Step-by-step implementation of BIM-LCA: A case study analysis associating defined construction phases with their respective environmental impacts

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Step-by-step implementation of BIM-LCA: A case study analysis associating defined construction phases with their respective environmental impacts

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Abstract. Building Information Modelling (BIM) supports construction processes by dealing with the variety and complexity of design in a single virtual model. The model may also be complemented by the static and energy performance of buildings. Facing the growing demand of sustainability strategies in the construction sector, the consideration of environmental information within the planning process influences the decision making of planners and stakeholders. Nevertheless, the life cycle assessment of buildings has been so far excluded in BIM, due to the high variety of accurate information and time required. In this paper, a systematic framework is presented and applied to a case study. BIM-LCA assists actors along the planning and designing phase, from the building conception as a whole, up to the elements' details and materials' definition. BIM and LCA intertwine in an application scheme of seven phases for integral planning and four levels of structural composition of a building. With respect to these, involved actors examine potential solutions through a tool which exploits alternative specifications in order to assess the environmental impacts. The goal of this paper is to demonstrate the application of a BIM-LCA model regarding decision making for reliable values of environmental impact in a given structural level of the building. The main findings of this framework are due to the multitude of actors and information orchestrated, namely to uncertainties which characterize the whole planning process and data handling. Through BIM-LCA, actors are assisted by ensuring flexibility of models and consistency of results throughout planning and designing.

1. Introduction

The construction sector is responsible for 50% of global greenhouse gases and roughly 40% of the total raw material consumption: as one of the main contributors to global environmental impacts, it is in the last years under particular attention in order to achieve a substantial change. [1]

For the environmental improvement of the building's lifecycle the LCA method is well established and gained importance, mainly as basis of the building certification labels and building product declarations. Its procedure consists in the calculation of a building-LCA by collecting materials and products over the whole life cycle. On the basis of the analysis, information can be selected and all relevant environmental impacts are calculated [2][3]. Even if LCA results depend mainly on materials, it is possible to gather more and more specifications on component or whole final product level within

comprehensive building LCA tools and databases. This is justified from the variety, complexity and interconnectedness of the products which do not allow for simple solutions for complete building LCAs: the design of the building shell, for instance, is important for the energy consumption, the location of the building can define transport distances and users' habits determine resource consumption during use and the maintenance and refurbishment activities [3].

Such observations lead to a paradox: a comprehensive LCA can be only carried out after the final design on the products through a detailed ex post data collection but the buildings impact is strongly defined during its conception, namely in the first stages. When the environmental impact is not only to be assessed but to be optimized, the LCA has to be applied in these early stages already. However, differently from technical and economical dimensions, the environmental value of a construction is yet hardly included during the early decision making process.[4] In addition to this, discussions about the current decision making approaches are ongoing: with the rising of building performances and complexity, the ordinary organizing and planning procedures are getting demanding in terms of costs and time; for such reasons, they are considered no longer suitable and further more integrated and dynamics strategies are investigated [5][6].

As solution to this matter, informatics entered in daily practice of the last 20 years and several tools became essential instruments for planner and technicians [6]. Among this variety, BIM (Building Information Modeling) realizes an integrated design starting from early stages, with a set of interacting policies, processes and technologies and facing the main issues, i.e. information fragmentation during lifecycle, building performance prediction and automated assembly [7][8]. Process efficiency studies report up to 40% elimination of unbudgeted change and 80% reduction in cost estimation time with almost 7% reduction in project time [9].

In conclusion, BIM and LCA methodologies are the key for a new approach of planning and design: by technical point of view, the implementation of LCA in BIM, thanks to informatics development and availability of libraries, is within range. However, environmental impact evaluation during the early decision stages and its significance for integrated design is still a strongly debated topic.

2. State of art

When the building is not well defined, technicians are involved in order to take decisions about the overall design and select available alternatives.

As demonstrated by Basbagill et al. (2013), postponing material and thickness decisions during the design development stage is not a successful strategy in terms of environmental impact. On the other hand, an aware and timely choice of materials can significantly reduce the total GWP emissions, avoiding designers' effort on inconsequential decisions during the critical early design stages. The knowledge of material properties, building shape and orientation, for instance, can be the basis for the optimization of final energy performance [10].

