Analysis of current practice and future potentials of LCA in a BIM-based design process in Germany

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Abstract The construction and building sector, responsible for 39% of global greenhouse gas emissions, is undergoing a fundamental digital transformation enabled by Building Information Modelling (BIM). Integrating life cycle assessment (LCA) in digital building design processes enables early evaluation of embodied impacts. This connection offers opportunities to generate predictive parameters to efficiently use environmental optimization potentials. The aim of this study was to investigate current barriers and incentives for practitioners to use LCA in combination with BIM in practice in Germany. Based on criteria identified in a systematic literature review, a survey amongst 161 practitioners is conducted, analysing five different user profiles. The evaluated criteria are added value, perception of relevance, intention, age, data availability, standardization, external demand and usability. The results present a recognised added value of integrating LCA in BIM from the perspective of all user profiles. Currently, measures in a political and social context have higher potentials, i. e. are more urgent to implement, than measures in the information technology context, whereas priorities vary depending on user profiles. The greatest drivers are external demand and pressure in forms of stricter political requirements and more demand from the public-sector. The presented insights, trends and need for action can support implementing procedures for achieving the urgent climate goals of the construction sector strategically through digital transformation.

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1 Introduction

The architecture, engineering and construction sector (AEC) is responsible for a share of 39% of global greenhouse gas (GHG) emissions [1], yet at the same time is undergoing a fundamental transformation enabled by growing technological potentials, such as Building Information Modelling (BIM). Life cycle assessment (LCA) is widely recognized as a powerful tool to predict the environmental impacts of buildings during their life cycle [2]. The connection of BIM and LCA offers the opportunity to generate predictive parameters to efficiently detect and use environmental optimization potentials [3]. BIM is increasingly used to explore design solutions to improve the life cycle performance [4]. In particular, it enables monitoring and early evaluation of embodied environmental impacts related to manufacturing, replacement, and end of life of building materials and components. Despite the urgent need for action in order to reach the climate goals, the potentials associated with the integration of LCA in early planning phases in BIM are not yet practically used in the AEC sector [5]. There seem to be barriers that prevent the early integration of environmental sustainability assessments into the planning process. Furthermore, there is a lack of incentives for the integration of LCA in early planning phases, which may result from lack of data, missing standards or missing external demand. The aim of this paper was to show which potentials, and which need for action exist in Germany in order to establish early BIM-integrated building LCA in the digital planning process for the goal of climate neutrality. Previous studies have investigated strategies and ideas on a theoretical level and are used in this study to analyse the current practice and future potentials of LCA in BIM-based design processes in the practice environment in Germany. The results presented in this paper are a selection of the relevant survey data. The selection presents data that evaluates the status quo in Germany and data that evaluates future trends.

2 Research Approach

Based on criteria identified in a systematic literature review, an online survey amongst 161 practitioners was conducted in the first quarter of 2021 to find out what the current user profiles are, and which measures could help each of them to successfully implement BIM and set the horizon for LCA integration in their BIM-based design processes in future.
A total of 40 scientific publications in German and English that are not older than five years have been reviewed. Science Direct, Google Scholar and ResearchGate have been used as search databases. The keywords used have been "Building Information Model(l)ing and sustainability", "BIM and sustainability", "Life Cycle Assessment and BIM", "LCA BIM", "Linking LCA and BIM", "LCA integration in BIM", "LCA BIM potentials", "LCA BIM strategies", "LCA BIM success", "Drivers for LCA and BIM" and "Barriers of LCA and BIM". The literature has been reviewed to find common criteria based on their frequency of mention. The criteria found are 1) added value / advantage, 2) perception of relevance, 3) intention, 4) age, 5) data availability, 6) standards, 7) external demand, and 8) usability. The criteria recorded from the literature review form the survey content in the quantitative survey and serve as a base for theses/focus questions in the subsequent evaluation (figure 1). After importing the survey data into an excel spreadsheet created for data analysis, the population of practitioners surveyed is divided into user profiles to investigate the relevant perspectives and motives on how LCA and BIM are used.

