Challenges in developing a holistic Whole Building Life Cycle Assessment (WBLCA) software tool: developers' goals

T Sartori[1], **R Drogemuller, S Omrani and F Lamari**

School of Architecture and Built Environment, Queensland University of Technology (QUT) Gardens Point campus. 2 George St Brisbane, QLD 4000 - Australia

[1] thais.goncalvessartori@hdr.qut.edu.au

Abstract. The Intergovernmental Panel on Climate Change (IPCC) recently released a report emphasizing the importance of reducing carbon emissions, indicating that the construction industry is a key player in this process. Whole Building Life Cycle Assessment (WBLCA) is the most efficient method for evaluating buildings' environmental impacts. It considers the effects of energy consumption during operation and the environmental impacts of extracting, manufacturing, transporting, assembling, and maintaining the building's components. However, numerous obstacles prevent WBLCA from being fully applied by decision-makers during the building project process (BPP). This paper discusses and suggests improvements to the challenges of integrating WBLCA and BPP. An online survey was performed with nine WBLCA software developers worldwide, examining the critical challenges and how to overcome them. Most participants agreed that increasing WBLCA demand is the most pressing issue. It would encourage the entire construction sector to adopt a life-cycle mindset, pushing WBLCA software developers to improve software tool integration with the BPP. Results from this study will assist software companies and policymakers develop tools and regulations more aligned with the interests of designers.

1. Introduction

The most recently Intergovernmental Panel on Climate Change (IPCC) report revealed the damage caused by carbon emissions in global warming, and the consequences in the near future if no action is taken [1]. The construction industry has a great responsibility in this scenario since it is responsible for almost 40% of the world's total carbon emissions [2]. Built environment professionals are working together to create mechanisms to increase public awareness [3], and countries have been developing regulations to reduce the contribution of buildings to global carbon emissions [4, 5]. A whole life-cycle approach should be considered to effectively reduce building's environmental impact.

Whole building Life Cycle Assessment (WBLCA) is an environmental impact assessment (EIA) methodology that considers all stages of building's life cycle. Figure 1 [6] shows the stages of the building life cycle, which includes product stages (A1-3), construction (A4-5), use stages (B1-7), end of life (EoL) (C1-4), as well as stages beyond the system boundary such as reuse, recovery and recycling potential [7]. Designers should be able to access this methodology to evaluate the impacts of their decision during all stages of building project process (BPP). The early stages of BPP are especially critical because that is when changes in the project do not significantly impact the overall cost [8]. However, WBLCA is a data intensive approach, and designers do not always have the data available at the beginning of the design. Thus, when WBLCA is performed in the later stages, the assessment results

only react to the design rather than taking a proactive approach, when the outputs should be used to make environmental improvements [9]. This issue becomes more critical when designers lack the knowledge necessary to interpret WBLCA data to then take action to reduce carbon emissions throughout the building's life cycle [10].