In literature, several approaches and tools for LCA in BIM are available but however not all issues have been so far solved or new challenges arose. By technical point of view, the creation of such tools as support instrument for decision-making showed problems, such as the missing interoperability between BIM interfaces and environmental databases, the import of BIM information into LCA software, the complexity for many actors of treatment of a BIM model [11]. The use of IFC format has proven to be advantageous, by facilitating building description and construction industry data exchange through an open file format and neutral platform [12].

Differently, the methodological aspect is more discussed. Antón and Díaz (2014) suggest a "material-oriented" approach: the BIM library can include relevant environmental information coming from previous analyses, so that the designer will consider such performance within the ordinary material choice procedure. As disadvantage of this approach, besides the low results accuracy (e.g. transport distances measurement), LCA database implementation showed problem in terms of efficiency [13].

An alternative to this may be an environmental impact assessment during the whole planning and design process: a more accurate approach, which avoids data reentry, and realizes a real-time assessment through a three-dimensional object. Most of existing applications in literature use 3D-Cad models to be

connected to an LCI database, which, in comparison to a BIM Model, are not capable to include relevant information such as recyclability, reuse and construction life span, together the with material collection [14][15].

Even though the huge potential, the combination of a BIM interface with this approach is not always effectively feasible. It has been observed, that not many standards and guidelines address demolition and aspects of refurbishment in the BIM [16]. A quick and accurate estimation of waste due to the demolition is possible only by calculating all material quantities of a building which has exhausted its service life but, even for existing buildings, this is not a direct calculation, which is a lack of accurate information that practitioners and clients face in daily practice [17].

As result of this discussion, it can be claimed that, BIM-LCA approaches, even if acknowledging the relevance of early stages, intended their application only from the early *design* phase. This because at the moment there are not available enough synergies between stakeholders, technicians and clients and none of these have achieved a full automation for calculations or information transfer between software [11][18]. As noticed by Röck et al. (2018), such application provides results and conclusions which cannot be generalized, since they depend on the quality of input data from both BIM and LCA model completeness and data accuracy [19][20].

3. Method

Within a research project "BIM based integrated planning", supported by the German Federal Ministry for Economy and Energy (BMWi), a procedure for the definition of planning and lifecycle phases has been developed [21]. As results of this, a model of concretization made of 7 phases has been realized for each of them, the information depth of BIM level and the required specifications have been collected, with particular attention to the data necessary for LCA [23].

The detail of such information depends mainly on the considered building levels: whole building, functional system, element system and component layers (see Figure 1).

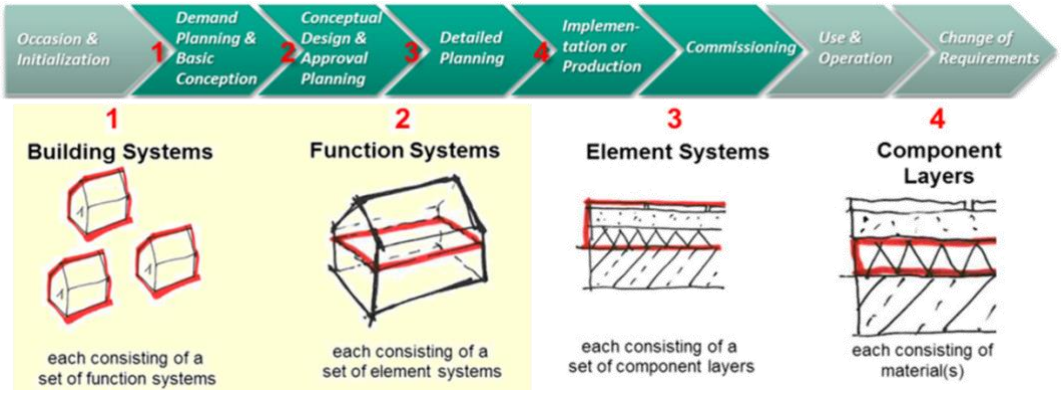

Figure 1. Building levels with reference to a model for concretization phases of planning and design process. [22]

In this section, basing on the above mentioned research project and further works [23] [24], a methodology is presented with focus on the early planning stages (phases 1-2 from the Figure 1), the involved actors and the information which is within required.

The information is *step-by-step* fragmented, reduced to the most detailed value, and converted depending on its characteristic (descriptive, quantitative, and boolean) in order to set up a full automation through informatics instruments.

