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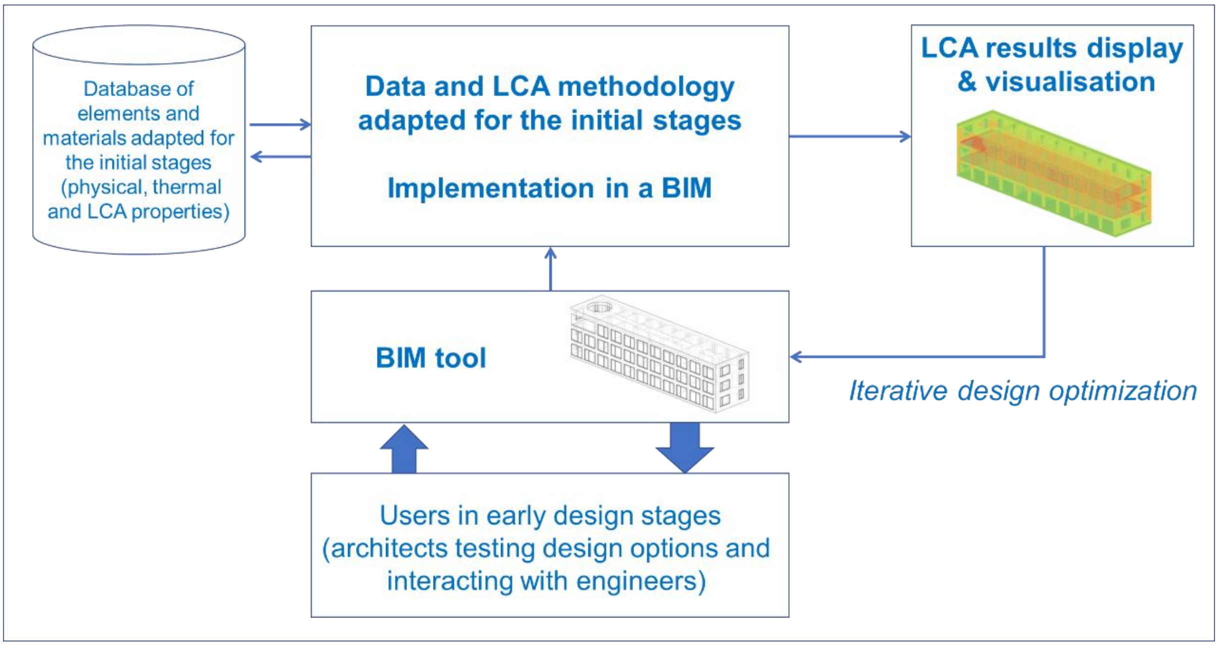
Final report dated 20.07.2022

Design-integrated Life Cycle Assessment using BIM (BIM-LCA)



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Zusammenfassung

Das Projekt zielt darauf ab, eine BIM-basierte Methode für die designintegrierte Ökobilanzierung während der Planungsphase zu entwickeln, die bereits in den entscheidenden frühen Entwurfsphasen beginnt. Die Forschung bietet eine kritische Überprüfung und ein Verständnis der aktuellen BIM-, Ökobilanz- und Verfahrensregeln für Architekten und Ingenieure. Dabei werden mögliche Arbeitsabläufe (die zum Teil im Rahmen dieser Forschung entwickelt wurden und zum Teil aus der bestehenden Forschung auf dem Gebiet der BIM-Ökobilanz stammen) für jede Phase der Planung vorgestellt, die eine einfache Anwendung und Übernahme in die Planungspraxis ermöglichen. Darüber hinaus werden Ansätze zum Umgang mit Unsicherheiten in frühen Entwurfsphasen und Visualisierungskategorien sowie deren Einfluss auf den Entscheidungsprozess diskutiert.

Die wichtigsten Ergebnisse des Projekts werden im Folgenden beschrieben:

1) Eine Beschreibung der aktuellen Situation der Designbedürfnisse und der von den Designern (Architekten und Ingenieure) in der Schweiz verwendeten Werkzeuge sowie ein Verständnis der verwendeten LCA-Daten.

2) Eine Methode für BIM-basierte Ökobilanzen in frühen Planungsphasen, einschliesslich Methoden zur intuitiven Visualisierung der Ergebnisse, die es den Planern erlaubt, die Informationen zur Optimierung des Gebäudes zu nutzen. Außerdem wurden Ansätze für den Umgang mit Unsicherheiten in frühen Entwurfsphasen vorgestellt.

3) Richtlinien für BIM-basierte Ökobilanzen in frühen Planungsphasen, die sich an Architekten und Ingenieure, aber auch an Softwareentwickler und nationale Organisationen (SIA, ecobau, Minergie, etc.) richten.

Die wichtigsten Erkenntnisse

1) Zeit- und Wissensmangel sind einer der Hauptgründe für die verspätete Einführung von Ökobilanzen in den Planungsprozess. Es ist wichtig, das Bewusstsein von Architekten und Ingenieuren für den Prozess der Ökobilanzierung zu schärfen, Wissen über relevante Werkzeuge zu vermitteln, das Bewusstsein für Fehler und die in den Werkzeugen verwendeten LCI-Daten zu schärfen und die Interpretation der LCA-Ergebnisse zu verstehen.

2) Die Interoperabilität (automatischer Datenaustausch) zwischen BIM-Plattformen und LCA-Tools ist nach wie vor eine Herausforderung, und es besteht Forschungsbedarf im Bereich des automatischen Datenaustauschs zwischen verschiedenen Tools, um menschliche Fehler zu vermeiden.

3) Eine frühzeitige Integration von LCA bietet die Möglichkeit, Designalternativen zu vergleichen, Hotspots der Umweltauswirkungen im Gebäude zu identifizieren und das Design durch die Generierung von Echtzeitparametern während des Designprozesses zu optimieren.

Résumé

Le projet vise à développer une méthode basée sur la BIM pour l'évaluation du cycle de vie intégrée à la conception pendant la phase de planification, dès les premières phases cruciales de la conception. La recherche fournit un examen critique et une compréhension de la BIM actuelle, de l'ACV et du code de pratique pour les architectes et les ingénieurs. Ce faisant, elle présente des flux de travail possibles (certains développés dans le cadre de cette recherche et d'autres issus de la recherche existante dans le domaine de la BIM et de l'ACV) pour chaque phase de la conception qui permettent une application et une adoption faciles dans la pratique de la conception. En outre, les approches pour gérer l'incertitude dans les premières phases de conception et les catégories de visualisation et leur influence dans le processus de prise de décision ont été discutées.

Les résultats attendus du projet seront les suivants :

1) Une description de la situation actuelle sur les besoins et les outils de conception utilisés par les concepteurs (architectes et ingénieurs) en Suisse ainsi qu'une compréhension des données ACV utilisées.

2) Une méthode d'ACV adaptée au BIM dans les premières étapes de la conception, y compris des propositions pour visualiser les résultats d'une manière intuitive pour les concepteurs afin optimiser le bâtiment. En outre, des approches pour traiter l'incertitude dans les premières étapes de la conception ont été fournies.

3) Des recommandations sur l'ACV adaptée BIM dans les premières phases de conception, destinées aux architectes et aux ingénieurs, mais aussi aux développeurs de logiciels et aux organisations nationales (SIA, ecobau, Minergie, etc.).

Principaux points à retenir

1) Le manque de temps et de connaissances est l'une des principales raisons de l'adoption tardive de l'ACV dans le processus de conception. Il est important de sensibiliser les architectes et les ingénieurs au processus de l'ACV, en leur fournissant des connaissances sur les outils pertinents, la prise de conscience des erreurs et des données de l'ICV utilisées dans les outils et la compréhension de l'interprétation des résultats de l'ACV.

2) L'interopérabilité (échange de données automatisé) entre les plateformes BIM et les outils d'ACV reste un défi permanent et des recherches sont nécessaires en matière d'échange de données automatisé entre les différents outils pour éviter les erreurs humaines.

3) Une intégration précoce de l'ACV offre la possibilité de comparer des alternatives de conception, d'identifier les points chauds des impacts environnementaux dans le bâtiment et d'optimiser la conception en générant des paramètres en temps réel pendant le processus de conception.

Summary

The project aims to develop BIM-based method for design integrated life cycle assessment during the planning phase, starting in the crucial early design phases. The research provides a critical review and understanding of the current BIM, LCA and code of practice for architects and engineers. In doing so it presents possible workflows (some developed as part of this research and some from the existing research in the field of BIM LCA) for each phase of design that allow for ease of application and adoption in the design practice. Furthermore, approaches to handle uncertainty in early design phases and visualisation categories and their influence in decision-making process has been discussed. The key outcomes of the project are outlined as below:

1) A description of the current situation on design needs and tools used by designers (architects and engineers) in Switzerland as well as an understanding of the LCA data used.
2) A method for BIM-based LCA in early design stages including methods to visualize the results in an intuitive way that allows designers to use the information to optimize the building. Furthermore, approaches to deal with uncertainty in early design stages have been provided.
3) Guidelines on BIM-based LCA in early design stages directed to architects and engineers, but also software developers and national organizations (SIA, ecobau, Minergie, etc.).

Key takeaways

1) Lack of time and knowledge are one of the key reasons for late adoption of LCA in the design process. It is important to increase awareness of architects and engineers about the process of LCA, providing knowledge on relevant tools, the awareness of errors and LCI data used in the tools and understanding the interpretation of LCA results.
2) There is still a continued challenge of interoperability (automated data exchange) between BIM platforms and LCA tools and research is required in automated data exchange between various tools.
3) An early integration of LCA offers opportunities to compare design alternatives, identifying hotspots of environmental impacts in the building and optimising design by generating real time parameters during the design process.

Contents

Abbreviations

API – Application Programming Interface

BIM – Building Information Modelling

BEM – Building Energy Model

BOQ – Bills of Quantities

eBKP-H - Elementbasierter Baukostenplan Hochbau eBKP-HKBOB - Ökobilanzdaten im Baubereich 2009/1:2016

gbXML - Green Building XML

GHG – Greenhouse gas

IFC - Industry Foundation Class

KBOB - Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren

LCA – Life Cycle Assessment

LCC – Life Cycle Cost

LOD – Level of Development

NNBS - Netzwerk Nachhaltiges Bauen Schweiz

PLCA – Parametric Life Cycle Assessment

SIA - Schweizerischer Ingenieur- und Architektenverein

SNBS - Standard Nachhaltiges Bauen Schweiz

1 Introduction

1.1. Background information and current situation

Choices in early design stages have a major influence on the environmental performance of the building throughout its life cycle. In these initial design stages, architects take most decisions in interplay with the client, especially in smaller projects where engineers and specialists are usually only involved in late design stages. Therefore, architects, building owners and clients are key stakeholders to make informed decisions about sustainability targets for a building project in the early design phases. After reducing the environmental impacts in the initial stages, designers are able to check whether the design meets the statutory requirements in terms of Greenhouse Gas (GHG) emissions and primary non-renewable energy use in later stages of design.

Several tools and methodologies have been developed to evaluate the impact of buildings with a growing interest to integrate Life Cycle Assessment (LCA) into early design stages as a design thinking and decision support tool. In Switzerland, different methodologies for the LCA of buildings have been developed. They are available in the technical books from the Swiss Society of Engineers and Architects (SIA - Schweizericher Ingenieur und Arkitektenverein) namely SIA 2031, SIA 2032, SIA 2040. Various sustainable building certification systems using LCA have also been developed (e.g. Minergie-Eco, Standard Nachhaltiges Bauen Schweiz {SNBS}) and are increasingly employed. Previous projects have contributed to the definition of LCA calculation rules for these certification systems (e.g., the Minergie-Eco project). LCA databases have also been developed. For example, the KBOB Ökobilanzdaten im Baubereich provides LCA values per kg or m^2 of material. Other databases (e.g. Bauteilkatalog, list of elements for the SIA 2032 default values) can provide aggregated values for predefined building elements (such as typical wall or ceiling constructions). Databases used in thermal simulation software like MaterialsDB contains materials and building elements linked to existing LCA databases for which the LCA can be tailored and adjusted to each building project needs. Finally, these methodologies and databases are translated in software to ease the calculations (e.g. Lesosai, Thermo, Eco-sai, Greg or more simplified tools like Excel spreadsheets).

The use of digital design approaches such as BIM has a great potential to facilitate the communication between the building stakeholders (e.g. architects, engineers, and clients). For Switzerland, SIA 2051 defines the basics for application of BIM. The level of detail of the available information increases from the early to the later design stages. Therefore, the definition of Level of Developments (LOD) has been introduced to describe the level of detail within a 3D model. These LOD range from LOD 100 - a simple volumetric representation of the cubature of the building - to LOD 500 describing the as-built situation. In early design stages, models with and LOD 100 to LOD 200 are typically used (BIMForum 2017). A range of different BIM tools and different data exchange formats exist today. This allows for efficient communication between different software depending on the type of assessment (e.g. gbXML to export the geometry of a building from a 3D modelling tool[1] to an energy calculation software, or IFC to export additional information attached to the geometry).

[1] A 3D modelling tool can be, but does not necessarily need to be a complete BIM tool.

The application of LCA in early design stages to improve the environmental performance of buildings has gained attention from both academia and industry to improve environmental performance of projects. With this report we present our research findings in the context of BIM LCA integration in early design phase, possibilities and tools to do so within the regulatory framework and the industry needs to transition from using LCA as a method for achieving certification compliance to using it as a method for design thinking and decision support. In the following sections of this report we present in detail chronologically the following:

- Current state of BIM, Building LCA, regulatory framework for design, industry practices at present, perception and needs;
- BIM LCA Integration Workflows – Challenges and possible workflows;
- Uncertainty in early design phases
- Visualisation as a method of design optimisation.

1.2. Purpose of the project

Up to now, the demand for LCA has mainly been driven by the certification systems like Minergie-Eco. The LCA calculations are generally conducted once the building design is well defined to fulfil the requirements of these labelling systems. However, early design LCA tool exist (e.g. the SIA 2040 Excel tool) that use default values for assessing the three domains “Construction”, “Operation”, and “Mobility” according to the SIA 2040 technical book. Similarly, some software packages such as the Wizard in the Lesosai software can serve both as modeller-assistant tool or as early design tool as it is based on a heating demand calculation based on a simplified model (predefined 3D volumes of the building using default construction elements). They facilitate the operational energy calculation (e.g. for the heating demand according to SIA 380/1) based on a limited number of parameters. These methods and tools usable in early design are useful but they format (static calculation in the Wizard for Lesosai or use of an Excel spreadsheet for the SIA 2040) lack of improved real time visualisation of design choices on the LCA results. Currently, they do not integrate real-time LCA calculations while changing the building shape or building element types.

The purpose of the project is to adapt current LCA calculation methods and databases in order to be able to use them with a 3D model of the building geometry and to perform LCA in early design stages to iteratively improve the design.

Next to the methodology and tools, the interpretation of results is most of the time limited to the compliance of the project’s results in terms of primary energy or GHG emissions with the limit or target values according to the available standard (SIA 2040) or certification systems (Minergie-Eco, SNBS). Further purpose of the project is to propose solutions for visualising the LCA results in the 3D design environment. Such visualisation of design alternatives’ improvement potential is highly relevant for architects and engineers and is currently missing.

1.3. Objectives

From a designer’s perspective, the workflow of the LCA must be fast, consistent in its methodology, but simple in its use. The objective is to provide an automated link between a 3D model of a building with material information and estimates on the technical systems and LCA calculation (including operational and embodied energy and other environmental indicators such as GHG emissions). The results can be directly visualized on the 3D model to facilitate interpretation and highlight the potential for improvement. Through changing the geometry, the materials or the type of technical systems, designers can easily generate and compare design options. This allows for an efficient iterative optimization in early design stages (Figure 1).

