results. The use of Dynamo for the entire calculation means that the model can also take advantage of the colour override functionalities it offers. The final results are interpreted visually in the BIM environment and numerically by being exported in an excel sheet where analytical charts are produced.
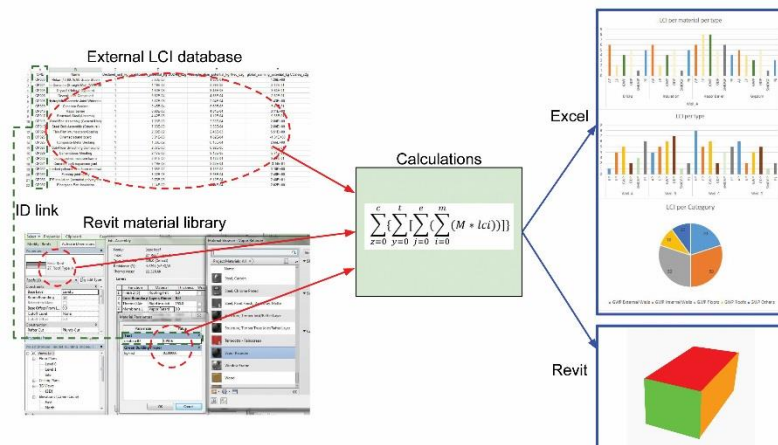

Figure 1: Overview of the proposed model for LCA integration to BIM.

3.1. Life Cycle Impacts database structure

The Excel based database (Figure 2) contains the life cycle environmental impacts of a number of predefined construction materials for specific impact categories. The materials' functional unit was chosen to be m^2 or m^3 since these quantities can be extracted from the BIM model. The materials that are modelled in Revit as membranes are stored with their impacts per m^2 while all the rest as impacts per m^3.

Figure 2: LCI database structure.

The environmental impacts are divided into manufacturing impacts and End-of-Life(EoL) impacts to enable the organization of the final results into the respective life cycle categories. For validation reasons information like the functional unit, the density and the source for each material are also stored in the database. The life expectancy of each material is given in three different values to enable the lifetime estimation of each material in the BIM model according to its exposure to the exterior environment. This way, the same material can be considered with different lifetime whether it is placed on the exterior of an exterior wall, on an interior wall or in the core of a wall.

3.2. Datasets and material linking

The unique ID which serves as the link between the database materials and the BIM materials is stored both in the database(Figure 2) and the BIM model. In the BIM model the material ID is stored as a material property which can be read by the VPL that will then identify and link it with a dataset. This way, a permanent link is created between the LCI database and the BIM material library reducing the time needed for a whole LCA performance since the user is not called to link the materials one by one as in most of the LCA applications. In this method, the link is performed only once when the LCI database and the BIM material library are formed. After this and for every new project the BIM material library will always contain the "key" (Figure 4) to its materials' respective datasets in the database.

3.3. Classification system

Although in most BIM applications the elements that can be used are sorted per categories like beams, walls, columns, etc., there are a lot of cases where elements have to be modelled as generic models. Regarding this specific application, this means that these elements and their respective environmental impacts cannot be included in a category in the interpretation of the results. By employing a classification system, these elements can be given a code which specifies what kind of element they are. Then, VPL, by reading these codes sorts the final results by code. This way, in the final results, in the beams' impacts not only the elements that were modelled as beams will be included but also elements modelled as generic models and used as beams.

In this specific application, the BIM7AA encoding system (BIM7AA 2015) is used because it is simple enough to use and provides all the functionalities needed. Similarly, other encoding or classification systems can be used according to the developer's or user's preference.

3.4. Dynamo script

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For the proposed IDM, the VPL works not only as the medium to translate and transfer the data to the Building Performance Simulation (BPS) tool, but as the BPS tool itself. Subsequently, the Dynamo script (Figure 3) contains coding for both reading-gathering data from the design tool (Revit) and the database and performing the calculations. The Dyn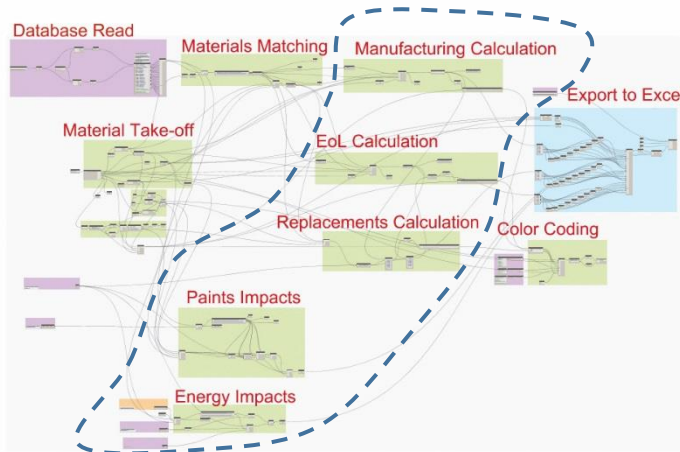amo script can be "divided" in parts-steps that undertake different functionalities. These functionalities can be divided to Material take-off, database reading, materials-datasets matching, LCI calculation and communication of results.