3.1 Occasion and Initialization

The project starts after the initiative of an individual, who is following own personal, political or entrepreneurial goals. The main activities regard evaluation of the solution sets, basing on a series of

implicit and explicit decisions and conditions. In this context, after the comprehension of the main issues and possible contributions to the project, specific solutions are considered, depending on the personal past experiences and knowledges. Such alternatives concern the whole building system, e.g. building type and construction methods (Figure 2).

The first and most important decision concerns the realization or postponement of the project, by taking into account relevant problematics (social and political) and the own experience. The functions addressed to the initiator are the research of information, the designation and experts and their corresponding commitments.

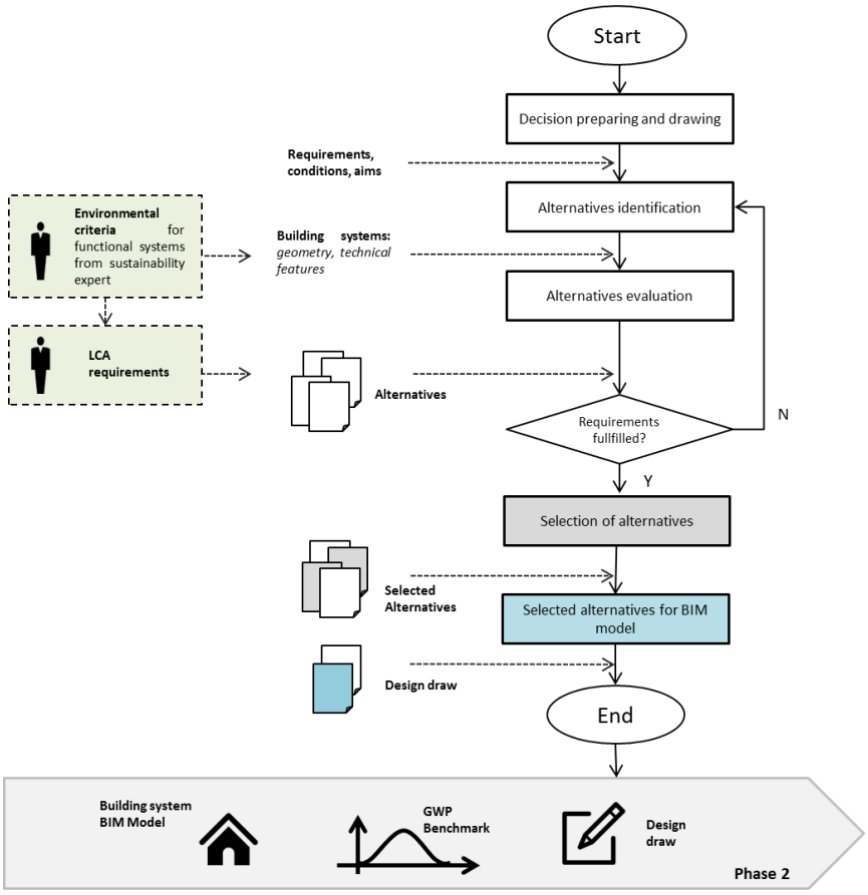

Figure 2. Stage 1: Process details and information needed [22]

The established project managers group provides general features, such as the usage type (office, residential, industrial …), category (single- or multi-family dwelling, school or university …) and location. This leads to first quantitative specifications, i.e. number of dwellings, offices, rooms, and consequently to the first evaluation of minimal using surfaces and volumes, such as mean floor area, net floor area (see f.i. ISO9837 or DIN277 standards). The plot of land location enables roughly to a hypothetic floor plant and building orientation. Furthermore, construction technologies can depend on design preferences and workforces experience as well as material availability of the neighborhoods.

As shown here, on this level, essential information is already available and a first environmental value of the whole building system can be estimated. However, this occurs *indirectly*: in fact, due to a still low workforces' awareness, sustainability problematics are not particularly taken into account unlike economic, technical and social aspects. As support during the whole project management, figures with particular sustainability expertise as wells as tools can be exploited and aims (with volunteer characters) and requirements (compulsory or guidelines suggestions, e.g. EEG for Germany) may be

provided [23]. On the basis of those, alternatives can be assessed and their choice can be supported with help of environmental *Benchmarks* derived from a tool which gather in its database either available other LCA results or normative regulations. A first design draw is lastly processed, which roughly represents the building system and describes technical features only in qualitative terms, and accompanied by overall environmental impact estimation.