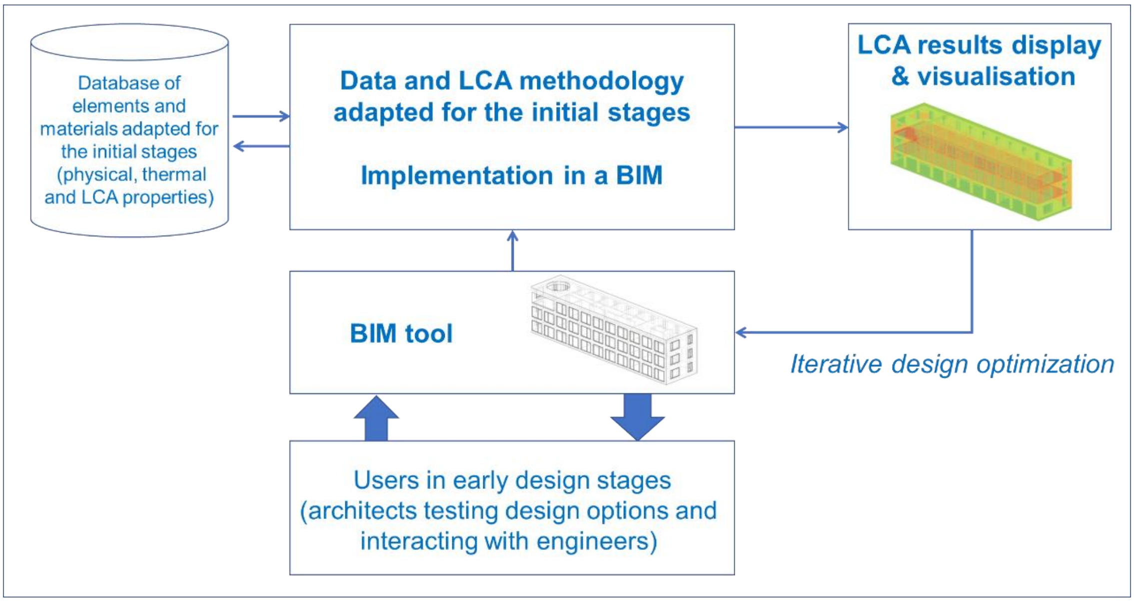


Figure 1: Workflow developed in the project

2 Methodology

This project proposes to first analyse (in WP1 – Chapter 3 of this report) the current situation to fully understand architects' and engineers' needs and the current limitations of the tools and data they use.

In the second work package (WP2 – Chapter 4 of this report), the existing methods and databases (e.g. Bauteilkatalog, eco-bau, Materials DB) are assessed and when possible, adapted to the requirements of a design-integrated BIM-LCA approach. In addition, an understanding is developed for BIM_LCA integration at different stages of design. For each stage of design possible workflows have been identified and explained. Two of these workflows for early design phases are specifically developed as part of this project.

In the third work package (WP3 – Chapter 5 of this report), the method for simplified BIM-based LCA is implemented based on the findings of WP2. First, it is defined which information from the 3D model will be extracted to allow for the holistic, simplified LCA including the embodied energy and environmental impacts from building elements and technical systems as well as the energy demand and resulting impacts of the use phase. Furthermore, the uncertainties introduced due to the simplified assessment in early design stages where certain materials have not yet been defined is addressed by using statistically derived benchmarks.

In addition to the calculation, methods for visualising the results are discussed in WP4 - Chapter 6 of this report and shared to the involved planners to get feedbacks on their appropriateness. To show and test the applicability, the method will be implemented in one 3D BIM design environment. Both the calculation and visualisation methods were tested at ETH in the Master of Integrated Building Systems studio project. Work package 5 – Chapter 8 of this report consists in the diffusion of the results for the research community (through the Swiss contribution to the international IEA-EBC Annex 72 project) and to the Swiss designers/planners (e.g. through the SIA and CRB channels for instance). The methodology is also visually represented in Figure 2 below.

WP1: 2 workshops (one in Zurich, 17th April 2019 and one in Lausanne, 20th May 2019) have been carried out to understand the current situation and expectation of the practice. A survey was separately sent to in relation to BIM LCA practices.

WP2: Consolidation of LCA database for BIM has been done. This was made in coordination between other similar projects in order to avoid overlap and better position the different projects. In particular, the work carried with Lignum, Eco-BAU and BFH on BIM object description and the work done by Intep on BIM database.

WP3: Work on uncertainty analysis and methods to minimise have been identified in the report.

WP4: Visualisation methods have been identified and a survey was conducted to understand preference of various user groups.

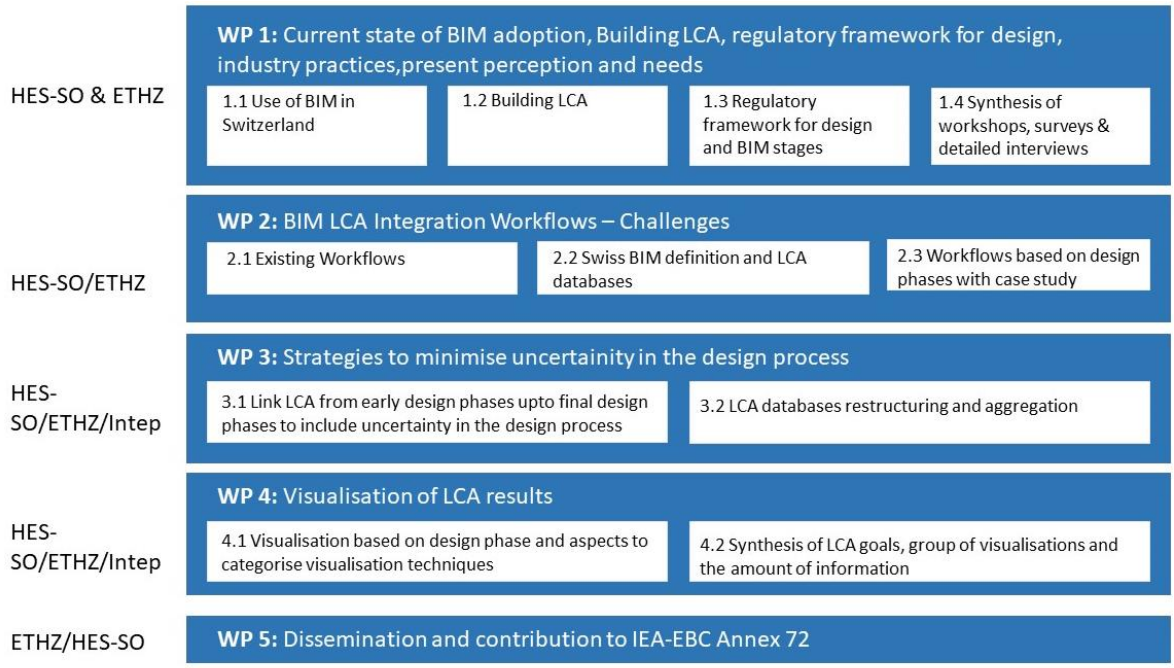


Figure 2: Research Methodology of the project

3 Current state of BIM, Building LCA, regulatory framework for design, industry practices at present perception and needs

This section presents the current situation in Switzerland regarding BIM, LCA & BIM LCA integration. The methodologies and tools commonly used as well as the working methods of the practitioners are detailed. Stakeholders such as architects and engineers were invited to workshops in order to fully understand their practices, their needs and the limitation of existing tools. The results of this survey were then compared to the existing literature and lead the foundation for further studies in this project.

3.1 Use of BIM in Switzerland

To encourage and standardise use of BIM in Switzerland, in the year 2017, SIA 2051 (Building Information Modelling (BIM) – Grundlagen zur Anwendung der BIM-Methode) practice-oriented working tool was introduced in consultation with various stakeholders. Its main aim is to create a basis for understanding the application of the BIM method, primarily aimed at architects, engineers and specialist planners, but also at clients and operators of buildings as well as contractors. It supports the introduction and implementation of the BIM method in the planning process and is based on the methodology of the project phases of SIA 112 (Modell Bauplanung Verständigungsnorm). The digital building models comprise of the physical and functional properties of a building or site. They are thus an information database and a reliable source for decisions during the entire life cycle, from strategic planning to deconstruction. As a common vocabulary, the standard therefore makes an important contribution to cross-disciplinary understanding and thus to the application of the BIM method in Switzerland. In support of the SIA 2051, document D 0270, provides a common understanding for the application of the BIM method in the form of a BIM Project Development Plan template and document D 0271 provides model-based quantity take-off according to eBKP-H (Elementbasierter Baukostenplan Hochbau eBKP-H).

3.1.1 Types of BIM

Building Information Modelling (BIM) is a working method that makes it possible for several people to work collaboratively on a project. The individual pieces of information are uploaded to the CDE (Common Data Environment) by everyone involved in the project, so that they can be viewed/edited by everyone. The decisive advantage of this method is that there are fewer collisions and errors in the planning of a building, which also reduces costs. Deadlines and budgets can therefore be adhered to easily and all simulations, that can stretch through the entire life cycle of the building, are also taken into account.

However, there are different types and variants of this working method. The two best known are Open BIM and Closed BIM.

Open BIM

Working in an Open BIM process is software-independent and can be used effortlessly with all individual specialist planning. The most commonly used file format is called IFC (Industry Foundation Class), which enables BIM data to be transferred regardless of the platform. The BCF (BIM Collaboration Format), in turn, is a file format that can be used to export collisions that were determined with the help of special coordination software. The various planners can thus import the BFC into their own system and get the errors displayed in the model.

The organisation behind this is buildingSMART, which is constantly developing the IFC. Due to the software-independent way of working, the open BIM variant offers the possibility of using the most suitable programme for each individual stakeholder. Different participants in a project, such as architects, building services planners or structural engineers, do not always use the same software for their models. The problem that can arise here is that programmes are not compatible with each other. Therefore, the neutral file format IFC is used. With the open BIM variant, these can be unified and merged into one model.

Closed BIM

In contrast to Open BIM, Closed BIM uses software products from a single manufacturer and proprietary formats for data exchange. This means that the entire planning team must use the same software so that the native interfaces can be used. This software must therefore be coordinated with all the individual specialist plans that belong to a building. One advantage of the closed BIM method is the use of the native format. With the use of the native format, all information is transferred in the best possible way, which is why there are no interface problems with the software solutions.

However, if a project is planned with external actors, the closed BIM variant offers little flexibility, which can make collaboration more difficult.

3.2 Building LCA

ISO 14040 and 14044 are standards which define the comprehensive generic methodology to perform the life cycle analysis of any object or process. At European level, EN 15978 is a building-oriented approach which provide guidelines on how to evaluate the environmental impacts of a building during its life cycle. It lists the main stages of the building life that should be taken into account. These are shown on figure 3.

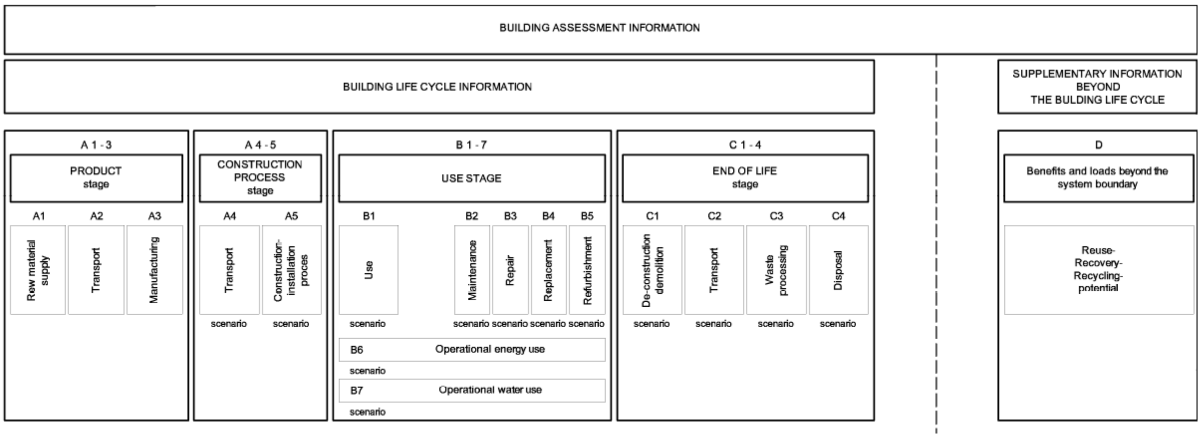


Figure 3: building life stages according to EN15978

In Switzerland, the SIA 2032 (Graue Energie von Gebäuden) technical book focuses on the primary energy evaluation of the construction materials and technical systems. The A1-3 and C1-4 stages as well as the replacement (B4) stage from EN 15978 are the only ones considered. Threshold values are given for various building categories in 2040 Technical bulletins.

In order to heavily reduce primary energy and greenhouse gasses emissions by 2050, the SIA 2040 (SIA-Effizienzpfad Energie) technical book widens the scope of the analysis and these two indicators (primary energy non-renewable and greenhouse gas emissions). The system boundaries are extended and in addition to materials, energy consumed during the use phase (B6) as well as occupant's mobility (outside the scope of EN 15798) are also considered. The materials part is based on SIA 2032 while energy consumption should be evaluated according to various SIA standards such as SIA 380/1(Heizwärmebedarf). User's mobility can be evaluated using the SIA 2039 (Mobilität – Energiebedarf inAbhängigkeit vom Gebäudestandort).

In addition to these technical books published by the SIA, various environmental standards have been established in the last 10 to 15 years. Minergie ECO is a label that promotes the thermal (the "Minergie" part) as well the environmental (the "ECO" part) performance of buildings. Before 2010, the ECO evaluation used to follow a qualitative approach. Since then, a quantitative evaluation of the materials primary energy and, since 2020, greenhouse gases emissions are also required.

NNBS 2.0 is a global durability label for Swiss buildings that takes into account environmental aspects as well as economical and societal ones. Among the criteria, greenhouse gases emissions and non-renewable primary energy must be contained within boundaries that are similar to the ones used by Minergie ECO. In addition a mobility calculation according to SIA 2039 is required. Another global standard pushed by the SGNI (Swiss Sustainable Building Council) is the DGNB, which originated in Germany. It is also a global sustainability concept that focuses on the same aspects as NNBS, plus site, technical and process quality. An LCA also has to be performed in order to evaluate various environmental indicators.

In order to certify a building, these labels usually require a level of information that are available only at the later stages of a project. For example, the temporary Minergie ECO certificate is issued only after the materialisation of the building is fully known. A comprehensive LCA of the construction elements is therefore required. The final certificate is issued after the construction is finished, where an inspector usually checks that the building is coherent with the documentation that was provided for the intermediate certificate. The same applies for NNBS. The composition of the construction elements as well as a precise calculation of the building energy needs according to the Swiss standards is required in order to answer the environmental criteria of the label. Although some choices are made earlier, none of these labels' certification processes requires any follow-up at level of details lower than LOD300 because the material choices are then undefined or under-defined.

Minergie ECO and NNBS require the use of the KBOB LCA recommendations list, which provided data for construction materials, energy vectors and transport means. All these databases use data from Ecoinvent 2.2+ database as well as on additional studies for particular datasets[1].

3.3 Current Industry Practices for BIM LCA

3.3.1 Current Modelling Practices for BIM LCA

This section introduces two methods in order to illustrate how most of the practitioners currently use BIM to perform an environmental evaluation of a building project.

Case 1: Insulated Models

As seen in chapter 3.2, the information needed for the building LCA is very close to the information relevant to the building energy calculation. Unlike the LCA, the energy calculation is a requirement for all new and renovation projects (SIA 380/1). Therefore, in situations where building planners are considering applying for an environmental label, the energy calculation model can be used and the missing information can be added. Calculation tools such as Lesosai, Thermo, Enerweb or Enercad, which originally focused on building energy calculation now also include some LCA functionalities.

Until 3D design tools became standard and the possibility to exchange information between tools appeared, the original method for engineers to create a model for thermal and then LCA calculation was to obtain the building characteristics from the architect and manually extract all necessary information from the 2D plans. Using this data, they build a new model, either in a specialised tool or even in a spreadsheet in order to perform the required calculations.

Although more and more building professionals try to use a more time efficient BIM process, this situation is still very common. Cases where documents are shared between stakeholders (architect, engineer) but without any direct transfer of digital information between software tools are characterized by SIA 2051 as "Little BIM" using "insulated models". This describes the overall situation in the above example. Instead of looking at the global picture, we can also focus on each tool independently. When doing so, there is another kind of BIM happening. Each tool uses its own digital model, which is unavailable to the outside world. What happens inside the energy/LCA tool is an example of "Closed BIM" using a "shared model" to perform different specialized tasks (energy and LCA calculation). The same could be said of design tools such as Revit, which can be used by different speciality trades (architects, heating/cooling engineers, etc.).

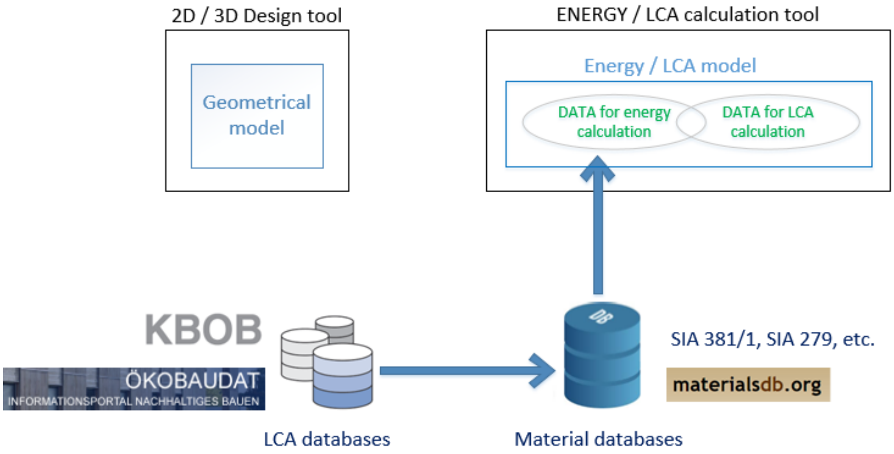


Figure 8: BIM example – semi insulated model

This case is illustrated in figure 8. A single model is used by the calculation tool, which contains data used for both LCA and energy calculation. Most of this data is shared for both calculations. For example, the area and material composition of each construction element of the thermal envelope needs to be known in order to evaluate the thermal losses. Materials thermal and physical properties usually come from a database, which can be integrated within the tool or external. The same parameters are used to assess the environmental impacts of these elements. To prevent the user from having to manually specify for each material which LCA data should be used in the calculation, the material database is usually directly linked to one or more LCA databases. Therefore, the relevant LCA data will automatically be selected when a material is chosen.