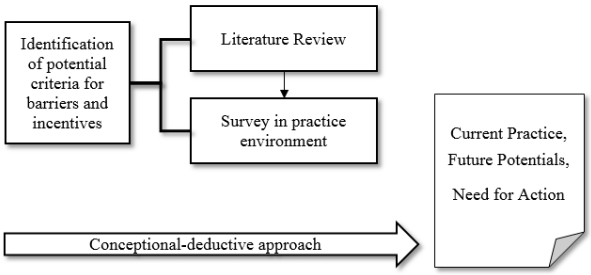

Fig. 1. Research approach

3 Screening and Results of Current Practice

Depending on whether a survey participant uses BIM and/or LCA, the five user profiles shown in Table 1 have been evaluated. Almost half of the total amount of participants use BIM (75 of 161) but only 13 of them use BIM in context with LCA.

Table 1. Use cases of current practice in Germany

	user profiles	number of participants N = 161 = 100 %	
		n absolute	n percentage [%]
1	Users of **LCA with BIM**	13	8,1
2	Users of **LCA** and **BIM**, no LCA with BIM	14	8,7
3	Users of **LCA**, no BIM	38	23,6
4	Users of **BIM**, no LCA	48	29,8
5	No LCA, no BIM	48	29,8

The number of participants in the user profiles 1 and 2, which are particularly relevant for this work, is relatively low and thus only allows for a low statistical significance. In these user profiles, the results can only be used for circumstantial evidence and indications, but remain an observation of subjective data. With the generated data basis as trend reference, further and more detailed evaluations could be carried out under extended conditions.

Wastiels and Decuypere [6] researched on LCA-BIM integration strategies and identified the workflows displayed in figure 2. Number 5, a fully integrated solution, is the target in future and aims for LCA enriched BIM objects. The recommendation by Wastiels and Decuypere in this workflow is to include LCA data in the BIM objects within the BIM software. The LCA then either is created in a plug-in or after export to an LCA software there. According to the survey, currently most practiced in Germany is workflow number 1.

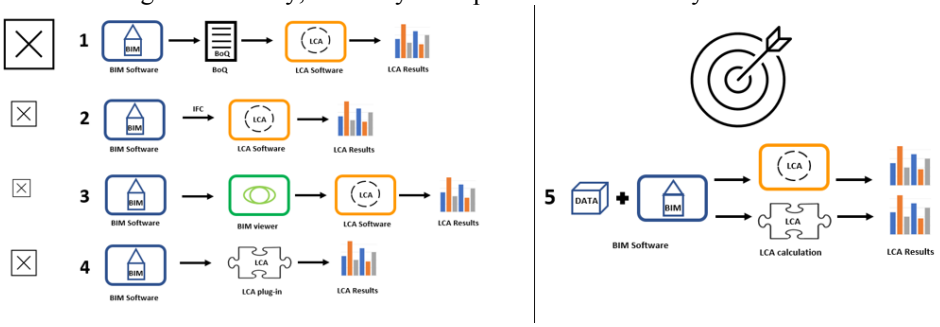

Fig. 2. Survey results concerning the workflows of LCA-BIM integration strategies of Wastiels & Decuypere (the size of the cross indicates the number of practitioners using each strategy)

The collected data from the answers of survey participants were evaluated as frequency distributions with a focus on particular theses/focus questions. For comparison of the theory reviewed in the literature review and practice shown in the survey data, table 2 shows tendencies of agreement. The survey data confirmed that BIM-based LCA adds value to digital building design processes and that the AEC sector is aware of the relevance of BIM-based LCA for climate-neutral construction. There is no confirmation, that LCA only takes place in the context of sustainability certifications. Younger users tend to be more likely to use BIM-based building LCA than older users. Higher LCA data quality and availability tend to be not primarily demanded by those who carry out LCA in early planning phases. All persons questioned and not only specific use cases demand a higher level of standardization and data availability. External demand, such as political requirements and legal guidelines, tends to be the most important factor for pushing BIM-based building LCA in Germany.

Table 2. Comparison of theory and practice

Criteria	These	Tendency
Advantage	BIM-based LCA adds value to digital building design processes.	Yes
Perception of relevance	The construction and building sector is aware of the relevance of BIM-based LCA for climate-neutral construction.	Yes
Intention	LCA only takes place in the context of sustainability certification.	No
User Age	Younger users are more likely to use BIM-based building LCA than older users.	Yes
Data availability	Higher LCA data quality and availability is primarily demanded by those who carry out LCA in early planning phases.	No
Standards	Open BIM users are more likely to be inhibited by insufficient standardisation of the process than closed BIM users.	No
External demand	Political requirements and legal guidelines are the most important factors for pushing BIM-based building LCA.	Yes
Usability	People who work with BIM and create building LCA separately, demand overall workload reduction.	Yes

Users of LCA and BIM, who do not conduct LCA with BIM (user profile 2) and users of only LCA and no BIM (user profile 3) create LCA mostly in the context of sustainability certifications. However, user profile 1, users who already execute LCA with BIM, mainly already use it in the planning process, for example to optimize energy concepts or selection of material (table 3).