3.2 Demand planning and basic conception

While the first phase is focused on the building technical and geometrical specification, the following one is centered on management of financial resources and evaluation of the investment risk. The actors are called to prepare and secure a project with outlook to an upcoming investment decision. Through the involvement of the real estate industry, capital and ideas are merged and developed into a project.

Information coming from the first phase are here processed, such as plot of land, location (to be linked to permissible land for construction), infrastructure supply, permissible main use, intended real estate market and users, and further technical specifications (building structure, storeys, building orientation). In comparison with the previous stage, alternatives may be assessed by means of *function systems* level (Figure 3).

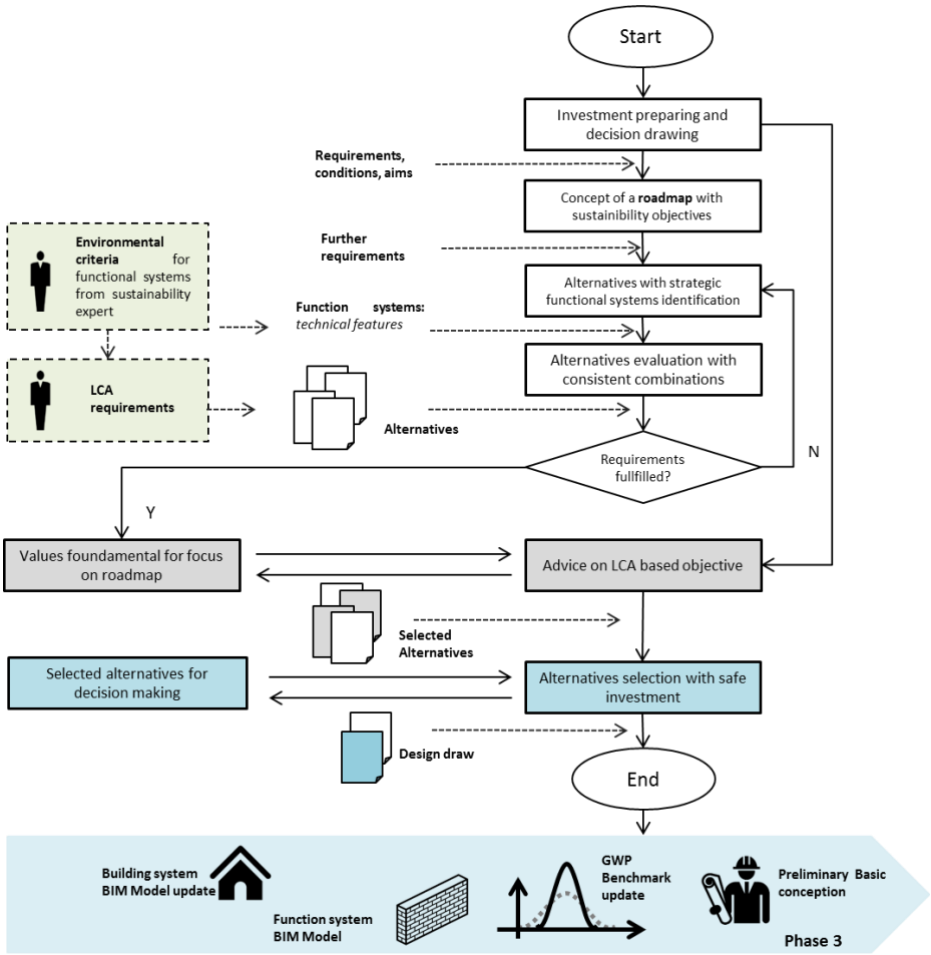

Figure 3. Stage 2: Process details and information needed [22]

Consequently, the whole building is differentiated in functional systems such as external walls, floors or roof and for each of them qualitative technical requirements are addressed (i.e. EnEV for Germany) and then connected to the already given geometry. As well as the initialization and ground concept,

environmental requirements and guidelines are provided and included in a so called "*roadmap"* [21][22].

The alternatives deemed consistent with the abovementioned requirements are then evaluated and the one which guarantee a safe investment selected. As results of this process, for each functional system a BIM model is generated, the tool calculates GWP benchmarks through its database and the previous models are updated with more accurate results. The first preliminary concept design can be then presented.