In this situation, a LCA might be conducted at various stages of the project, from early design to detailed specifications. However, the process is far from efficient. The creation of the energy/LCA model from scratch is time consuming, especially for large buildings. Modifications to the architectural project will impact the energetic and environmental performance of the building. In this situation, they are not automatically translated. Therefore, additional work will be required to keep both models up to date.

Case 2: Independent Models

The main drawback of the previous example was the lack impossibility of automatically retrieving information from the geometrical model. In order to correct this, software such as Lesosai explored the possibilities of communication with CAD tools. Since 2011, Lesosai users have been able to recover data from their architectural model through gbXML importation. gbXML is a BEM (Building Energy Management) format, well-structured and well-documented. Most 3D architectural tools allow exporting a project in the gbXML format:

- Revit: native support
- Sketchup: through the gModeller plugin
- Archicad: initially through the CADimage plugin but now also offers native support
- IES VE: native Support

This situation is illustrated in Figure 9. The energy/LCA model is semi-automatically created using the gbXML file exported from the 3D modelling tool. This approach saves a lot of time. All the construction elements (internal and external) and their dimensions are retrieved from the gbXML data. If their material composition was defined in the CAD tool, these along with their properties are also automatically created in Lesosai. The user is left with a few simple tasks such as assigning rooms to thermal zones or choosing construction models for the walls and floors if these have not been defined in the design tool. Important information such as shadings and thermal bridges (junctions of certain types of walls/floors/roofs) is also extracted from the 3D model and taken into account in the energy calculation.

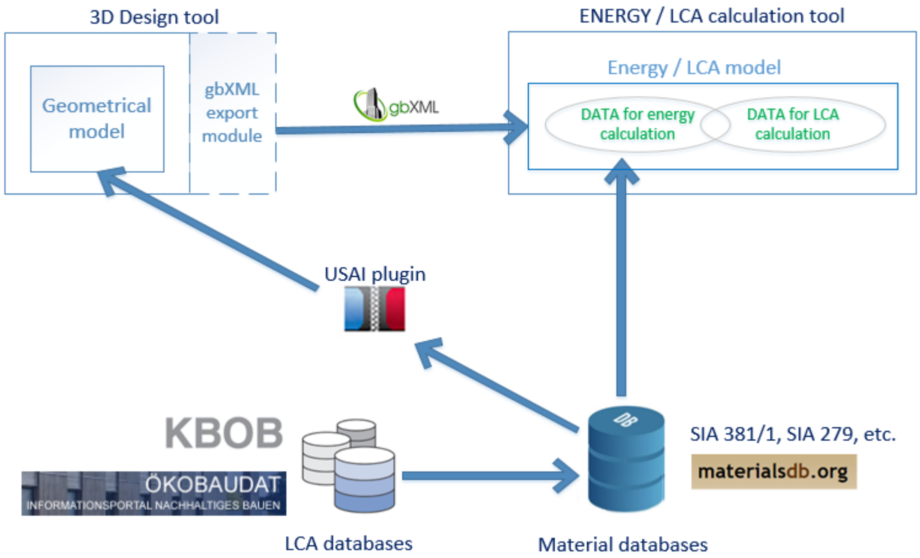


Figure 9: BIM example – independent model

gbXML being an open-source digital format that can be used by any tools, this situation can be described as a case of "Open BIM" using independent models.

Although this was an important step forward towards an efficient BIM process, a few problems still remain:

- The geometry required to perform an SIA 380/1 energy calculation is the same as the one used to perform an environmental assessment according to SIA 3032: the external dimensions of construction elements should be taken into account. The problem is that not all 3D modelling tools offer the same gbXML export possibilities. For example, the CADImage plugin for Archicad exports the external geometry, which is exactly what is needed for swiss calculations. However, Revit considers a planar geometry taken at the centre point of the walls and floors. There are currently no option available to change that. That means a gbXML exported with Revit will generate an inaccurate thermal or environmental assessment, given that the area of the thermal envelope and internal components will be slightly lower.

- The 3D model used to export gbXML must be of good quality. The drawing must be very precise, the construction elements junction needs to be perfect in order to avoid generate a clear gbXML model that can easily be imported.

- In some situations, there are still some bugs within the 3D modelling tools or the plugins that export gbXML. Sometimes the wrong element types are generated or there are some inconsistencies between the exported file and the gbXML standard definitions.

- Currently, gbXML only serves as a way to transfer the geometry of the building to the energy/lca tool. The gbXML model is not updated with new information or transferred back to the 3D design tool. This lack of "shared model" induces problems in the design process. If an architectural modification needs to be made in the design tool, the gbXML must be exported a second time. Lesosai offers a re-importation wizard which allows the user to reconfigure only the elements that have changed since the first importation. Although this helps in some cases, if too many design changes occurred it is sometimes easier to import the gbXML as a new project rather that a modification of an existing one. Whenever a construction element's ID or its situation changes within the design tool, it will require user input to take the change into account properly. Therefore, this is not ideal for early-design. It is mainly used when detailed information about the building is available.

3.3.2 Commonly used tools for LCA and/or energy modelling

The table below provides a comprehensive list of different tools used by practitioners to evaluate the environmental impacts of a building in Switzerland. They can be divided in two categories. The first one comprises early design tools, which provide quick and simplified estimate of building performance. The second one regroups late-design tools, which offer a comprehensive and precise evaluation of a building's environmental impacts and is mostly used for environmental labelling.

Tool	Type	Main objective	Phase	ECO Standards	Database
BauteilKatalog	Web-based	U-Value, LCA	Early design	Minergie ECO	KBOB
Eco-Sai	Desktop application	U-Value, LCA	Early-Late design	Minergie ECO, SNBS, SIA 2040	KBOB, Ökobaudat
Minergie Eco Calculation tool for early design	Excel-based	LCA	Early design	Minergie ECO	KBOB
SIA 2032	Excel-based	LCA	Early design		
Oneclick LCA	Web-based	LCA	Early-Late design		KBOB
Enercad	Desktop application	Thermal calculation	Late design	-	KBOB
Enerweb	Web-based	Thermal calculation	Late design	Minergie ECO	KBOB

Greg	Excel-based	LCA		Minergie ECO, SNBS	KBOB
Lesosai	Desktop application	Thermal calculation	Late design	Minergie ECO, SNBS, SIA 2040	KBOB, Ökobaudat
Sméo	Web-based	Sustainable development in building project management			
SNARC	Method	Sustainable development in architectural design			
Thermo	Desktop application	Thermal calculation	Late design	Minergie- Eco	KBOB

Amongst that second category, there are very few tools which were designed specifically for building LCA calculations. Unlike thermal calculation, LCA are not mandatory when designing a new building or renovating an existing one. It is only performed in the framework of environmental labels that require an evaluation of the primary energy or greehouse gasses emissions. These objectives are mainly sought for state-owned constructions or on a voluntary basis by private owners.

Therefore, due to the limited customer base, it is not financially viable to develop a tool specifically for LCA. Most of the current building LCA tools already existed before environmental regulations appeared and were modified in order to provide additional LCA functionalities. Inputs required for LCA are closely linked to the inputs required for a thermal calculation.

Tools such as Lesosai, Enercad or Enerweb allow to calculate the building energy needs according to standards such as SIA 380/1 (monthly calculation) or even SIA 2044 (hourly calculation) for some of them. On the other side, tools such as the Bauteilkatalog or Eco-sai are limited to calculating construction elements U-Values. The scope of the thermal model needs to be slightly enlarged to be able to use it for LCA calculation according to SIA 2032. In addition to the thermal envelope, internal floors and walls as well as elements from non-heated zones must be added.

When performing the ecobalance of a construction element, an LCA dataset and a quantity are required. These inputs are already available when performing the thermal losses calculation. Material mass is deduced from its density and its layer thickness. The LCA dataset can be automatically chosen if the local materials database is linked to a LCA database. As long as construction elements are considered, the only additional piece of information required is the materials’ lifespan.

Using existing inputs for technical systems such as heat production and distribution or ventilation is not as straightforward. These systems only exist in the thermal model for hourly calculations such as SIA 2044 or when technical losses are taken into account (SIA 384/3 for example). The way they are described in for thermal and LCA are quite different and therefore, linking both calculation requires special attention.

3.4 Regulatory framework for architectural design in Switzerland

In the regulation specifying the fees for architects and engineers, LCA is not explicitly mentioned. It is part of the planning process for buildings that shall comply with Minergie Eco, SNBS or SIA 2040. However, first developments exist (e.g. the SIA 2040 Excel tool) that use default values for assessing the three domains “Construction”, “Operation”, and “Mobility” according to the SIA 2040 technical book. Similarly, software tools (e.g., Lesosai) provide a heating demand calculation based on a simplified model (predefined 3D volumes of the building using default construction elements). They facilitate the operational energy calculation (e.g. for the heating demand according to SIA 380/1) based on a limited number of parameters. For submission to a certification, LCA practitioners are often hired externally by project teams due to lack of in-house expertise. These methods are not directed towards iterative design improvements but are geared towards reporting of statistics for certification and hence may not fully match the designers’ needs.

To understand the decision points in the design process, it is therefore imperative to understand critical decision points in early design phases (environmental performance target definition and assessment and competition design stage) as demonstrated in the figure3 below. The functionality required by LCA also determines the information required from BIM. The goals of the study and the structuring of information in the model, follow the cost structure set up for development of model in the Swiss context and thus form the basis for LCA calculations as well.

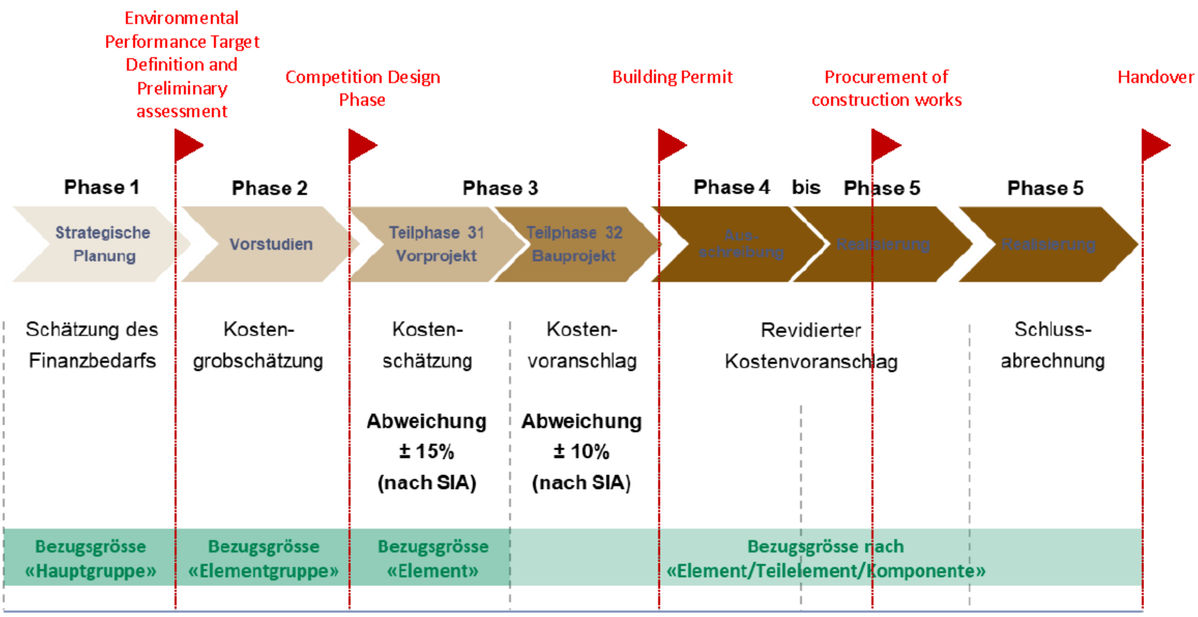


Figure 4: Relation between building design phases based on SIA 112, level of details required in model for costing and milestone stages of a project (base image source: Bauen Digital Schweiz, 2018 presentation)

3.5 Findings from workshops, surveys and detailed interview

3.5.1 Workshops with BIM & LCA practitioners

As part of this project, we conducted two workshops in Switzerland in the year 2019. Two different focus groups were engaged in a structured workshop each gathered 20-25 participants.

- Zurich Workshop was conducted on the 17th April 2019. Most experts were more LCA experts than BIM practitioners. It allowed to get a good understanding of the way early design LCA is carried in practice.
- Lausanne workshop was conducted in 20th May 2019. Most experts were BIM practitioners concerned about operational energy in buildings. They used BIM from the very early design, but do not carry out LCA calculations. LCA is only used for operation energy calculations when certification (Minergie) is needed. This is done in later design stages of design.

Workflows vary between different user groups. The practitioners can be largely divided into two of the following segments:

- Those who make the architectural model (big architectural firms, independent architects
- Those who perform the thermal or calculations (architects, engineers in big firms, independent engineers, LCA experts).
-

Based on the above defined user groups, different level of information is required in the building model for different objectives such as ecobalance calculations and so on. The project recognises that not one single solution of workflow can be made applicable and hence while finding solutions for current problems or shortcomings, we aim to propose method for BIM LCA that aids decision making in the early design process.

General findings from the workshops exhibited that ArchiCAD, Revit and others are the most commonly used tools amongst workshop participants. All such tools can be directly used from the early design. A common practice is to have a so-called "pen phase" when all concepts are decided, but no digital tools are used. This is followed by the BIM development phase where Revit is the classic tool used. However LCA and energy calculation are very rarely carried in Revit. They are usually done at the end for certification purpose. The current workflow for carrying out LCA calculations is either directly importing bills of quantities (BoQs) in a dedicated LCA software, where building components are linked to LCA profiles or parameters are imported in an open exchange format like Industry Foundation Class (IFC) format. For projects aiming at Minergie ECO or SNBS, preference is to use the tools Lesosai or Thermo. Visualisation and analysis of results are dependent on the capabilities of the LCA software used. While the former is most commonly used method, it does not allow for iterative process of design. The latter workflow could support an iterative design process however IFC is not an editable format, therefore any iteration may have to be performed in native BIM format in which the model was prepared.

The detailed workshop materials of both the workshops can be found in Annex II and III of this report.

3.5.2 Survey Findings

An independent survey was conducted on practices in terms of the BIM approach and the calculation of the eco-assessment (LCA) of buildings in French-speaking Switzerland, for which the research team had received 16 responses. The respondents included architects, building physics and energy engineers, project heads and managers in sustainable construction, professors and engineers from various building design and construction fields and BIM coordinators.

The survey was conducted in the format of a google form in three parts:

i) respondent information and expertise,
ii) stock taking of respondent's practice of CAD building modelling tools that can be used in a BIM approach and current difficulties and finally
iii) stock taking of respondent's practice of building eco-balance calculations that they perform, for example, following a heat balance, or a sizing of technical installations.

If the respondent's do not yet carry out an ecobalance calculation but carry out, for example, thermal calculations, and/or construction costs or others, they were given a choice to indicate them in the last 3 sections of the survey. Detailed responses of the survey respondents can be separately found in Annex I of this report.

The survey highlighted that depending on the size of the company (big or small), the BIM process can vary significantly. For all processes, the reference model is usually the architectural model developed by the architects of the project. Based on the survey, for the development of an architectural model, most commonly used tools are ArchiCAD, Revit, AutoCAD and Sketchup. A common model that everybody use and update with its own properties or results is currently a utopia. The current situation is that there are separate models for architecture, CVC, etc and the BIM manager is in charge making sure the different models are updated when a change occurs.

Current difficulties in BIM approach from the survey are as follows:

- **Data recognition from one software to another... Difficulty in implementing BIM in the upstream phases, on non-detailed projects.**
- **"gbXML tool (Lesosai): loss of information between .ifc to .gbXML conversion; importing a complex gbXML model is time consuming and sometimes impossible**
- **Lack of interoperability**
- **a basic problem is that, in practice, one must often make an estimate very early in the project in order to make choices (whose stakes are often linked to other parameters such as safety, comfort, financing, etc.), when one has only rare, vague or conditional information (cf. This is inherent in any construction project, but it can be very uncomfortable and time-consuming. The information is obtained when the choices are not necessarily feasible.**
- **difference between architectural drawing and specific needs for calculation**

Respondents also expressed the need exchange data in an open file format such as IFC ("Open BIM" according to SIA 2051), need for a dynamic method for this project.