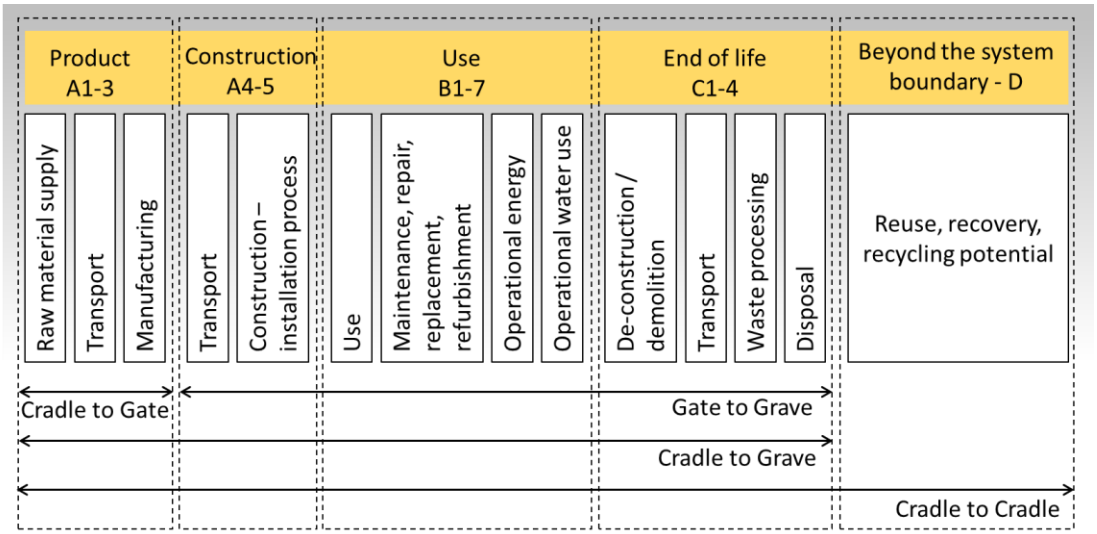

Figure 1. Stages of building's life cycle [6]

Companies have been developing tools to better integrate WBLCA into BPP. Bach and Hildebrand [11] performed a comparative overview of EIA tools finding that, despite the tools' effort to integrate with design, there are still some issues regarding the appropriate database usage, the assimilation of operational energy and the consideration of other natural resources. Sartori, Drogemuller [6] analysed LCA tools used for Green Building Rating Systems (GBRS) certification, concluding that software tools perform LCA in parallel with the design project, instead of being integrated. There is also an effort to integrate the assessment with the design through Building Information Modelling (BIM) [12-14]. However, most assessments only use BIM for materials take-off, and less than 20% of the studies fully integrate LCA with the 3D model [12]. Consequently, challenges still need to be overcome to fully integrate WBLCA with the building project process (BPP).

This paper investigates the challenges of integrating WBLCA with BPP. Nine WBLCA software tool developers worldwide were surveyed to comment on and to suggest solutions to the challenges. The survey was developed based on the literature, collecting the most common challenges faced by the designers during assessment. Subsequently, results from the literature were compared with the outputs from survey, and an analysis of the relationship of the WBLCA challenges were presented.

The discussions highlighted in this article provide insights to policymakers and software tool developers on how to address the challenges associated with combining WBLCA and the BPP. This study shows interim results of a survey, which is part of an ongoing PhD candidature.

2. Literature Review

A structured literature review was conducted to build the theoretical foundation for the survey and develop the survey items. The first criteria for selecting the articles was the designer-centered approach, i.e. peer-reviewed articles that have conducted a survey, interviews or focus group with users of building's environmental impact assessment (EIA) tools. Although the selection criteria for publications focused mostly on LCA tools, the scope was expanded to include energy performance tools, as only a few papers referenced LCA. In addition, only the articles published in the last ten years were considered. Table 1 lists the references selected and the challenges they have cited.

Table 1. Challenges and their respective references

Challenges	Total	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[10]	[22]	[23]	[24]	[25]	[26]	[27]	[28]
Align software tools with the building design process	10			X	X		X		X	X	X		X	X	X	X
Include WBLCA as part of the designers' education, culture and practice	10	X		X	X	X	X	X	X	X	X			X		
Make WBLCA methodology easier for designers	7		X			X	X		X	X	X	X				
Increase the collaboration between designers and other WBLCA sectors, such as industry, researchers and tool developers	7		X	X					X	X			X	X	X	
Increase WBLCA demand, e.g., from clients, certification bodies and government	6		X				X		X	X	X	X				
Reduce the time and cost of performing WBLCA	6		X	X			X	X		X	X					

One of the most cited challenges is the lack of alignment of software tools with the building design process. Bleil de Souza [26] mentioned the inappropriateness of the input interface, which requires detailed information which is not always available at the beginning of design. Indeed, LCA tools are typically developed by LCA experts, making them more appropriate for academic study or the development of Environmental Product Declaration (EPD) [20]. However, while scientists tend to focus on the underlying methods, designers are more concerned with achieving the desired result. In other words, while academics are problem-focussed, designers are solution-focussed [29]. Due to these divergent approaches, the adaptation of LCA tools to the design practices is still inadequate [20]. Designers are more interested in the relationship between the inputs and outputs, i.e. the association between the design decisions and the building performance, which the existing eco-design tools are not sufficiently offering [26]. In addition, the use of more sophisticated analysis methods, such as statistical uncertainty analysis, may miscommunicate the results to non-LCA experts [20].