4. Case study

The presented framework is applied on an exemplary multi-apartment building in Germany. With help of the online tool SBS for building sustainability evaluation, total GWP impacts have been calculated for building and functional system. An Excel tool has been set up for results collection and benchmarks calculation for alternatives comparison. The building and functional systems examples are derived from previous works and projects available in the SBS-onlinetool (www.gabi3.com) database and exploited as statistical values in order to derive Benchmarks based on typological standard. [25]

4.1 Building systems evaluation

For the initialization, the selected information cover general building features such as construction type, using type, energy standard and installation standard. Such features are the ones considered relevant for LCA and therefore their variation leads to different GWP value feedbacks. Each characteristic has been defined as specified in Table 1.

By fixing, for instance, the building use type and energy standard, different installation standard and construction types may be considered. As shown in Table 2, installation standard on this level has no relevance on the resulting GWP Benchmarks; on the other hand, the construction type can be relevant for the total potential emissions and this reduction is due to the production phase. Hence, for a multi apartment building with KfW55 energy standard, a light construction has been chosen [26]. By comparing the results with the DGNB reference for new constructions [27], the total GWP seems to be underestimated.

Table 1. Stage 1: Information needed, sources and selected example

Building system	**Info**	**Reference**	**Example**
General information	Building Type	Use type in according to	Multi- apartment building - Fixed
	Energy standard	EnEV, KfW, Passive house, Plus energy building	KfW55 – Fixed
	Installation standard	Low/high	Variable
	Construction type	Massive/Light	Variable
	Net surface		**707,4 m²**

Table 2. Stage 1: Benchmarks results [kg CO2/m²net surface year] [25] [27]

GWP [kg CO2 eq./m²y]	Massive Building/ Low installation standard	Light Building/ Low installation standard	Light Building/ High installation standard
Production CG 400+300 + EoL CG 300 + CG 400	5,59	1,26	5,59
Use phase KfW55	22,94	22,94	22,94
Total	***28,53***	***23,2***	***28,53***
	DGNB Reference value [NWO15(V16)] [26]		***53,11***

4.2 Functional systems evaluation: external wall

For the definition of a functional system different standard solutions of external and internal walls, floors, roofs and installation sets have been derived by simplified BIM models belonging to SBS database (see Table 3). For each of them, LCA analyses. For this case study floors, roofs, and internal walls have been fixed and external walls and installation sets varied, by taking into account that the previous analysis suggests a light construction technology for a multi apartment building and finally a new total impact due to production and end of life is calculated (see Table 5).

Table 3. Stage 2: Information needed and benchmarks

Functional system – Cost group [DIN 276]	Example	Amount [26]
Basement – CG320	Basement with overlying insulation – Fixed	294,4 m²
External walls – CG330	1) Wood Walls 2) Wood fibers	776,8 m²
Ceiling – CG350	Wood ceiling with structural beams- Fixed	588,8 m²
Roof - CG360	Slope Roof- Fixed	294,4 m²
Installation set – CG400	1) KfW55:Domestic water distribution stainless steel, Ventilation system, Composite pipe, Buffer storage ***Underfloor heating***, 2) KfW55: Domestic water distribution stainless steel Ventilation system, Composite pipe, Buffer storage***, District heating station.***	707,4m²

Table 4. Stage 2: Information needed, sources and selected example on functional system (Standard systems from previous projects [25])

Cost Group DIN276	Construction	GWP [kg CO2 eq./m²] [25]	Specification Unit [m²]
CG 320	Basement with overlying insulation	148,55	Basement surface
CG 330	1) Wood ext. walls	3,38	Ext. walls surface
	2) Wood fibers ext. walls	17,96	
CG 350	Wood ceiling with structural beams	-19,60	Ceiling surface
CG 360	Terrace Roof-	139,10	Roof surface
CG 400	KfW55:Domestic water distribution stainless steel, Ventilation system, Composite pipe, Buffer storage		net surface
	1) with *Underfloor heating*,	56,73	
	2) with *District heating station*	28,78	

Table 5. Stage 2: Information needed, sources and selected example on building system

GWP [kg CO2 eq./m²y]	**Wood walls/ underfloor heating**	**Wood walls/ district heating**	**Wood fibers walls/ district heating**
Production + EoL CG 400+300	3,28	2,72	3,04
	DGNB Reference value [NWO15(V16) Construction] [26]		**3,98**

Differently from the previous analysis, on this level the installation sets are more relevant for the final results, which are now provided in a more comprehensive form. The calculated benchmarks towards the DGNB reference value provided for the construction of a new residential building (NWO15 Profile) [26]: this prove the good accuracy of the results provided by SBS-onlinetool database.
On the other hand, due to a lack of comprehensibility regarding simulation data, specific installations and auxiliary energy, any further information about use phase is not given and therefore results cannot be yet enhanced.