3.5.3 Collaboration with IEA Annex 72 and findings relevant to Switzerland

As part of IEA Annex 72 a global survey was also conducted with the aim to investigate the level of awareness and acceptance of environmental performance assessment and LCA of buildings, the use of related information sources and tools as well as the application of Building Information Modelling (BIM) in connection to LCA. The survey highlighted that primary drivers for architects and civil engineers to undertake LCA were the client demand. The top three barriers in the DACH (Germany, Austria & Switzerland) were client influence, lack of in-house expertise to perform LCA and optimise the design process and considerable time effort required[2]. The survey also aimed at understanding trends in application of BIM and LCA in design of buildings. At present only 9% of respondents from Europe reported to currently apply BIM for integrating LCA data.

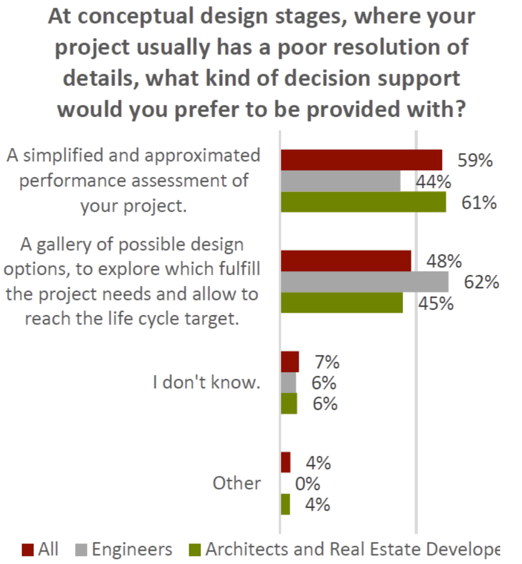


Figure 5: Comparison of exploration and assessment approaches, out of 256 answers

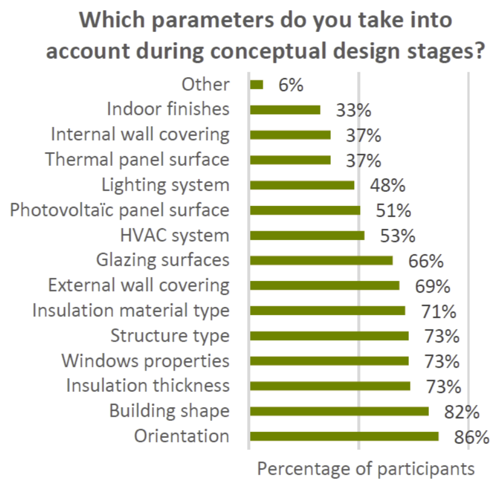


Figure 6: Consideration of design parameters at conceptual design stages, out of 263 answers

(Source: Data-driven method for low-carbon building design at early stages, Jusselme et al.)

In another extensive survey conducted by Jusselme et. al (figure 4 & 4) 59% of the respondents agreed to use simplified performance assessment to handle the low resolution of details of these stages. Still, the ability to explore a gallery of possible design options is acclaimed by 48% of them[3].

The synthesis from the workshops and surveys conducted thus far clearly highlight that there is a need for decision support at the early stages of design. We overlapped the milestone stages in design process to identify the type of decision support required as the projects progress. **At the early stages, designers are keen to understand the environmental impacts of design choices with high level inputs to the design options. It is imperative to note that at the early design stages the designers must also include factors such as materials, daylighting, thermal comfort, energy consumption, cost, building systems and therefore they require a multi criteria decision approach to iteratively improve performance of the design.**

3.5.4 Detailed Interview findings

From the workshop participants in the year 2019, we then conducted a detailed interview (in the year 2020) with one participant selected on the basis of knowledge and understanding of the BIM LCA topic. There were two main points of discussion to gain further insights into the current trends and practices in the industry:

> 1. Existing workflows in the design process adopted by the participant: various aspects such as (Application Programming Interface) API competencies, interdisciplinary collaboration and coordination, interoperability, database structuring, client requirements, relation to design process laid out by SIA 112, present use of BIM and LCA were discussed in detail.
>
> 2. Proposed workflows in relation to design phases: Various workflows were discussed based on their relation to design phases and BIM Model development. The interview participant expressed the need for a super early design phase BIM LCA workflow, often referred to as volumetric (form finding) phase or pen-phase where various design options are considered on parameters such as compactness of building form. The participant also expressed that expertise for analysis of report is often needed order to propose optimisation strategies.

The analysis of BIM adoption, LCA standards along with workshops, survey information from Annex 72 and the detailed interview had collectively provided the current state of the industry adoption. **While there is a strong aspiration to adopt BIM, BIM LCA and use the digital tools iteratively to improve whole life cycle of a building, there exists gaps in the workflows, available tools, interoperability between available tools and knowledge of individuals putting the tools to use.** The next chapter in this report provides possibilities to close the gaps in the findings of the current situation.

4 BIM LCA Integration Workflows

4.1 Existing Workflows

There has been significant research done in the past regarding BIM LCA integration in consultation with the industry. The intention to use digital tools is the identification of environmental hotspots and their mitigation during the design process. BIM is forecast as the next generation of information technology (IT) to replace drawing production-focused computer aided drafting (CAD) and involves the processes of generating, storing, managing, exchanging and sharing of building information in an interoperable and reusable way. Such information, referred to as n-dimensional (nD), includes the time, cost, accessibility, sustainability, maintainability, acoustic, thermal requirements etc[4]. BIM therefore serves as a repository of both graphical and non-graphical information allowing extraction of quantities, geometry, material properties for building, building services, facilities and infrastructure.

Although for performing cost, operational energy performance, LCA analysis various other tools are available which use the parameters specified in the BIM. BIM can reduce the time-consuming nature of the LCA for collecting data as it allows for performing quick quantity take-offs[5]. This flow of information can be bidirectional and real time for comparison of design alternatives. Anton and Diaz presented two possible proposals for the integration of BIM and LCA. First, direct access to BIM model information in order to calculate the environmental performances of buildings (Closed BIM). Second, use of the Industry Foundation Classes (IFC) data sharing format to extract information from the BIM model (Open BIM)[6].

Wastiels and Decuypere presented a comprehensive classification of BIM-LCA into five categories[7]. Based on that, a systematic literature review (SLR) was published by Obrecht, Tajda Portč et al[8]. The study investigates how different researches process the BIM-LCA workflow and how much manual work is needed. The need for more manual work is a result of poor interoperability and thus makes the process of iterative design time consuming and lead to inaccuracies. Contrarily an automated link between LCA and BIM simplifies the assessment of embodied impacts.

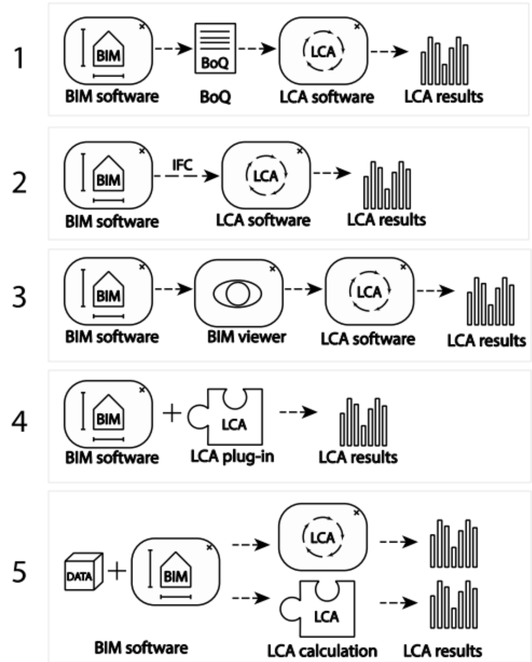
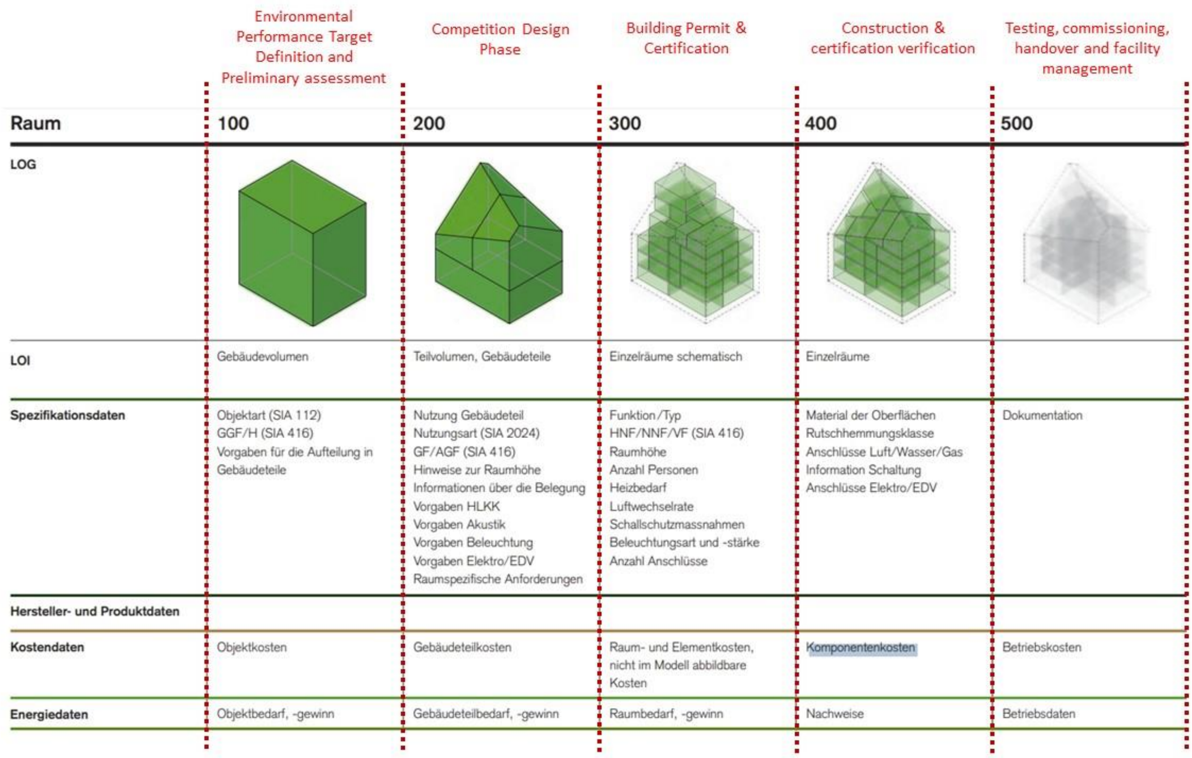


Figure 7: BIM-LCA integration types adapted from Wastiels and Decuypere. Source:[8]

4.2 Swiss BIM definition and LCA databases

In the context of Switzerland, Swiss BIM LOIN-Definition (LOD) Verständigungis[9] is a comprehensive document that aims is to make the different levels of geometry and information understandable and to create a reference to practice. For the purpose of comparison, the component groups in the illustrations are supplemented by the designation of the standardised breakdowns of the construction cost plan for building construction eBKP-H of the CRB (Swiss Central Office for Construction Rationalisation).



	Environmental Performance Target Definition and Preliminary assessment	Competition Design Phase	Building Permit & Certification	Construction & certification verification	Testing, commissioning, handover and facility management
Raum	100	200	300	400	500
LOG					
LOI	Gebäudevolumen	Teilvolumen, Gebäudeteile	Einzelräume schematisch	Einzelräume	
Spezifikationsdaten	Objektart (SIA 112) GGF/H (SIA 416) Vorgaben für die Aufteilung in Gebäudeteile	Nutzung Gebäudeteil Nutzungsart (SIA 2024) GF/AGF (SIA 416) Hinweise zur Raumhöhe Informationen über die Belegung Vorgaben HLKK Vorgaben Akustik Vorgaben Beleuchtung Vorgaben Elektro/EDV Raumspezifische Anforderungen	Funktion/Typ HNF/NNF/VF (SIA 416) Raumhöhe Anzahl Personen Heizbedarf Luftwechselrate Schallschutzmassnahmen Beleuchtungsart und -stärke Anzahl Anschlüsse	Material der Oberflächen Rutschhemmungsklasse Anschlüsse Luft/Wasser/Gas Information Schaltung Anschlüsse Elektro/EDV	Dokumentation
Hersteller- und Produktdaten					
Kostendaten	Objektkosten	Gebäudeteilkosten	Raum- und Elementkosten, nicht im Modell abbildbare Kosten	Komponentenkosten	Betriebskosten
Energiedaten	Objektbedarf, -gewinn	Gebäudeteilbedarf, -gewinn	Raumbedarf, -gewinn	Nachweise	Betriebsdaten

Figure 10: Image from Bauen Digital Schweiz, depicting level of geometry and level of information progressively from LOD 100 to 500. Source: [Bauen Digital Schweiz. 2018. "Swiss BIM LOIN-Definition (LOD) Verständigung." https://bauendigital.ch/assets/Downloads/de/180222-BdCH-SwissBIM-LOIN-Verstaendigung-web.pdf.]

The marks in red on Fig 10 describes phases of design each requiring decision support with a different level of geometry and information available. Hereafter we have developed two possible workflows that aid decision support required in early stages and documented three other workflows corresponding to the detailed design phases developed externally to this research. As more details are added in the form of parameters BIM reaches higher level of details. A similar logic can be followed for database structuring and aggregation, in early stages an average impact value per sqm to specific impacts for design option as the design progresses. In the example below (Fig 11), the Bauteilkatalog for the early phase and KBOB for detailed phases were selected.

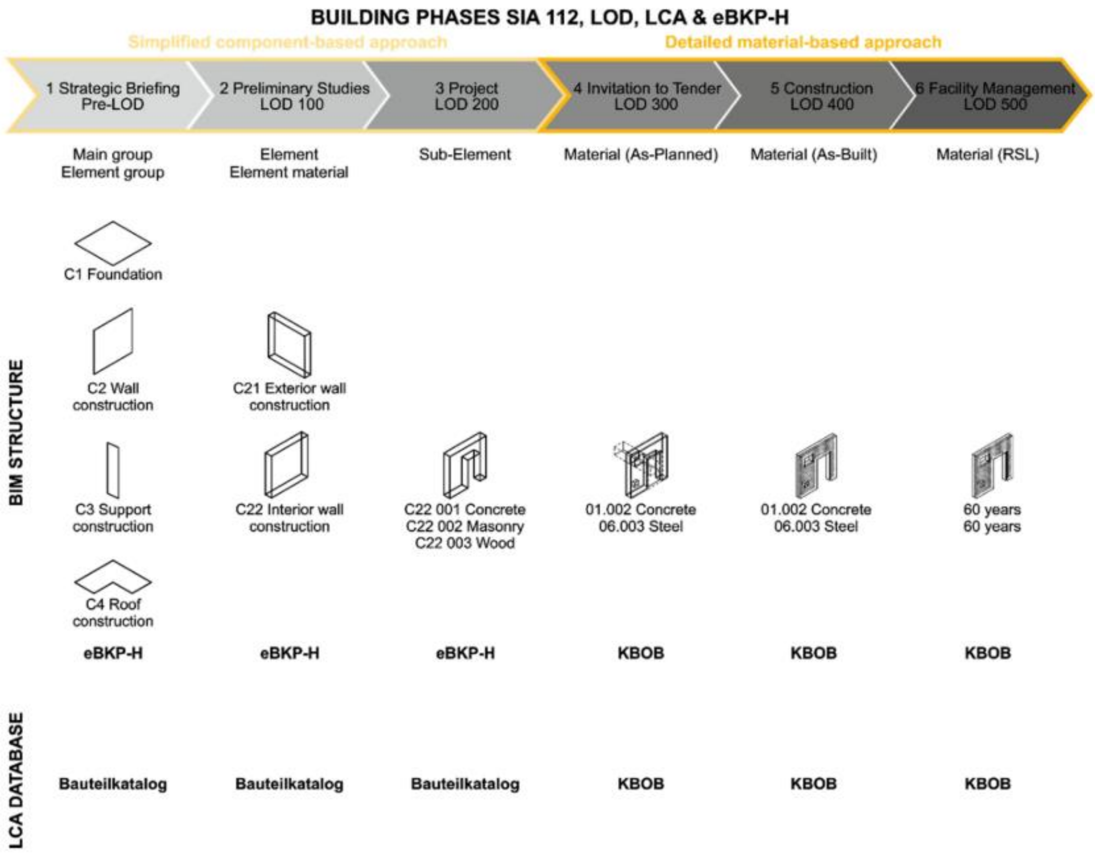


Figure 11: Overview of different BIM data structure and LCA database in a different project phase. Source: [10]

4.3 Workflows based on Design Phases

In this chapter we present four different BIM LCA workflows that support each phase of design process and requires different level of geometry and information required in the building model. **The first two workflows (4.3.1 and 4.3.2) are specific to the early design process have been developed at ETH as part of this research project. The other two workflows presented are developed externally outside the scope of this project but are relevant to present here as these represent possible workflows in the more advanced stages of design.**

4.3.1 Environmental Performance Target Definition & Preliminary Assessment Phase

This specific workflow addresses the super early design phase (LOD 100) or form finding phase where based on very few design parameters the client and architects would like to understand the feasibility of the project and decide on one possible volumetric form. Such a method has been used for volumetric studies previously by Hollberg et.al[11]. Using generative design feature in BIM, range for parameters such as the length, width, height, wall to window ratio, u values of roof, external walls, windows and ground slab are given to generate design options (see figure 12). The parameters for the study impact the overall lifecycle performance of the project.