Figure 3: Dynamo script overview.

The material take-off gets all the materials' quantities in m^2 or m^3 depending on if they are modelled as membrane or regular materials. The database reading results in importing of the excel database into Dynamo and the sorting of the data into appropriate lists which facilitate the calculation thereafter. The materials-datasets matching actually links every material with a dataset by creating a list of keys which is of equal size with the materials' list and leads to the corresponding datasets (Figure 4).
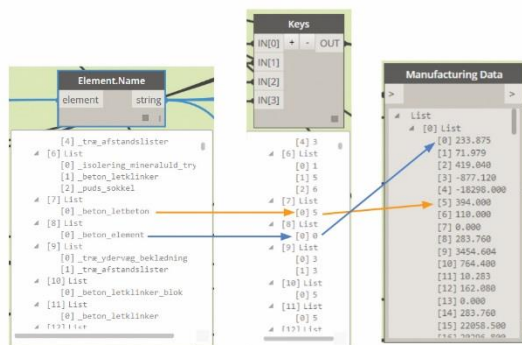
Figure 4: Revit material linkage with LCI.

The LCI calculation takes under consideration the manufacturing, the EoL and the use stage of each material. The use stage is considered by the number of replacement of each material during the building's lifetime. This is achieved by estimating each material's lifetime according to its exposure to the exterior environment and the lifetimes provided in the database. Furthermore, the impacts of the paints and the energy used are also included. The paints are treated differently since it is a common practice not to be added as materials in the BIM model but as a graphical representation or text information. For this application, the paints information is added as text information in the material which is then recognized by the script that can treat it as a regular material. The energy impacts are included in order to make the final report more complete. Ideally the energy consumption would be calculated in the design tool itself being automatically accessible by the VPL.

Finally, after the calculation of the impacts, the communication of the results occurs both analytically and visually (Figure 5). VPL, taking the advantage of producing the results in the BIM environment, color-codes all elements in the geometrical model according to their contribution to the final impacts. This color-coding can be performed for any impact category or element category (walls, roofs, etc.) according to the user's preference. The elements can also be color-coded according to some predefined reference values or relatively to each other.

Figure 5: Visual (left) and analytical (right) representation of results.

As for the analytical results, these are exported to an Excel sheet sorted by material, family type, classification number and life cycle stage. This detailed production of results enables better comparison of design options by using charts that are produced automatically in Excel.

3.5. Pre-check

The accuracy of the produced results by the proposed LCA IDM depends on the accuracy of the datasets and the accuracy of t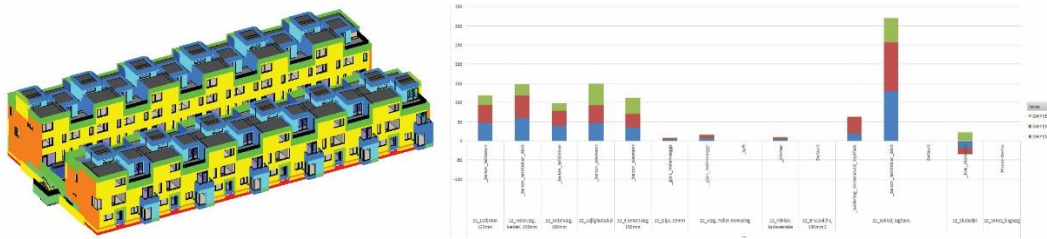he information of the Revit model. To ensure that all needed information are included in the Revit model, a new IDM is used to check the BIM model before the LCA IDM is run. This IDM performs various checks before it approves that the BIM model is ready to be used to the LCA IDM. Of course the LCA IDM is built in a way that it surpasses and ignores (but reports) any potential errors so that it gives a final result. This pre-check IDM's purpose is to enhance the accuracy of the LCA model's results by informing the modeller what is not modelled correctly. The checks performed by this IDM include missing classification codes, missing or invalid material IDs, wrong material links and elements with no materials assigned. The results of these checks are communicated by text in the VPL environment and visually by color-coding the problematic elements in the BIM model.

4. EVALUATION OF THE LCA INTEGRATED DYNAMIC MODEL

The proposed IDM was evaluated in terms of accuracy of results and time needed for a full LCA analysis. This was done by performing a building's assessment with the developed IDM, LCAbyg (Statens Byggeforskningsinstitut Aalborg Universitet 2016) and tally(KT Innovations et al. 2015). LCAbyg was chosen because it is among the most popular LCA tools for assessing buildings in Denmark and its results were used for assessing the accuracy of the developed IDM. As for tally, since it uses an American database and a different LCA method than the custom LCI database, a deviation was expected between its results and the results of the IDM. It was chosen though mainly for comparing the efficiency of the two methods in terms of time needed for a full LCA assessment. For the same case study, the Global Warming Potential (GWP) results are presented at Table 1.

Table 1: GWP results of case study.