5. Conclusion and future outlook

With the presented framework, environmental impact results can be provided already during the first decision making process and before the early design stages. Peculiarity of such framework is the necessity of sustainability expertise and respective tools supporting the project manager and providing construction alternatives and GWP values starting from the early stages. As shown in the case study section, such tools have to handle issues due to data requirement and inaccuracies. Most of them are caused by missing information about specific energy consumptions as well as refurbishment or renovation measures, which depend on the user's habits and choices and are all considerable sources of uncertainties for LCIA analyses.[18] These uncertainties have to be included in the decision making process to provide the practitioner both the sustainability feedback and the robustness of this value. Even on completion of final building design and data collection, environmental impacts cannot be still depicted by a single trustworthy value, but better by a range of values of which width or distribution depends strongly on uncertainties. [29]
Finding a solution to this matter represents indeed the next challenge: in terms of results robustness, an improvement of SBS-onlinetool can be realized in a first instance by enrichment of the available database and provision of statistical records to keep constantly up to date. Moreover, with regard to the overall methodology, more dynamic and probabilistic approaches are nowadays still on investigation. Such approaches aim to reach an environmental impacts prediction by considering of a multitude of variants and factors. Among them, the German Excellence Cluster "IntCDC" establishes research networks called to investigate innovative integrated Co-design including predictive Life Cycle Assessment, in order to achieve a real-time decision support and robust statements during the early design stage with limited environmental information basis and uncertain boundary conditions. These forthcoming improvements on LCA methodology aim to provide and to successfully communicate robust statements on environmental performance already in or before early design. Hence, through addressing the data quality and availability related issues not only in early design for LCA, some of the current implementation issues in BIM-integrated LCA may be overcome. [30]

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References

[1] International Energy Agency (IEA) and Global Alliance for Buildings and Construction (GABC) 2017 Global Status Report 2017 Towards a zero-emission, efficient, and resilient buildings and construction sector
[2] ISO 14040:2006 - *Environmental management - Life cycle assessment - Principles and framework*
[3] Frischknecht R, Wyss F, Büsser S, Knöpfel I and Stolz P 2015 Life cycle assessment in the building sector: analytical tools,environmental information and labels *Int J Life Cycle Assess* **20,** pp 421–425
[4] Tritthart W, Staller H, Zabalza I, Malmqvist T, Peuportier B, Wetzel C, Hajpal M, Stoykova E and Krigsvoll G 2010 LoRe-LCA Low Resource consumption buildings and constructions by use of LCA in design and decision making: State of the art report -Use of Life cycle assessment-Methods and tools
[5] Kovacic I , Filzmoser M, Faatz S and Koeszegi S T 2011 Research Project Cost Benefits of Integrated Planning: First experiment-results, Research paper, pp 255-263 [DOI 10.5592/otmcj.2011.1.5]
[6] van Aken J E 2003 On the design of design processes in architecture and engineering: technological rules and the principle of minimal specification, Working paper (Eindhoven Centre for Innovation Studies, Technische Universiteit Eindhoven, June 2003,)
[7] Succar B 2009 Building information modelling framework: A research and delivery foundation for industry stakeholders, *Automation in Construction*, V **18,** pp. 357–375
[8] CRC Construction Innovation 2007 Adopting BIM for Facilities Management Solutions for Managing the Sydney Opera House (Cooperative Research Center for Construction Innovation, Brisbane, Australia)
[9] CIFE 2007 - CIFE Technical Reports (22 November 2007) [http://cife.stanford.edu/Publications/index.html]
[10] Basbagill J, Flager F, Lepech M and Fischer M 2013 Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts, *Building and Environment* **60**, pp 81-92
[11] Gantner J, Schneider S, Fischer M, Lozanovski A and Gehring F 2014 BIM as a data source for LCA and building certification schemes Certification schemes and BIM as a possible solution German research project BIMiD, *New Zel. Life Cycle Assess. Conf.*, pp. 116–119.
[12] BuildingSMART 2006 Anwenderhandbuch Datenaustausch BIM/LCA, Dokumentversion 1.1 (Munich: IAI, 30 November 2006)
[13] Álvarez Antón L and Díaz J 2014 Integration of life cycle assessment in a BIM environment, *Creative Construction Conf. CC2014*, *Procedia Engineering* **85**, pp 26–32
[14] Seo S, Tucker S and Newton P 2007 Automated material selection and environmental assessment in the context of 3D building modelling, *Jour. of Green Building* **2**, pp 51- 61
[15] Nwodo M N, Anumba C J, FASCE and Asadi S 2017 BIM-based Life Cycle Assessment and Costing of Buildings: Current Trends and Opportunities, Conference Paper, ASCE Int. Workshop on Computing in Civil Engineering (Seattle, Washington, 25–27 June 2017)
[16] Chong H Y, Lee C Y and Wang X 2017 A mixed review of the adoption of Building Information Modelling (BIM) for sustainability, *Journal of Cleaner Production* **142** , pp 4114-4126
[17] Galic M , Dolacek-Alduk Z, Cerovecki A, Glick D and Abramovic M 2014 BIM in planning deconstruction projects, Conference Paper, 10th European Conference on Product and Process Modelling (ECPPM 2014 Vienna, Austria, 17-19 September 2014)
[18] Lilleheim Vik A 2018 Investigation of requirements for use of BIM-based LCA in early stages of building design, Research paper (Norwegian University of Science and Technology, Department of Civil and Environmental Engineering, June 2018)
[19] Röck M, Hollberg A, Habert G and Passer A 2018 LCA and BIM: Integrated assessment and