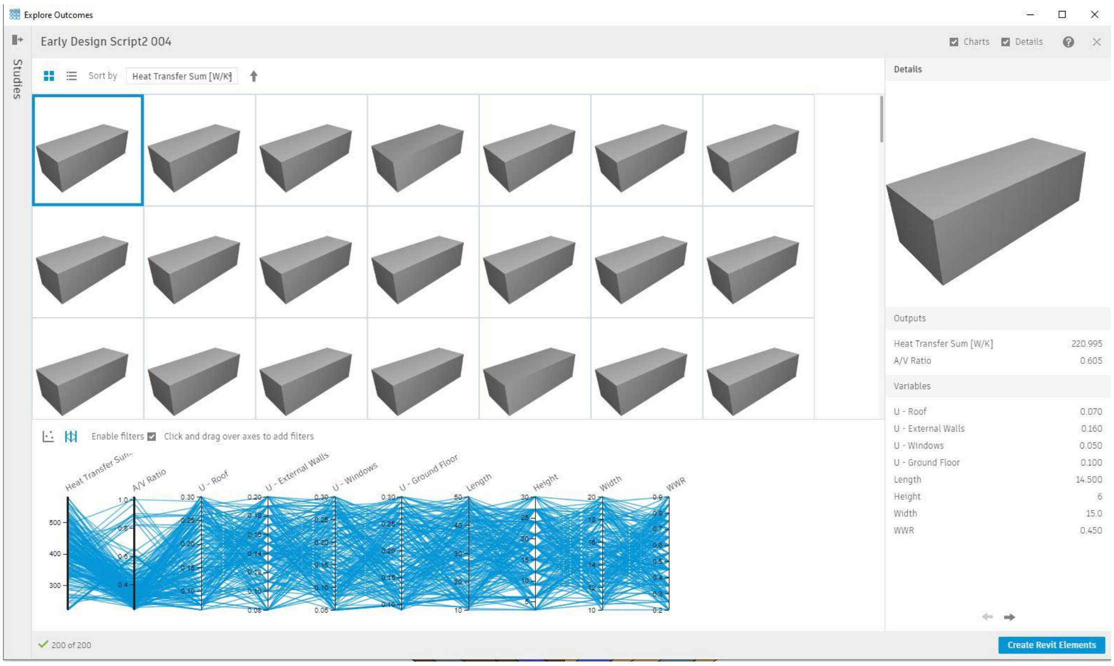


Figure 12: Various building volumetric studies using algorithms and range of parameters specified by the designer. Source: Internal ETH

Given the parameters above, the generative design tool produced 200 different options. Further parameters like maximum compactness and minimal heat transfer coefficient were then set in the generative design script to find the optimal volumetric designs for the building. A/V Ratio (Surface/Volume) and Building Envelope Heat Flow as depicted below (see fig 13)

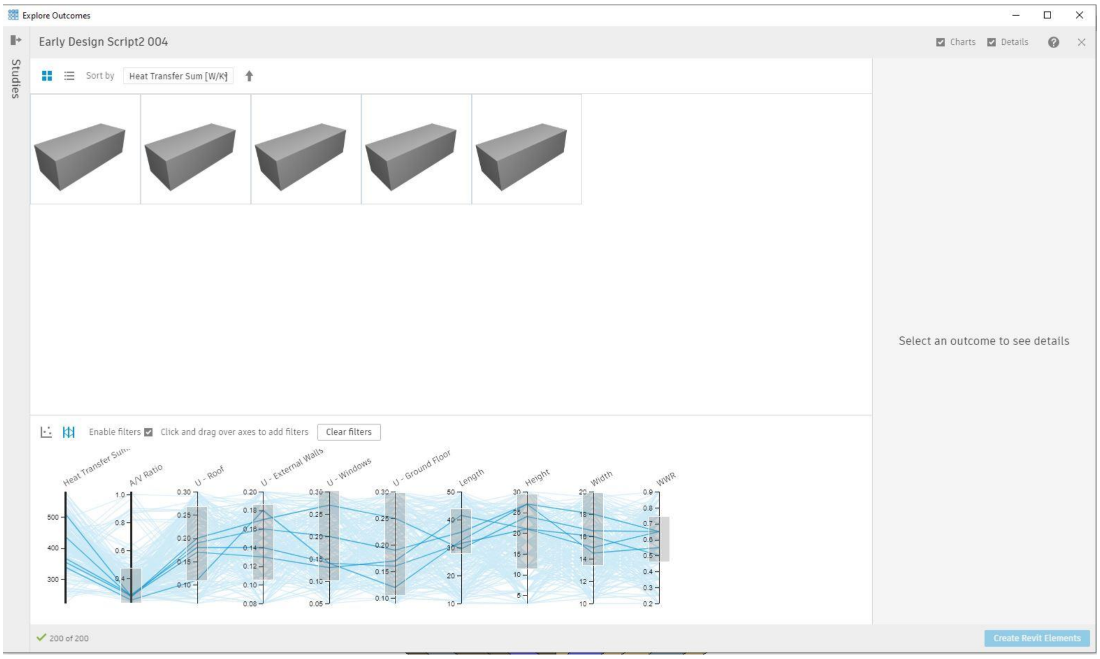


Figure 13: Optimum options based on modified range of parameters. Source: Internal ETH

Each option can then be analysed for the environmental impact by linking with an aggregated database which provides average values of impact for each of the 5 options above (see fig 14). The workflow is exemplified by a case study. The building is modelled in Revit using surfaces only. Dynamo is used for generative design scripting. For LCA and thermal modelling a plugin called Rhino inside Revit allows for Revit model to be used in Grasshopper environment. On the building level, only the four inputs height, use, energy standard and main material are needed (see Figure 15). This provides all necessary information for the calculation of the embodied impact, but also the operational impact. For example, if the energy standard PassivHaus is selected, the tool filters the exterior walls that match the u-value of 0.15 or below. The u-value is mostly influenced by the thickness of the insulation layers in this case. For an ETICS system on a masonry wall, this would mean 24 cm of EPS insulation, for example. The database used to filter and give out under-specified design options is based on the Swiss Bauteilkatalog using most typical building components in Switzerland. Based on the filtering, the average values of all construction that fulfil this criterion will be retrieved from the database. The approach to aggregate database in order to provide average impacts has also been demonstrated in the publication as part of this project by Hollberg et.al[12].

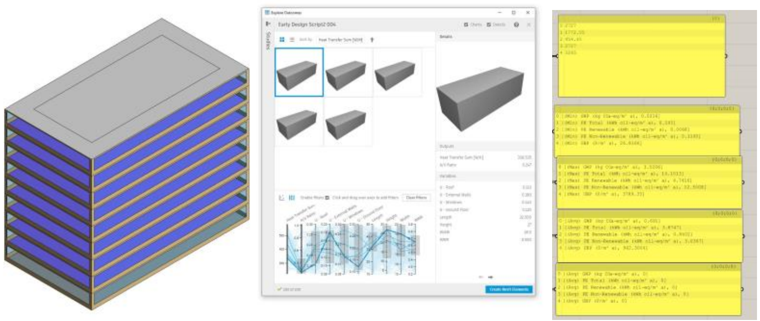


Figure 14: Environmental Impact of each volumetric option in real time. Source: Internal ETH

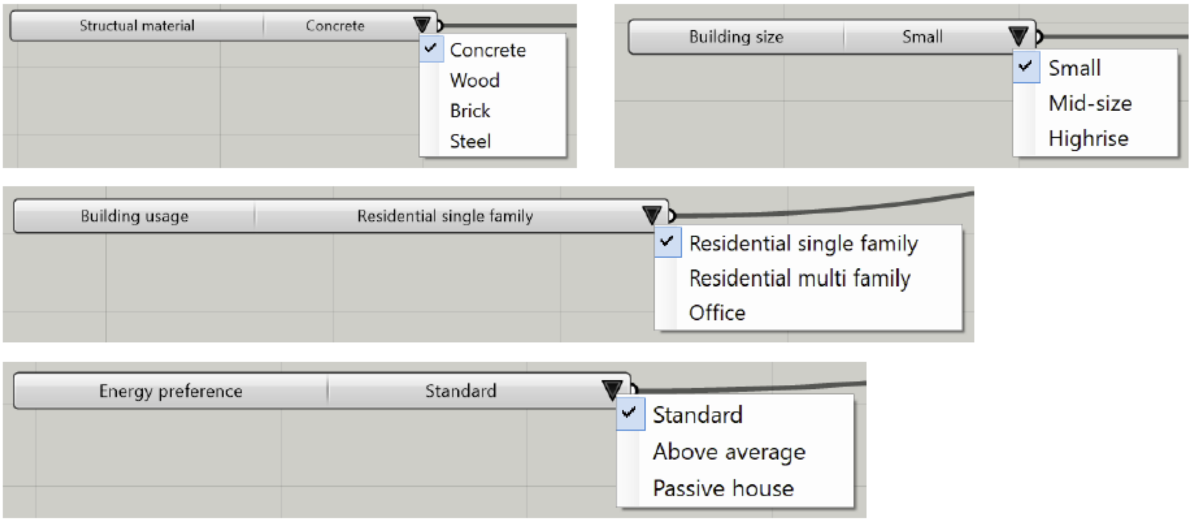


Figure 15: Simplified input on building level in Bombyx V2. Source: Internal ETH

This approach provides high degree of design freedom and choices to the designers, yet providing aggregated impact of the volumes selected. The workflow is completely automated and least time consuming as opposed to traditional methods of drawings various design options and calculating environmental impact individually. The working files of this script have been attached in this report as Annex IV.

Key findings and learnings from this method

1. Definition of LODs of BIM models for design phases allows for standardisation of the modelling and data input requirements, thus easing one of the interoperability issues between BIM & LCA platforms.

2) To solve the issue of information shortage on building materials in early building design stages especially in low LODS such as LOD 100 and LOD 200 **evaluating the range of LCA results instead of exact value in early design stages is recommended in this approach**. The range of LCA results is then balanced with understanding of optimal building form, compactness ratio and minimum heat transfer coefficient.

3) The uncertainty in the range of results is handled restructuring and aggregating of database as discussed further in this report in section 5.2.

4) Further improvements in the range of results can be done by using vagueness percentage as described in the section 5.1 of this report.

4.3.2. Competition Design Phase

In this phase a Parametric LCA (PLCA) approach is combining the principles of parametric design with a simplified LCA method can be applied. In this workflow, a shoe box model based on Sketch up or Rhino (LOD 100 or LOD 200) can be connected to the KBOB database.

Changes in geometry and materiality can be checked for sustainability during the design process. Designers are able to provide evidence based design decision at this phase.

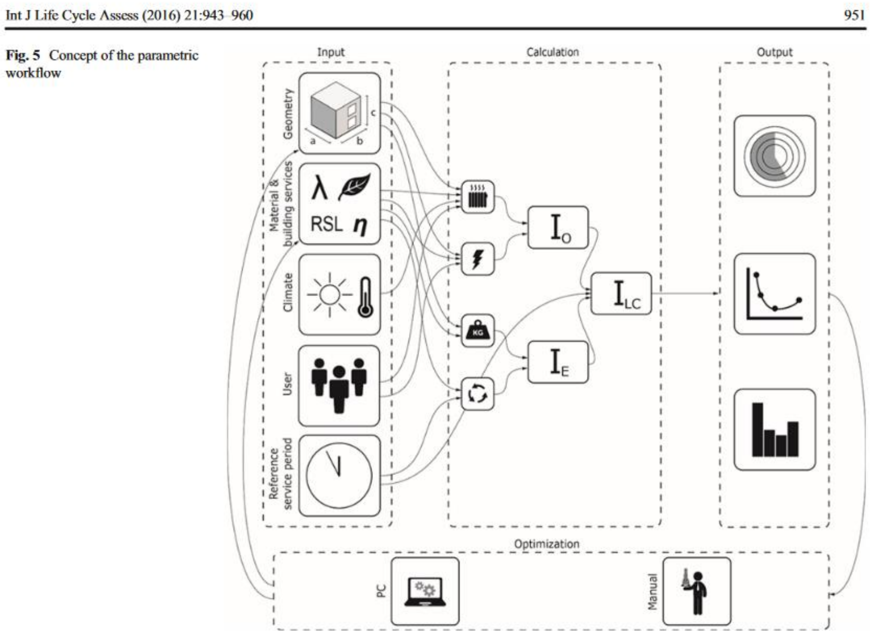


Figure 16: Concept of parametric workflow. Source: [13]

The workflow is exemplified by a case study in the publication under this project. The building is modelled in Rhino or Revit using surfaces only. The surfaces are assigned to predefined layers corresponding with the eleven elements (see Figure 16). The predefined Grasshopper script reads in the area and orientation of these surfaces to generate a thermal model and calculate the bill of quantities. In the Grasshopper viewport, the specification of the materials and the technical system is done.

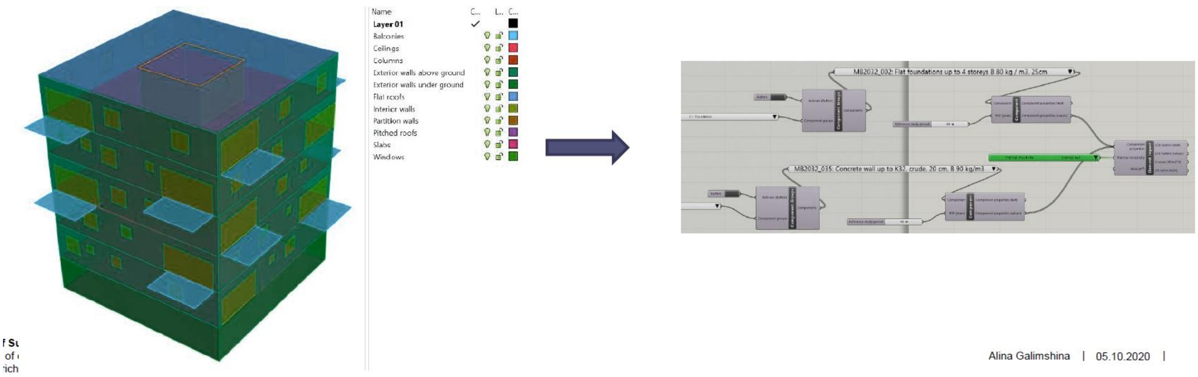


Figure 17: surfaces assigned to predefined layers and connected with grasshopper script. Source: Internal ETH

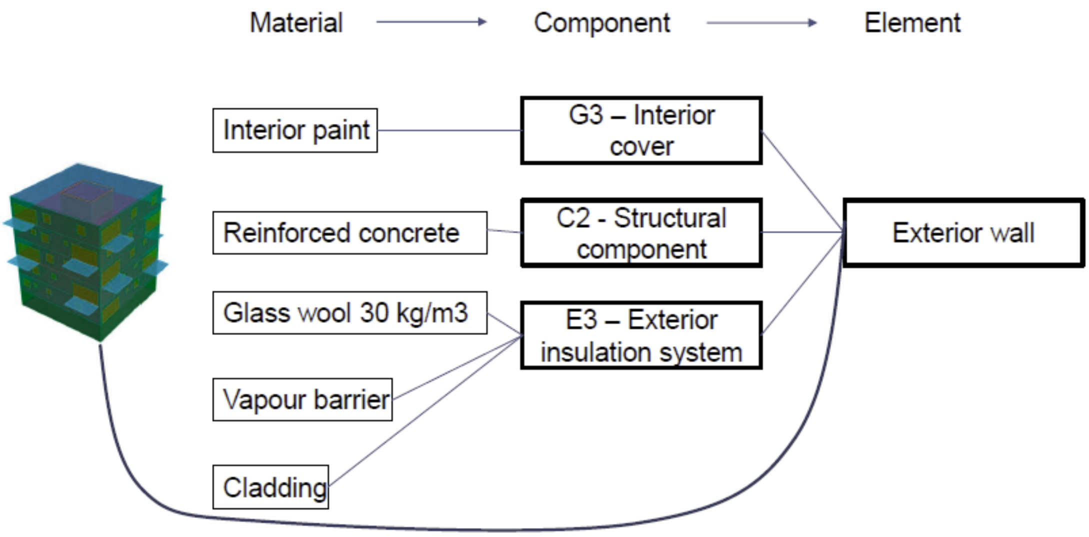


Figure 18: Example of exterior wall to explain structuring of the database for Bombyx v1. Source: Internal ETH

The workflow is completely automated and least time consuming. Users are able to identify high impact areas in design and optimise the design by both changing the envelope and by replacing with low carbon material selection from the database.