Tool/Method	GWP (kg CO_2 Eq.)	Deviation
Integrated Dynamic model	1,38E+06	0%
LCAbyg	1,44E+06	+4%
Tally	2,84E+06	+51%

Regarding the time needed for a full assessment, the proposed IDM created results in less than one minute while using tally this time was more than two hours since all

materials had to manually be linked with datasets one by one. The IDM's strongest advantage though, is the fact that it is a tool that can be easily modified by the user to meet any specific requirement. By modifying the custom LCI database and adding new "equivalent" datasets the practitioner can overcome issues like including elements that are not modelled in the BIM model (screws, foils, tapes etc.), including non-conventional materials and in general to adjust the whole process according to the standards the BIM model is produced.

5. DISCUSSION

After the evaluation of the developed IDM, it appears that it could potentially be useful for engineers and architects who try to monitor and minimize the environmental impacts of their design in all stages, from the pre-conceptual to the end of the detailed one. Nevertheless, there are factors that can affect the validity of the results of the developed IDMs. These factors include the precision of the BIM model, the material take-off precision and the accuracy of the database. The BIM model precision is related with the geometry modelled by the modeller, while the material take-off is related to the software itself. For the purpose of this study it is assumed that the material take-off produced from Revit is accurate enough for use in LCA. As for the database, since it is custom made by getting datasets from other databases or by creating new ones, its accuracy can strongly affect the final results. For this reason it is recommended that the database's datasets come from the same source.

Furthermore, the same concept with the developed IDM can be used to perform Life Cycle Cost (LCC) assessments of buildings. Similarly with the LCA IDM, an LCC IDM can use a cost database of materials or elements and thus estimate the cost during the building's life cycle.

6. CONCLUSION

The case studies of the proposed IDM showed that such a model could facilitate the assessment of a building from the early stages of design and provide useful feedback in a short amount of time. The level of detail of the produced results facilitates the further analysis by the LCA practitioner. The results can be interpreted in material, construction type and construction category level, helping the practitioner perform a hotspot analysis, detect materials and constructions causing higher impacts and perform the necessary changes. The visual representation of the results directly in the BIM environment by color-coding of the building elements is also a feature that is helpful in terms of quickly detecting the hotspots in the construction type level.

Regarding the complexity, the use of IDMs for LCA is considered not more complicated than the use of conventional simplified LCA tools. The complexity in this case has mainly to do with the use of the VPL language. The practitioner must have some basic knowledge in VPL while at least one practitioner in the design team should be able to verify the final results and maintain the LCI database. On the other hand, the assessments are performed much faster in the IDM while LCA knowledge is not a prerequisite for a practitioner to perform them. This, combined with the fact that the inventory is automatically updated when changes occur in the geometrical model, enables the production of more results with a lot of iterations in considerably less time and leaves the LCA specialist more time to analyse the results instead of creating

them and then analyse them. In the same time the modeller can use the time saved for more iterations or other tasks more relevant to their discipline.

To conclude with, this study showed that the use of LCA IDMs can help towards the integration of LCA in the design process and the design of more sustainable constructions in terms of environmental impacts. The developed IDM, with some further development and improvements could be used by design teams while they could be the basis for development of new more stable and precise LCA IDMs.

REFERENCES

Abd Rashid, A.F. & Yusoff, S., 2015. A review of life cycle assessment method for building industry. *Renewable and Sustainable Energy Reviews*, 45, pp.244–248.

Autodesk, 2015. Dynamo. Available at: http://dynamobim.org/learn/.

Autodesk, 2016. Revit. Available at: http://www.autodesk.com/products/revit-family/overview.

BIM7AA, 2015. BIM7AA TYPE CODE V. 2.1 - 2015.07.09 UK. , pp.1–28. Available at: http://www.bim7aa.dk/.

Eastman, C.M., 2011. *BIM handbook : a guide to building information modeling for owners, managers, designers, engineers and contractors*, Wiley.

European Commission -- Joint Research Centre -- Institute for Environment and Sustainability, 2010. *International Reference Life Cycle Data System (ILCD) Handbook -- General guide for Life Cycle Assessment -- Detailed guidance*,

Jensen, L.B. & Nielsen, T.R., 2011. Obstacles and new opportunities for integrated design.

KT Innovations, Thinkstep & Autodesk, 2015. tally. Available at: http://choosetally.com/.

Liu, S., Meng, X. & Tam, C., 2015. Building information modeling based building design optimization for sustainability. *Energy and Buildings*, 105, pp.139–153.

Negendahl, K., 2015. Building performance simulation in the early design stage: An introduction to integrated dynamic models. *Automation in Construction*, 54, pp.39–53.

Ortiz, O., Castells, F. & Sonnemann, G., 2009. Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials*, 23(1), pp.28–39.

Statens Byggeforskningsinstitut Aalborg Universitet, 2016. LCAbyg. Available at: http://www.lcabyg.dk/.

Tao, R. & Tam, C.-M., 2013. System reliability theory based multiple-objective optimization model for construction projects. *Automation in Construction*, 31, pp.54–64.

Zabalza Bribián, I., Aranda Usón, A. & Scarpellini, S., 2009. Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment*, 44(12), pp.2510–2520.