visualization of building elements' embodied impacts for design guidance in early stages, Conference Paper, 25th CIRP Life Cycle Engineering (LCE) Conference (Copenhagen, Denmark, 30 April -2 May 2018)

[20] Meex E, Hollberg A, Knapen E Hildebrand L and Verbeeck G 2018 Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design, *Building and Environment* **133**, pp 228-236

[21] Karlsruher Institut für Technologie (KIT)- Fachgebiet Building Lifecycle Management: BIM-basierte Integrale Planung– Projektübersicht (9.8.2018), [http://blm.ieb.kit.edu/1313.php]

[22] Ebertshäuser S, Graf K, von Both P, Di Bari R and Horn R 2019 Sustainable building information modeling in the context of model-based integral planning. In proceedings, (SBE 2019 conference, TU Graz, Graz) [to be published]

[23] Rexroth K, von Both P, Gantner J and Schmid C 2018 Ein Ansatz für die typologiebasierte Vervollständigung von Gebäudeinformationen zur Unterstützung der frühen Planungsphasen am Beispiel LCA, Conference Paper, BauSIM 2018 (Karlsruhe, Germany, 26-28 September 2018)

[24] Gantner J, von Both P, Rexroth K, Ebertshäuser S, Horn R, Jorgji O, Schmid C and Fischer M 2018 Ökobilanz – Integration in den Entwurfsprozess BIM-basierte entwurfsbegleitende Ökobilanz in frühen Phasen einer Integralen Gebäudeplanung, *Bauphysik 40*,V **5** (2018)00016

[25] SBS Building Sustainability, Version 1.2 (14-01-2019) [https://www.gabi3.com/] – Generis [www.generis-solution.eu]

[26] Institut Wohnenund Umwelt 2005 - Deutsche Gebäudetypologie Systematik und Datensätze [https://www.iwu.de/fileadmin/user_upload/dateien/energie/klima_altbau/Gebaeudetypologie_Deutschland.pdf]

[27] Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) 2018 Kritienkatalog Gebäude Neubau – ökologische Qualität

[28] Mahler B, Idler S and Gantner J 2018 Mögliche Optionen für eine Berücksichtigung von grauer Energie im Ordnungsrecht oder im Bereich der Förderung, Endbericht

[29] Ellingham I and Fawcett W 2006 *New Generation Whole-Life Costing: Property and construction decision-making under uncertainty* (Oxford: Taylor & Francis)

[30] EXC 2120: Cluster of Excellence IntCDC – Integrative Computational Design and Construction for Architecture [https://icd.uni-stuttgart.de/?p=24111]