This approach of BIM LCA integration was then applied by Master of Integrated Building Systems students to optimise the whole life carbon for their studio project which is a multi-family house project in Obersiggenthal, Baden originally designed by JOM Architects.

Case study below of a design proposal conducted calculations for the embodied impact entirely through Bombyx, splitting our 3D model into the respective building elements (eg. Exterior walls above ground, Interior walls, Ceilings, etc.) and assigning materials to each element that we defined using the Bombyx material components per layer, each with the appropriate thickness (eg. for the Interior–not partition–walls: Light-clay straw plaster 0.02m, Poured earth 0.15m, Light-clay straw plaster 0.02m). The embodied impact calculated through Bombyx results from production and the end of life of the building (modules A1-A3, C3 and C4) for a reference study period we set in Switzerland for 60 years and reference service life of the component as is defined in SIA 2032. Bombyx coupled the surfaces the students provided from Rhino/Revit to Grasshopper with the density and specific embodied impact factor of each material from the KBOB database Ökobilanzdaten im Baubereich, multiplied by the thickness of the material layer.

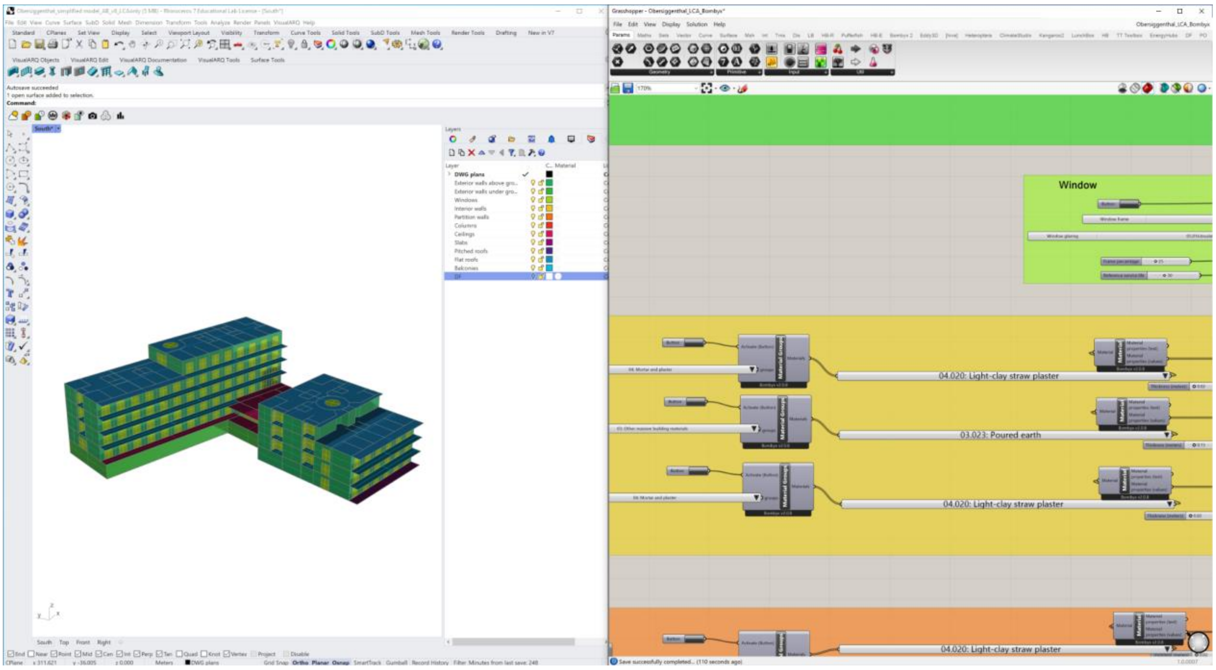


Figure 19: building geometry structured in building elements' layers (left) and Bombyx construction material layer definitions (right). Source: Internal ETH

Results of the embodied CO_2 impact were analysed from the construction materials of the different building elements. This allowed for optimisation of various building elements to low carbon alternative materials in early stages of design.

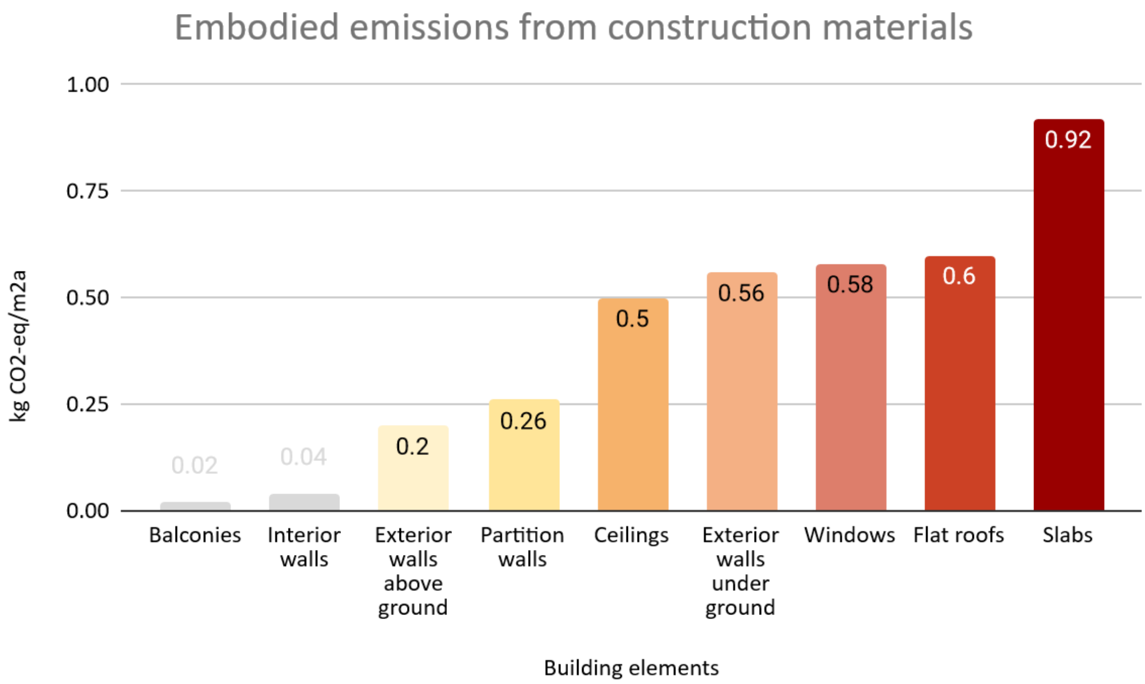


Figure 20: Embodied emissions from construction materials per building element Source: Internal ETH

Key findings and learnings from this method

1. The database used to filter and give out under-specified design options is based on the Swiss Bauteil Katalog and the EcoKomposit database provided by project partner Intep using most typical building components in Switzerland. This will be sufficient for state-of-the-art constructions, but does not allow to integrate novel, innovative solutions into the assessment. As such, the building component catalogue and the structured database should be extended continuously.

2) Further properties should be integrated into the material catalogue, allowing to connect further analysis methods to the under-specified workflow, e.g. daylight or Life Cycle Costing (LCC)

3) Visualisation techniques as discussed in section 6 of this report can be developed based on design goals of specific projects

4) Further improvements can be done to the script for analysing embodied and operational impact can be done by integrating the changing Swiss energy mix and climate change model to review if the options designed are robust for the foreseeable future with change in climate.

4.3.3 Building Permit and Certification

At advanced stages in design LOD 300 onwards, more details are required in the model in order to generate reports specifically for the purpose of certification submission. The Institute for Sustainability and Energy in Buildings (INEB) of the FHNW is developing a greenBIM program which caters to this stage by providing an integrated database with components from Components Catalog.ch, Lignum, SIA 2032 and KBOB leaflet. It is a plugin in Revit or ArchiCAD which can be used to calculate gray energy according to SIA data sheet 2032 gray energy, as well as according to standards, e.g. Minergie-ECO and SNBS.

A menu to describe the building typology, heated floor area, building technology prompts users to add data based on the design (see fig 14). Upon selection of suitable component, it can be assigned to an element from the building model and calculations are performed for the gray energy and greenhouse gas emissions based on the quantity of element used (see fig 15). The calculation is then compared with two benchmarks - one at the element level, which provides information about the element itself, and one at the building level, which takes the entire building into account. The building benchmark follows the dynamic requirements of Minergie-ECO, based on the building type, the renewable technologies built into it and its floor space. The model itself and the various building elements are then colored accordingly.

While this approach does provide guidance in understanding of impacts from various elements in building, it requires for design and materiality to have both evolved up to LOD 200 or more. Thus, the optimisation to design with such an approach is often addressed by changing into alternate building elements with low impact or by choosing building systems with higher systemic efficiency.

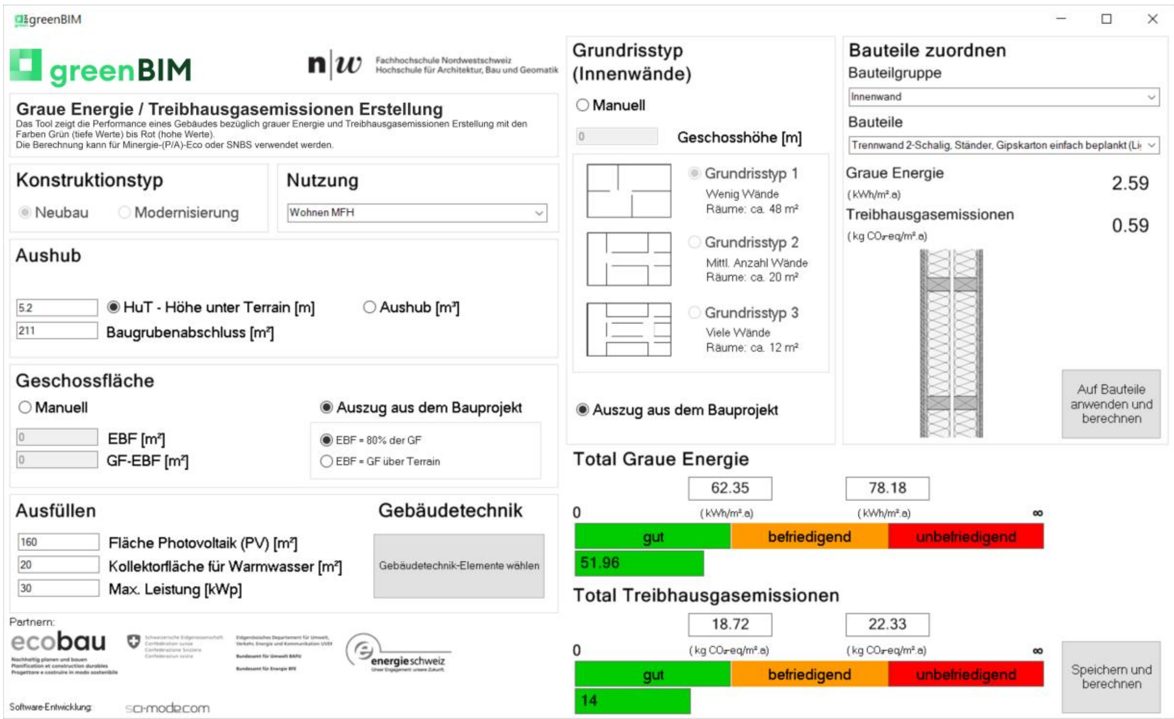


Figure 14: Cockpit of the greenBIM tool (Revit version) with guidance through the inputs and direct result output. Source: [14]

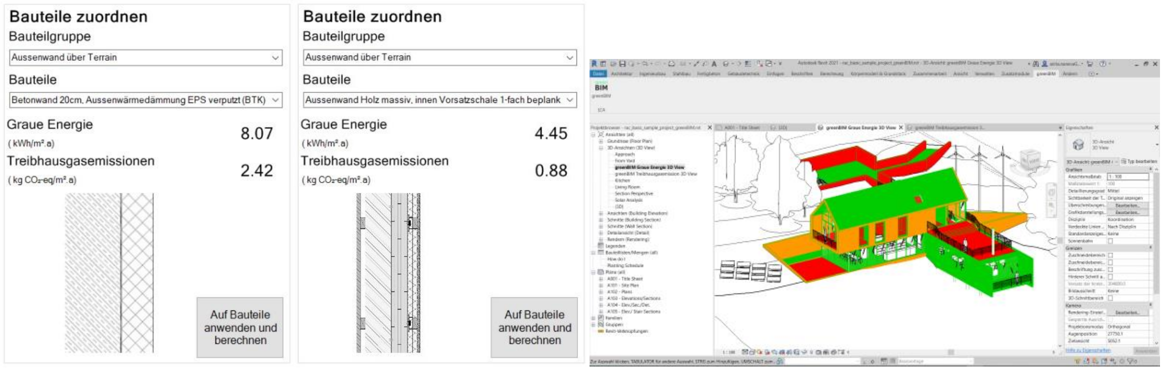


Fig 21: Components of the design (architectural model preliminary project) are linked with integrated components of the plug-in. Visualisations of LCA results in model.

4.3.4 Construction Verification and Handover Stage

Similar to handing over systems and maintenance manuals as a standard procedure towards handover, a virtual model that is used for facility management can contain higher level of information about building components. An inventory of materials used and possibility of reuse, biodegradability and waste could be possible. The EU funded project Buildings As Material Banks (BAMB)15 project aimed at reducing waste and using less virgin resources used material passports as a way of storing parameters for reuse, recycling etc. Honic et. al16 has applied such a method at the end-of-life stages of building to create material passport and encourage circular resource flow.

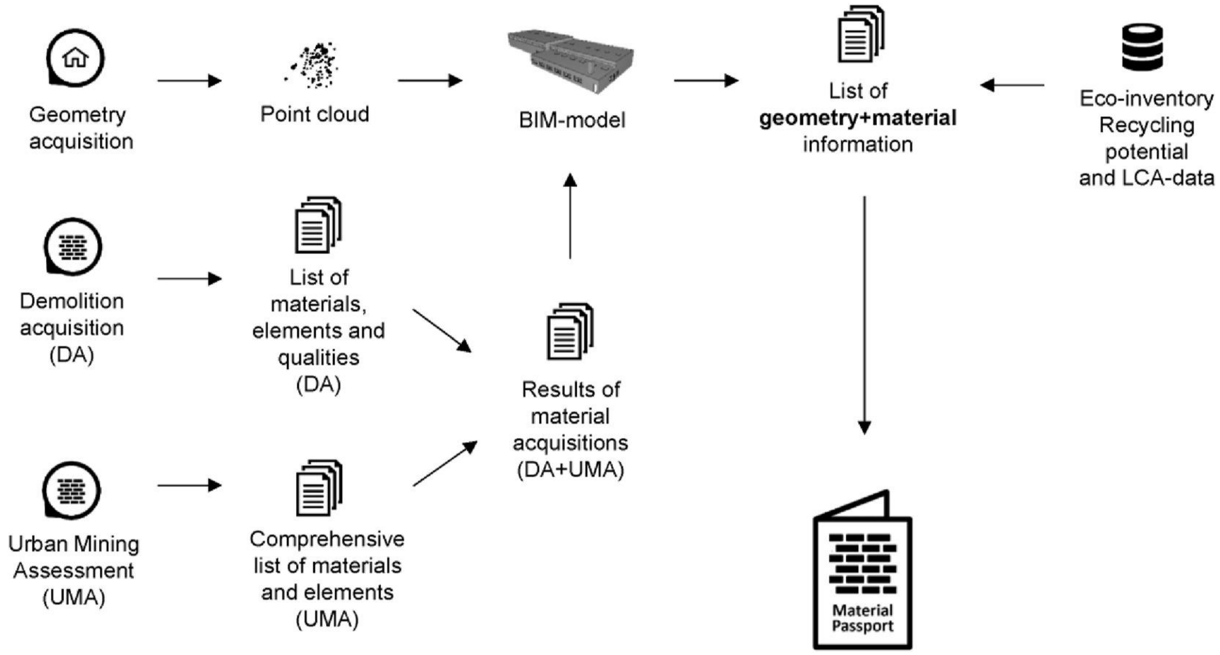


Figure 22: Workflow for the compilation of the BIM-based MP for the end-of-life stage. Source [16]

Compilation of material passport requires an exact material composition, as well as geometry of buildings. This research used various data acquisition methods on existing building (where no previous BIM Model was available), to figure out the exact geometry of the building, a surveying company applied laser scanning technology, upon which a point-cloud was generated, which served as basis for creating a BIM-model.