Table 3. Frequency distribution for intention

What is your main intention of creating building LCA?

	1	2	3	total
	[%]	[%]	[%]	[%]
sustainability certification for buildings (DGNB, BNB, etc.)	38,5	57,1	68,4	60,0
In the planning process, e.g. for optimising energy concepts or material selection	61,5	42,9	31,6	40,0
Unanswered	0,0	0,0	0,0	0,0

Embodied energy and GHG emissions of technical building equipment are considered in most of the building LCAs today in Germany in all user profiles. However, users who already conduct LCA with BIM (user profile 1) represent the group who disregards the technical building equipment most often (Table 4).

Table 4. Frequency distribution for consideration of embodied energy and emissions of technical building equipment

Do you consider embodied energy and GHG emissions of the technical building equipment in the LCA of buildings?

	1	2	3	total
	[%]	[%]	[%]	[%]
Yes (detailed or simplified procedure)	61,5	71,4	81,6	75,4
No	38,5	28,6	18,4	24,6
Unanswered	0,0	0,0	0,0	0,0

4 Results and Discussion on Future Potentials of LCA in BIM-based building design

Figure 3 ranks possible measures, that according to the survey in future could help and be drivers of LCA in BIM-based building design. The participants see the highest potential in external demand and pressure in forms of stricter political requirements (legal frameworks) and more demand from the public-sector.

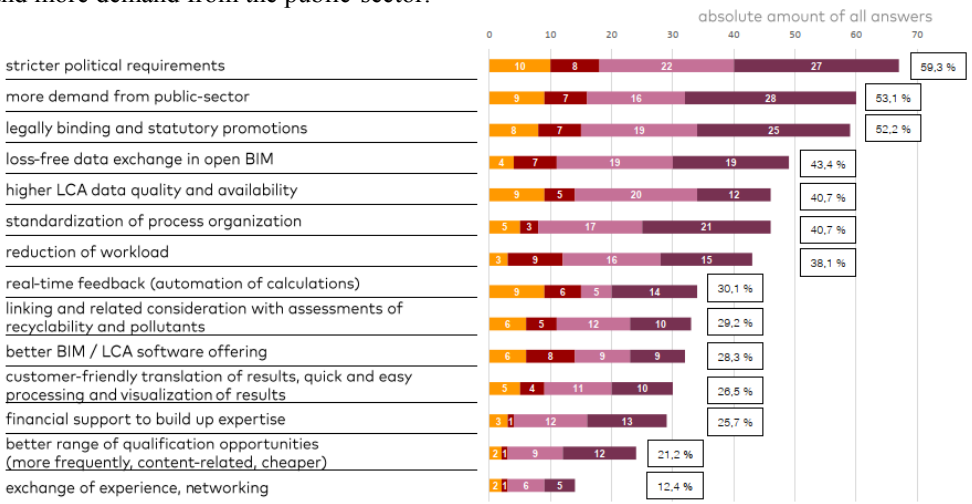

Fig. 3. Future Potentials of LCA in a BIM-based design process in Germany

The relevance ranking of the measures results in the first three measures with shares over 50 % as the most relevant and urgent need for action. Table 5 highlights, that each user profiles sees the measures prioritized differently, which shows they all have individual need for action. However, the biggest drivers for all of them are external demand in forms of more political requirements and increased demand from public clients. In total, currently, measures in a political and social context have higher potentials, i. e. are more urgent to implement, than measures in the information technology context, whereas priorities vary depending on the user profiles. This behaviour may indicate that the investigated user profiles are still in the process of adapting to the new possibilities offered by BIM.

Table 5. Ranking of priorities within the evaluated user profiles 1, 2, 3 and 4

	1 LCA + BIM	2 BIM - LCA	3 LCA, no BIM	4 BIM, no LCA
stricter political requirements	1	2	1	2
more demand from public-sector	2	3	5	1
legally binding and statutory promotions	3	3	3	3
loss-free data exchange in open BIM	6	3	3	5
higher LCA data quality availability	2	5	2	9
standardization of process organization	5	7	4	4
reduction of workload	7	1	5	6
real-time feedback (automation of calculations)	2	4	10	7
linking and related consideration with assessments of recyclability and pollutants	4	5	6	10
better BIM / LCA software offering	4	2	8	11
customer-friendly form of translation of results, quick and easy processing and visualization of results	5	6	7	10
financial support to build up expertise	7	8	6	8
better range of qualification opportunities (more frequently, content-related, cheaper)	8	8	8	9
exchange of experience, networking	8	8	9	12

As shown in table 6, perception of relevance is evident in all user profiles.