Several references agreed that designers may use WBLCA tools more regularly if the methodology became embedded in their education, culture, and practice. There is a lack of understanding among design professionals about the basics material's physics and how this influences the energy performance and carbon emissions of buildings [26]. This is because architects are usually concerned about the overall aesthetics of the building shapes, functions and spaces, failing to analyze the quantitative performance indicators [17]. Numerical simulations are not sufficiently included in the architects' academic background, so the results from software tools cannot easily be interpreted and converted into design guidance [10, 17]. Additionally, the challenge of implementing environmental impact assessment tools into the daily design practices varies according to the size of the business [10, 20]. While larger firms can retain a dedicated sustainability department, smaller offices, due to limited resources, lack the time and skilled professionals to perform this activity. Regardless of the firm's size, environmental issues should be an intrinsic part of the design rather than a technical or project-based activity [10].

Another challenge is the complexity of LCA methodology, which requires a great amount of geographically related data, i.e., LCA data varies depending on the building location. The reliability of the data is also a concern, and checking its accuracy requires a level of understanding not compatible with the designer's expertise [19]. The literature suggests ways of making WBLCA easier during the

design practice. For instance, Building Information Modelling (BIM) can decrease the time and effort of performing WBLCA because it enables the connection with WBLCA tools and quantities take-off [12-14]. Another way to make WBLCA more accessible is to homogenize the LCA requirements in the various regulations and certification schemes, such as the life cycle definitions, the required parts of the building, function units, characterization model and impact categories [19]. The release of standardized benchmarks or target values would reflect the building's position on an environmental impacts scale, indicating whether the project performed better, average or worse than expected [10]. Schlanbusch, Fufa [22] mentioned the necessity of LCA guidelines that speak the designer's language.

A challenge frequently mentioned was the lack of collaboration between designers and other WBLCA sectors, such as industry, researchers and tool developers. There is miscommunication among the members of the project team, such as architects, building consultants, engineers and contractors [16, 17, 26]. To increase collaboration, developers of environmental impact assessment (EIA) software can share their knowledge to optimise the user experience [25, 27] and authority bodies can develop codes, rules and regulations that take into account the perspectives of building project stakeholders [22, 25, 27].

The lack of WBLCA demand was also mentioned as one of the barriers to integrating this assessment methodology into the building project process. Although there is an effort to harmonize technical terms [30] and standardize LCA at a product level [31, 32], at the building level there is a lack of regulatory obligations [20], and voluntary certifications do not give enough credits to motivate wide spread WBLCA performance analysis [10, 33]. Lack of clients demand was mentioned as one of the biggest barriers in a study conducted by Olinzock, Landis [23].

When incorporating EIA into a project, the design team spends more time managing data instead of performing the assessment. According to a survey conducted by Jusselme, Rey [16], performing an LCA on each design alternative at the early design stage takes between 18 to 33 hours, from data collection through results interpretation. This adds not only time to the project but also work and cost. However, architects argued in a focus group experiment that each design alternative should take no more than 30 minutes to complete if they were to provide effective design guidance [21]. Therefore, it is important to identify strategies to reduce the time gap between the current practice and the designer's expectations [18].

3. Research Methodology

A questionnaire followed by an interview was undertaken with WBLCA software tool developers from April to June 2021. Several WBLCA software tool developers were contacted via email available on the software website. Table 2 summarises the software tools that participated in the survey. Tally contributed two software developers, bringing the total to nine.

Table 2. List of software tools that participated in the survey

Software tool name	Country	Company	Website
Athena	United States	ASMI – Athena Sustainable Materials Institute	http://www.athenasmi.org
CAALA	Germany	Bauhaus University Weimar	https://caala.de
EcoEffect	Sweden	KTH – Royal Institute of Technology	http://www.ecoeffect.se/
Etool LCD	Australia	Etool	https://etoolglobal.com
LCAbyg	Denmark	National Building Research Intitute	https://www.lcabyg.dk/
One Click LCA	Finland	Bionova Ltd	https://www.oneclicklca.com
Pleiades ACV EQUER	France	IZUBA energies	https://www.izuba.fr/logiciels/outils-logiciels/pleiades-acv/
Tally	United States	KT Innovations	https://choosetally.com

Figure 2 shows a schematic flow of the survey. In the survey, participants ranked in order of importance the list of challenges that should be addressed to integrate WBLCA with the BPP. The list of the six challenges was obtained from literature, as shown in Table 1. Participants were encouraged to add more challenges to the list. After answering the survey, software developers were contacted for an online interview, when they explained their selection and suggested solutions to the top three challenges they had previously ranked.