4.3.5 Material passports as a method of upstream design thinking

The concept of material passports can also be applied at the early design phase of buildings and components can be visualised based on their end-of-life potential. Use of urban mining as a way of material reuse in new building planning can also be visualised in early design phases to understand impact on the LCA. This work was conducted as part of the interdisciplinary Master Project at ETH (see fig 23). In this approach, students presented works in which part of early design BIM LCA optimisation was required to include end of life potential of new materials used and urban mining for material reuse in new building stock from existing buildings in the early design phase. The students then utilised the same model for parametric LCA calculation of their design alternatives. This form of upstream design thinking can help designers to plan for the materials use for the new building design with an added temporal dimension of complexity.

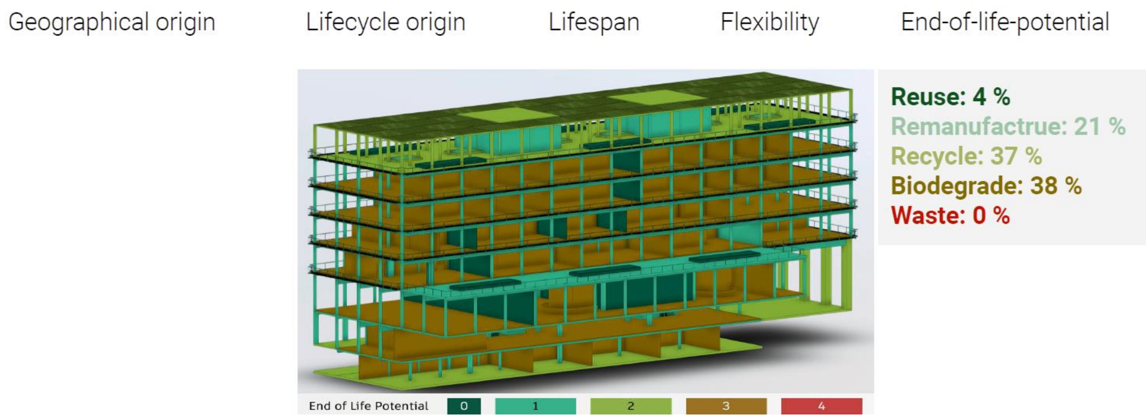


Figure 23: Building elements coloured according to end-of-life-potential. Source: Internal ETH

5 Uncertainty in the design process

This section of the report provides an overview of different uncertainty sources in building LCA, dividing them into two major categories (i) exogenous uncertainty, namely uncertainty that the designers cannot influence, and (ii) endogenous uncertainties during the design phases, namely uncertainties that the designers can influence. This section provides guidance on how to handle uncertainties from the second category specifically.

During the design phases uncertainty due to endogenous factors are primarily caused by multiple design variants during early stages and due to incompleteness during early phases. As the design progresses, this incompleteness could be reduced to zero in the “as-built phase, because all parameters are known. However, in practice the effort to account for every detail might not be worthwhile. Therefore, assumptions are also taken in the detailed design stage. KBOB provides values for technical equipment in the building based on the account of heated gross floor area of the building, for example.

5.1 Link LCA from early design phases upto final design phases to include uncertainty in the design process

One of the proposed methods is provided by Schneider-Marin, P. et al.[17]. Her team defined the building in an early phase as a parametric design (Concept phase) in which 3 groups of inputs are defined: (a) Geometrical data, which are taken out of the early BIM model (slab, floors, roof and external walls). Second group of inputs is (b) Window Construction and Interior and they are defined by the user. The third group of inputs is defined as (c) technical specifications (u-values, construction thicknesses, and reinforcement amount).

On top of the inputs, vagueness is added. It is defined as the amount of uncertainty on the mentioned groups of inputs in the early project phase. They define it as Building Development 2 (BDL 2). The values of Vagueness are defined as 10% for (a) Geometry and 25% for (b) Window Construction, Interior and (c) Technical Specifications. Based on that, the authors processed the sensitivity analysis which demonstrated the uncertainty contribution to every mentioned group.

As a case study, a simple building was used. The proposed workflow combines the Industry Founded Classes (IFC) model with a generic database Oekobaudat. Authors repeated the mentioned process two more times (BDL 3 and 4) in more developed project phases and changed the uncertainty correction factors as it is shown in the following figure.

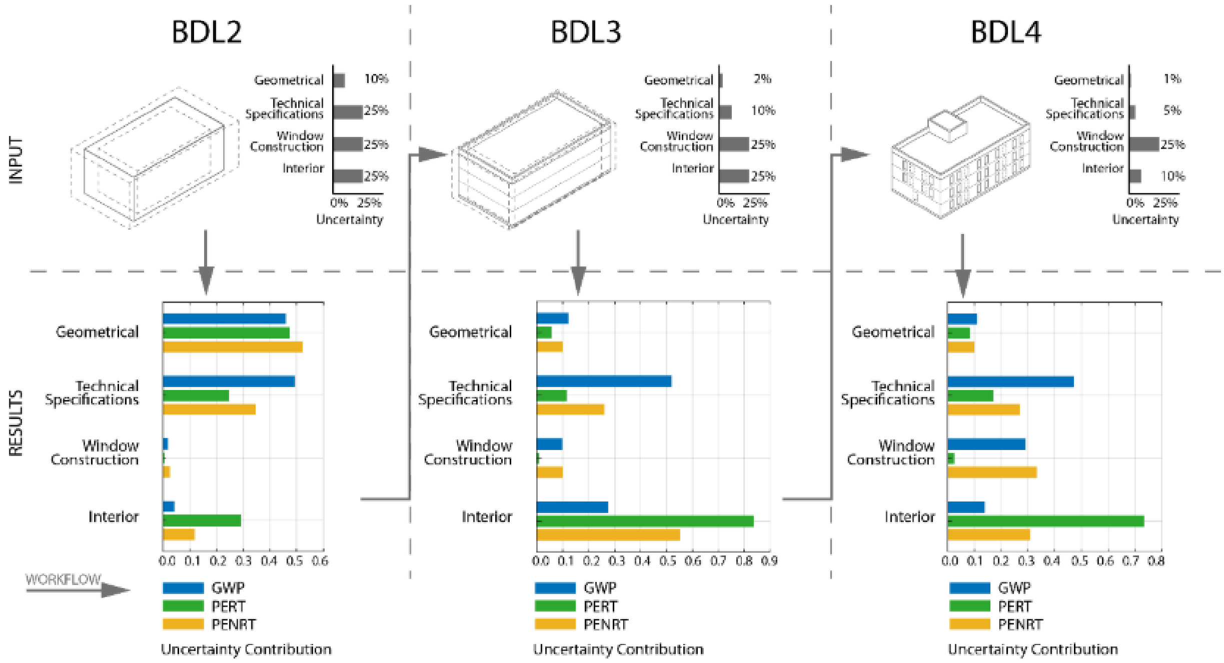


Figure 24: Overview of the used correction factors in a different phases. Source: [17]

The second step of the proposed work, was the contribution analysis which clearly showed the amount of embodied indicators (Primary Energy Renewable – PERT, Non-renewable - PENRT, and Green House Gas Emissions - GWP) in the specific parts of buildings. Results show around 50% of GWP for the building's concrete bearing structure. After replacement of the reinforced concrete with wood, GWP decreased to 33%.

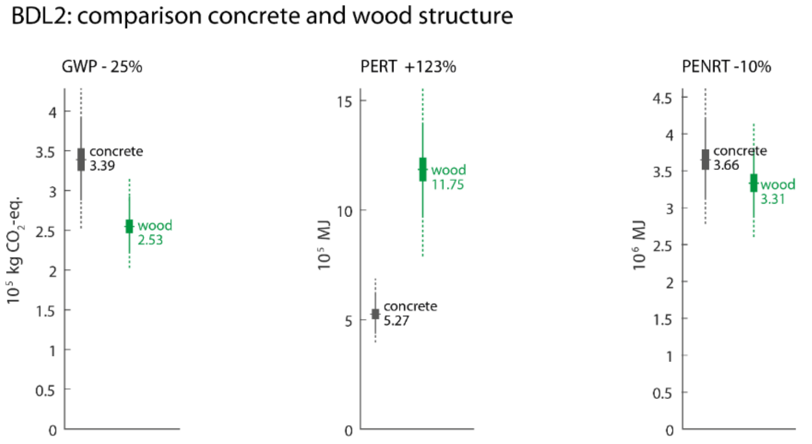


Figure 25: Contribution Analysis and comparison of concrete and timber structure. Source: [17]

Study also shows that adding vagueness into consideration can be used for the embodied indicators in the early design phase successfully.

5.2 Restructuring and aggregating database

The second proposed approach is different. Instead of adding a correction factor, the database adjustment is used to be able to aggregate data from the early to detailed design phase. This method is similar to the Life Cycle Cost (LCC). In this case, instead of cost data, environmental data is used. Therefore, data can be used in the aggregated form, such as PE or GWP per sqm.

First example of the possible workflow was introduced by Naneva, A. et al[10]. There is a struggle with data export from BIM, because a reliable type of data structure is needed. This workflow takes advantage of already existing LCC data structure, the Baukosten Kochbau (eBKP). This particular structure is valid for the Swiss context. The point is to pair the BIM elements within its different Level of Development (LOD) with the environmental data. In this study, the Bauteilkatalog for the early and KBOB for detailed phases were selected. The schema of the presented BIM development is shown in Figure 8.

Other work from Cavalliere, C et al.[5] used the structure of the building element description in order to calculate different average impact depending on the level of details for each specific components.

To propose the LCA at different design stages of design, the concept of Level of Development is used. The LOD defines the minimum content requirements for each element of the BIM at five progressively detailed level of completeness, from LOD 100 to LOD 500. Figure 20 gives a better understanding of design process and LODs of various construction activities.

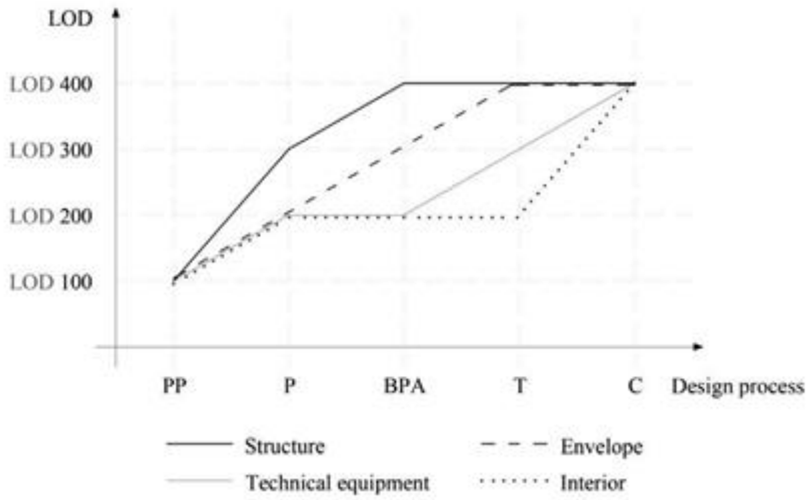


Figure 26: Design process and LODs for different construction categories. (PP) Project Planning, (P) Project, (BPA) Building Permit Application, (T) Tendering and (C) Construction. Source: Carmine Cavalliere et al., "Continuous BIM-Based Assessment of Embodied Environmental Impacts throughout the Design Process," *Journal of Cleaner Production* 211 (February 2019): 941–52, https://doi.org/10.1016/j.jclepro.2018.11.247..

The elements are composed of different components, and the impact of these components depends on the LOD, either very generic at a moment of the design process when low level of details is known for this specific component. For instance finishing are chosen very late while structural components are known earlier.

BAUTEILKATALOG			KBOB	LOD 400	LOD 300	LOD 200	LOD 100
Construction categories	Building components	Constructive solutions	Materials				
C. Structure	Load-bearing wall	Wooden frame construction	Hard wood	GWP	GWP	GWPaverage GWPmin GWPmax	GWPaverage GWPmin GWPmax
			Wood fibre insulation board	GWP			
			...	GWP			
		Concreete frame construction	Concreete	GWP	GWP		
			Reinforcement steel	GWP			
				GWP			
		...	...	GWP	GWP		
E. Envelope	Exterior wall cladding	Wooden cladding	Pine wood	GWP	GWP	GWPaverage GWPmin GWPmax	
			Larch wood	GWP			
			...	GWP			
		plasterboard plastered, wooden substructure	Plaster	GWP	GWP		
			Hard wood	GWP			
				GWP			
		...	...	GWP	GWP		
G. Finishing	Interior wall finishing	Gypsum finishing	Gypsum	GWP	GWP	GWPaverage GWPmin GWPmax	
			Paint	GWP			
			...	GWP			
		Wooden finishing	Wood	GWP	GWP		
			Paint	GWP			
			...	GWP			
		...	...	GWP	GWP		

Figure 27: Example of the proposed method for LCA of exterior wall above ground at the Building Permit Application phase. Source: Cavalliere et al..

The proposed LCA method is validated using a case study of a multi-family house based on a real building named WoodCube. The result of the study regarding the evolution of Global Warming Potential of the building during design process is summarised on figure 22.

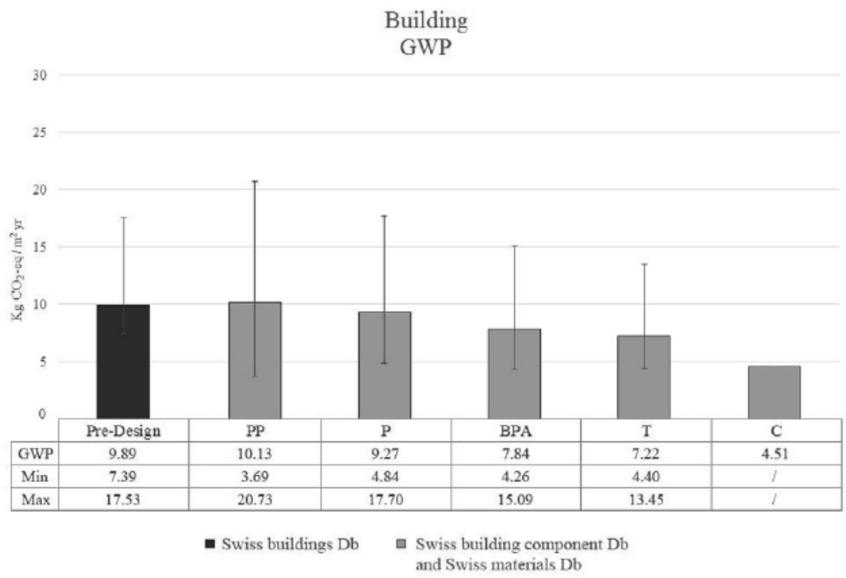


Figure 28: Evolution of calculated GWP of the building during the design process. Source: Cavalliere et al..

The study shows that the results for the entire building in a certain design phase is in line with the forecasted variability range in the previous stages. The study also emphasises that the minimum values should be only considered as the indication of a potential and not a benchmark. Yet, the final result of the real case study is notably close to the minimum value in the PP phase, implying that it can be achieved in reality.

6 Visualisation of LCA results

As part of this project and in collaboration with Annex 72, the paper on visualisation by Hollberg et al.18 highlights as the choice of workflows change as the design progresses, so does the need for visualisation. Visualisation is a powerful tool for interpretation of LCA results for both experts and non-experts and thus can inform the decision making process significantly.

6.1 Visualisation based on design phase and aspects to categorise visualisation techniques

As part of this project and in collaboration with Annex 72, the paper on visualisation by Hollberg et al.19 highlights as the choice of workflows change as the design progresses, so does the need for visualisation. Visualisation is a powerful tool for interpretation of LCA results for both experts and non-experts and thus can inform the decision making process significantly.

In the early design phases, an overview identifying hot spots on a low level of detail or the relation to the national limit values or a comparison of different volumetric options is sought. In the later phases of design, a hot spot analysis on a more detailed level (building elements or life cycle phases). In further detailed stages, very detailed hot spot analysis (individual materials or temporal analysis to identify when impacts are caused).

Four aspects were used to characterise the collection of visualisation from the review, namely:-
Number of environmental indicators
- Type of variables
- Number of variables
- Hierarchy levels

Using these aspects eight groups of visualisation have been identified from the current literature (see Fig 23 below).