Table 6. Frequency distribution for perception relevance

Do you think it will be important to be able to implement and offer BIM-based/integrated building LCA as a practical planning tool in terms of climate neutrality?

	1 [%]	2 [%]	3 [%]	4 [%]	total [%]
Yes	100,0	78,6	86,8	89,6	88,5
No	0,0	21,4	10,5	10,4	10,6
Unanswered	0,0	0,0	2,6	0,0	0,9

All user profiles stated standardized LCA benchmarks could be of help in early planning phases (Table 7).

Table 7 Frequency distribution of standardized benchmarks in early planning phases

In early planning phases, the information content is low.
Do you think it makes sense to establish standardized LCA benchmarks (based on statistical evaluations) at the component level in order to provide in initial ecological decision-making?

	1 [%]	2 [%]	3 [%]	total [%]
Yes	92,3	92,9	89,6	90,7
No	7,7	7,1	10,4	9,3
Unanswered	0,0	0,0	0,0	0,0

Based on the survey results, it can be stated that in order to be able to make greater use for optimising the design, especially during the early planning phases, simple procedures are

required in addition to the further development of suitable technological prerequisites. There must be virtually no additional effort in terms of time and costs. Promotional points of attack are to be found in the political and financial support programs with at the same time ongoing reduction in the workload. It would not be appropriate to demand ever more complex verification procedures, which may even make projects more expensive. Public support and action, such as financing facilitation or exemplary projects by public clients, would create incentives here. BIM is recognized as ideally suited as a method for the digital building planning process due to its high data density and intensive interdisciplinary cooperation by both, reviewed literature, and survey results. If the direction of implementing high-quality LCA data availability for future-oriented automated building LCA is maintained and the advantageous data and information basis provided by BIM are used accordingly and will be supported by stricter political requirements in Germany, ideal conditions may be expected to be created for taking a major step towards climate neutrality in the AEC sector through the assessment and consideration of embodied energy and GHG emissions.

5 Conclusion

The survey of 161 participants in Germany identifies LCA as a means for assessing embodied energy and GHG emissions in the digital planning process to be an accepted method in the practical environment. The survey results indicate that the investigated user profiles are still in the process of adapting to the new possibilities offered by BIM and that different measures may have different potentials. Both, the reviewed literature, and survey data find holistic building data structuring and working with the BIM method offer a high potential for creating and optimizing building LCAs more efficiently. In particular, added value consists of being able to use building LCA more comprehensively and in higher quality for environmental sustainability optimization through simpler and more structured and thus faster and more accurate results. The quality of the data within the digital building model is essential here, as well as the availability of LCA data, which is low in the early planning phases. This analysis shows a high level of interest in integrating building LCA into BIM workflows and a high level of motivation for contributing to the reduction in environmental impacts of the AEC sector in Germany. LCA and BIM are used both for sustainability certifications, which already seem to be an established practice, and for planning optimization purposes. Here, the survey participants demand to establish standardized LCA benchmarks based on statistical evaluations for early planning phases. It can be assumed that in future the practical environment will mostly adopt automated solutions and a fully integrated workflow as described by Wastiels and Decuypere [6] as long as this does not cause an increased workload. To use the practitioners' given awareness of relevance and responsibility, action is needed to increase political requirements and legal support, financial incentives. Furthermore, loss-free data exchange in open BIM projects, role model projects, further development and improvement of quality and quantity of LCA data and promotion of understanding and user-friendly communication of LCA results are needed. Finally, the evaluation of embodied energy and GHG emissions in the digital building planning process through an early integration of LCA offers opportunities to generate real time parameters and thus to efficiently use optimization potentials during the design process. Looking to the future based on the survey results, it can be assumed that with increasing awareness of responsibility and the degree of digitalisation in the AEC sector worldwide, with the application of BIM-integrated LCA, and thus growing transparency with regard to the evaluation of embodied energy and GHG emissions, an increasing efficiency in using the given environmental optimization potentials will be possible. To make use of these optimization potentials in the AEC sector will be crucial for reaching the climate goals.

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