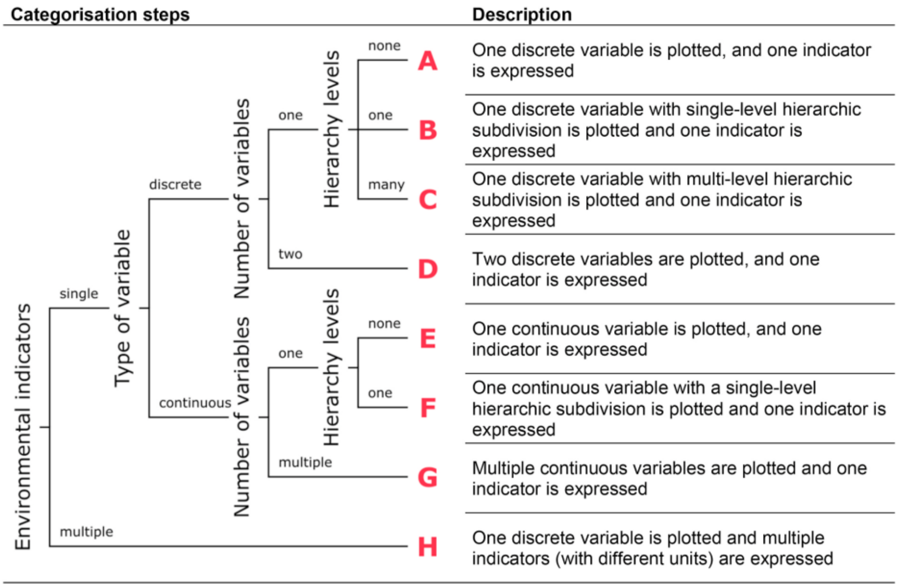


Figure 29: Categorisation steps to define groups of visualisation types and description of the groups. Source [18]

6.2 Synthesis of LCA goals, group of visualisations and the amount of information

The results of the analysis of visualisation types are synthesised based on goals of the interpretation phase and the category of visualisation type (see figure 24 below). Identification of hotspots and comparison of design variants are most common LCA goals in which options presented in group A, B, C allow for comparison of one variable. Group D allows to visualise two variables. Design and design process can be complex and can require integration of many criterions such as heating systems, daylighting etc. The most typical example of multi-criteria found in literature are 2D or 3D scatter plots as shown with group G&H.

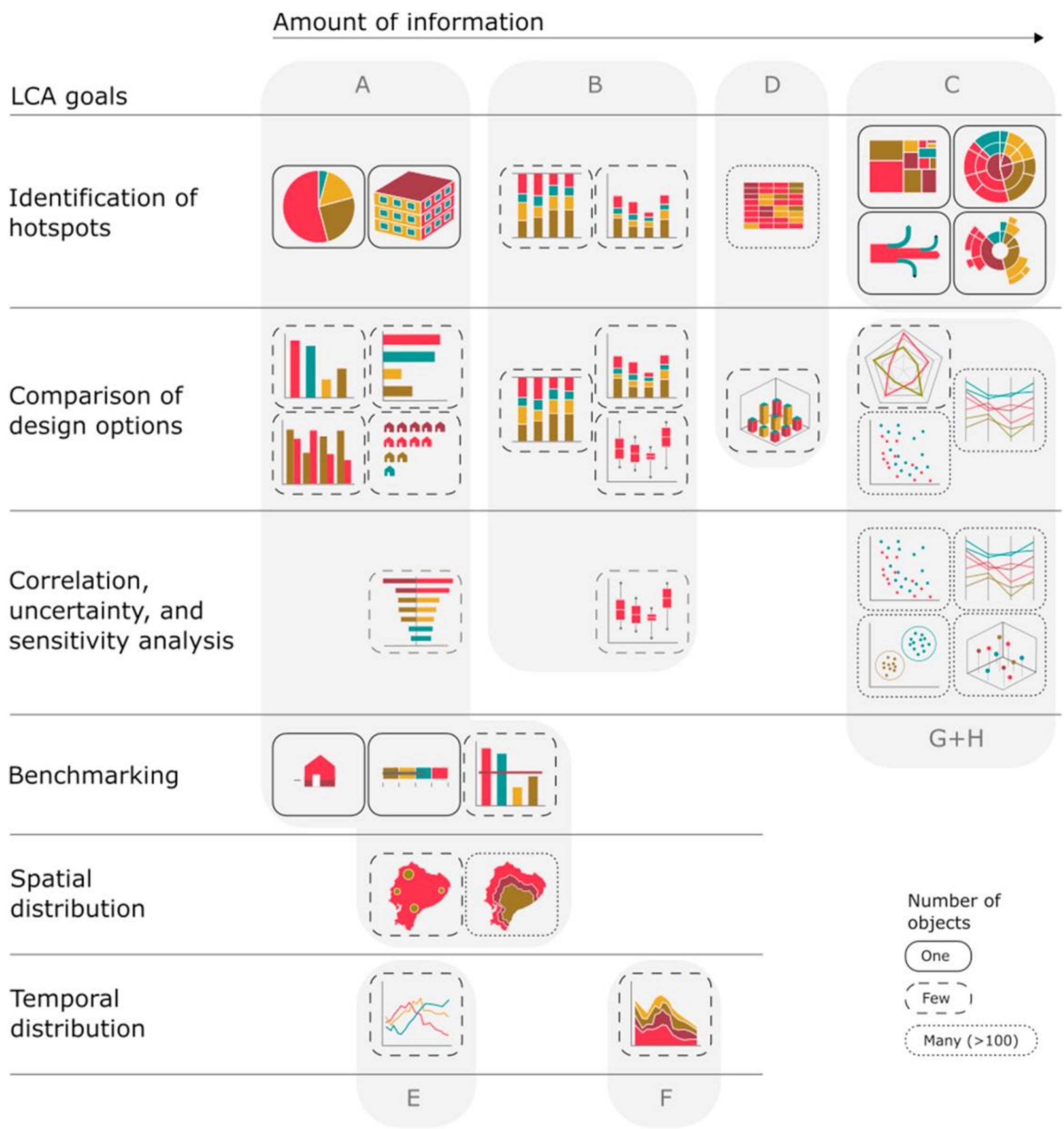


Figure 30: Synthesis of the LCA goals, the group of visualisation types, and the amount of information displayed in the visualisation. Source [18]

The review of literature has clearly emphasised the need for visualisation of LCA results for the LCA experts but also for non-expert stakeholders involved in decision-making. Increasingly LCA results are being incorporated into design decision making and are KPIs for the project brief stage and therefore visualisation can be informative for such decision making. One alternative method developed to enhance multi criteria analysis is dashboards that present information of many criteria simultaneously both at buildings and urban scales.

Figure 25 below is an example of the parametric net zero GHG emission neighbourhood (ZEN) dashboard[20] which defines its KPIs such as GHG emissions, transport related emissions etc and are visualised among other parameters. The pilot study for the tool was conducted on a new and retrofit school design in Trondheim, Norway as seen below.

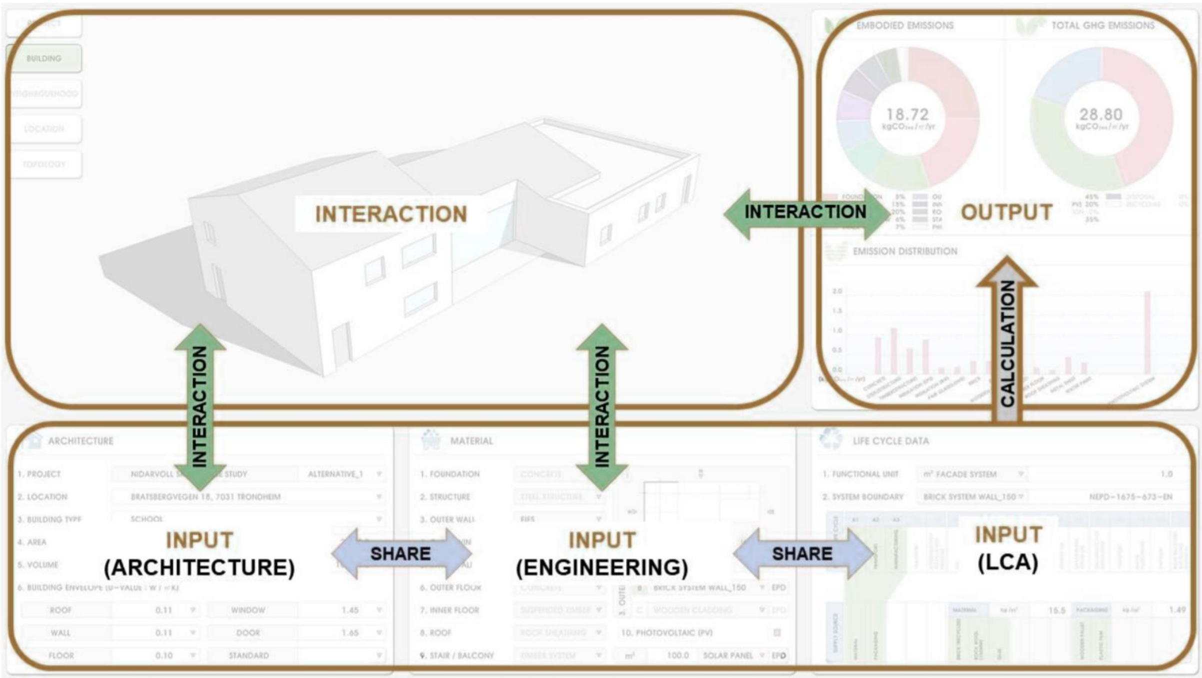


Figure 31: Synthesis of the LCA goals, the group of visualisation types, and the amount of information displayed in the visualisation. Source [19]

7 Discussion and Recommendations

The interviews and workshops conducted as part of this project, Annex 72 and other existing literature point to the increased adoption of BIM in design stages and the practitioners interest in using LCA as a decision making tool in early design stages. The present situation revealed that lack of time and knowledge are one of the key reasons for late adoption of LCA in the design process. Another reason, is that of managing uncertainty in the early design phases. As part of this report we presented an approach to BIM LCA in parallel to code of practice for architects and engineers, several possible workflows were presented and discussed for their pros and cons at different stages. Similarly, we presented two approaches to handle uncertainty in early design phases.

Another observation from literature and workshops was the designer's need to approach multi criteria decision and understand interrelation of carbon with other factors of design. To provide for this approach, we reviewed the visualisation process and setting of LCA goals and discussed current applications of multi criteria analysis in the dashboard format. Early setting of design goals can allow to for such an analysis (as depicted in Figure 9 & 10). We recommend to consider the options in this report with focus groups in industry to understand further adoption and decision support needs from practice.

8 National and International Collaborations

During 2019, we understood that our project had many common objective with the work EcoBau was doing in developing BIM compatible LCA. We decided to intensify this collaboration, in particular in the development of the LCA database.
On the work on visualization of LCA, we managed to attract interest from different international universities which are partners of the IEA Annex 72. This international collaboration allowed to propose a more common agreement on visualization strategies.
Finally, HES-SO and ETH are involved in the IEA Annex 72 and continue their activities in this Annex during 2020 and 2021.

9 Publications

The strategy for organisation of BIM compatible LCA database has been published in a scientific paper. (Cavalliere et al. 2019. Continuous BIM-based assessment of embodied environmental impacts throughout the design process. *Journal of Cleaner Production*, 211, 941-952)

The early design BIM LCA prototype has been presented in a conference (and won the best paper award). (Basic et al. 2019. A design integrated parametric tool for real-time Life Cycle Assessment – Bombyx project. Sustainable Built Environment Conference 2019 (SBE 2019), Graz, Austria, IOP Publishing, September 11-14, 2019. DOI: 10.1088/1755-1315/323/1/012112)

The revision of early design BIM LCA prototype to perform under specified LCA was also presented in Beyond 2020 World Sustainable Built Environment Conference 2020, Göteberg, Sweden (Hollberg et al. 2020 A data-driven parametric tool for under-specified LCA in the design phase (WSBE 2020), Göteberg, Sweden, IOP Conf. Ser.: Earth Environ. Sci. DOI: 10.1088/1755-1315/588/5/052018)

A paper review of visualisation of LCA results in the design process was also published in the year 2021. (Hollberg et al. 2021 Review of visualising LCA results in the design process of buildings, Building and Environment, Volume 190, March 2021, https://doi.org/10.1016/j.buildenv.2020.107530)

10 References

1 “Home,” ecoinvent, accessed October 8, 2021, https://ecoinvent.org/.

2 M Balouktsi et al., “Survey Results on Acceptance and Use of Life Cycle Assessment among Designers in World Regions: IEA EBC Annex 72,” IOP Conference Series: Earth and Environmental Science 588 (November 21, 2020): 032023, https://doi.org/10.1088/1755-1315/588/3/032023.

3 Thomas Bernard Paul Jusselme, “Data-Driven Method for Low-Carbon Building Design at Early Stages” (Lausanne, EPFL, 2020), https://doi.org/10.5075/epfl-thesis-10122.

4 A. H. Oti et al., “Structural Sustainability Appraisal in BIM,” Automation in Construction 69 (September 1, 2016): 44–58, https://doi.org/10.1016/j.autcon.2016.05.019.

5 Carmine Cavalliere et al., “Life Cycle Assessment Data Structure for Building Information Modelling,” Journal of Cleaner Production 199 (October 20, 2018): 193–204, https://doi.org/10.1016/j.jclepro.2018.07.149.

6 Laura Álvarez Antón and Joaquín Díaz, “Integration of Life Cycle Assessment in a BIM Environment,” Procedia Engineering, Selected papers from Creative Construction Conference 2014, 85 (January 1, 2014): 26–32, https://doi.org/10.1016/j.proeng.2014.10.525.

7 L Wastiels and R Decuypere, “Identification and Comparison of LCA-BIM Integration Strategies,” IOP Conference Series: Earth and Environmental Science 323 (September 6, 2019): 012101, https://doi.org/10.1088/1755-1315/323/1/012101.

8 Tajda Potrč Obrecht et al., “BIM and LCA Integration: A Systematic Literature Review,” Sustainability 12, no. 14 (July 9, 2020): 5534, https://doi.org/10.3390/su12145534.

9 “180222-BdCH-SwissBIM-LOIN-Verstaendigung-Web.Pdf,” accessed October 10, 2021, https://bauen-digital.ch/assets/Downloads/de/180222-BdCH-SwissBIM-LOIN-Verstaendigung-web.pdf.

10 Anita Naneva et al., “Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context,” Sustainability 12, no. 9 (May 5, 2020): 3748, https://doi.org/10.3390/su12093748.

11 Alexander Hollberg et al., “Design-Integrated LCA Using Early BIM,” in Designing Sustainable Technologies, Products and Policies, ed. Enrico Benetto, Kilian Gericke, and Mélanie Guiton (Cham: Springer International Publishing, 2018), 269–79, https://doi.org/10.1007/978-3-319-66981-6_30.

12 “A Data-Driven Parametric Tool for under-Specified LCA in the Design Phase - IOPscience,” accessed October 11, 2021, https://iopscience.iop.org/article/10.1088/1755-1315/588/5/052018/meta.

13 Alexander Hollberg and Jürgen Ruth, “LCA in Architectural Design—a Parametric Approach,” The International Journal of Life Cycle Assessment 21 (July 1, 2016), https://doi.org/10.1007/s11367-016-1065-1.

14 “GreenBIM Programm,” FHNW, accessed October 11, 2021, https://www.fhnw.ch/de/die-fhnw/hochschulen/architektur-bau-geomatik/institute/ineb/ineb-forschung/nachhaltiges-bauen-und-betreiben/greenbim.

15 “BAMB - Buildings As Material Banks (BAMB2020) - BAMB,” accessed October 11, 2021, https://www.bamb2020.eu/.

16 Meliha Honic et al., “Material Passports for the End-of-Life Stage of Buildings: Challenges and Potentials,” Journal of Cleaner Production 319 (August 1, 2021): 128702, https://doi.org/10.1016/j.jclepro.2021.128702.

17 Patricia Schneider-Marin et al., “Uncertainty Analysis of Embedded Energy and Greenhouse Gas Emissions Using BIM in Early Design Stages,” Sustainability 12, no. 7 (January 2020): 2633, https://doi.org/10.3390/su12072633.

18 Alexander Hollberg et al., "Review of Visualising LCA Results in the Design Process of Buildings," Building and Environment 190 (March 2021): 107530, https://doi.org/10.1016/j.buildenv.2020.107530.

19 Alexander Hollberg et al., "Review of Visualising LCA Results in the Design Process of Buildings," Building and Environment 190 (March 2021): 107530, https://doi.org/10.1016/j.buildenv.2020.107530.

20 Marianne Kjendseth Wiik et al., "A Norwegian Zero Emission Neighbourhood (ZEN) Definition and a ZEN Key Performance Indicator (KPI) Tool" 352 (October 2019): 012030, https://doi.org/10.1088/1755-1315/352/1/012030.