The articles selected in the literature review and the interview transcriptions were coded and analyzed through NVivo, a qualitative data analysis. Nvivo was used to compare the word frequency between the results of the literature review and the responses from the software developers. The result of this comparison are described below.

Figure 2. Survey schematic flow

4. Survey Findings

Figure 3 shows the results of the first part of the survey when the 6 WBLCA challenges were ranked in order of importance.

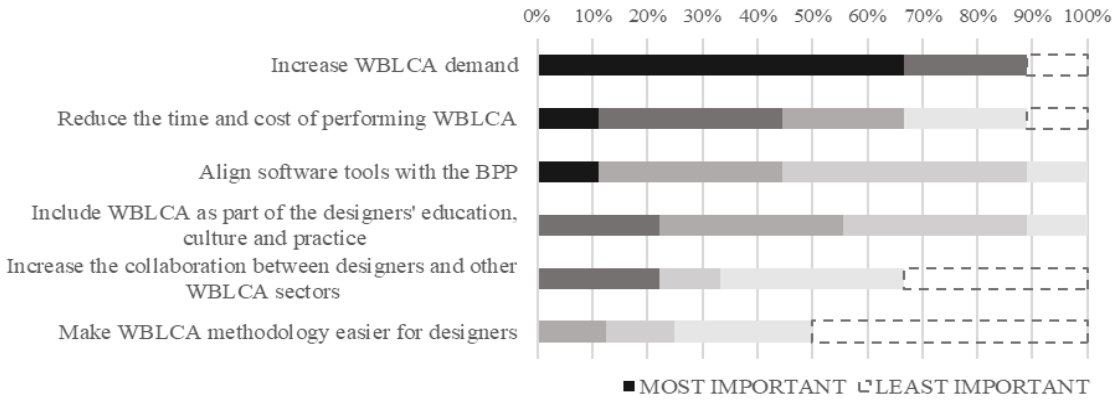

Figure 3. Challenges importance level

Increasing WBLCA demand was the most important challenge that needs to be addressed to integrate the assessment with the buildings project process (BPP). Many of the participants agreed that increasing WBLCA demand would trigger other challenges. For instance, by making WBLCA mandatory, the construction industry will push software companies to develop tools more aligned with the BPP to reduce assessment time and cost. However, making LCA mandatory is insufficient if it is not used to guide decisions from the early stages of design. It was suggested stablishing a Pigouvian tax to overcome the negative externality caused by the building's production, maintenance, occupation, and demolition. By including a Pigouvian tax based on a WBLCA, the construction industry will be forced to assess the

additional cost of the negative externalities, which will be passed on to the consumer, making the more pollutant materials or processes more expensive [34]. This would also motivate the construction industry to search for cleaner processes and actions to promote positive externalities, such as investments in research and development (R&D). To increase the demand, one of the interviewees suggested increasing the WBLCA credits given by certification systems. In other words, certification systems would create a "super credit" that includes all categories whose impact can be quantified using WBLCA.

Aligning software tools with the BPP and reducing the time and cost of performing WBLCA were often mentioned together by the participants, as the former is the solution to the latter. In fact, when tools are integrated with the design process, the time and cost associated with performing the assessment significantly decreases. Some of the suggestions to overcome these challenges are developing more accessible databases, harmonizing Environmental Product Declaration (EPD), building a user-friendly software interface and making available a library with rules of thumb suitable for designers. The European Comission has been working on harmonising rules for the marketing of construction products, providing a common technical language to assess the performance of construction products [30]. One participant suggested that, rather than reducing the time and cost of performing WBLCA, time and cost should be included in the project contract. While efforts are being made to simplify LCA for designers, it is indeed a complex assessment, and reducing time and cost may compromise the outputs' reliability.

Developers showed optimism about introducing WBLCA into designers' education, culture and practice, arguing that it is an ongoing process. The most concerning issue is the designer's understanding of the uncertainties inherent in the WBLCA outputs and the appropriate actions to mitigate the environmental impacts. Users should be trained to identify inconsistencies in the results and then investigate the source of the inconsistency. Certification systems have dominated the environmental impact assessment (EIA) scenario for many years, and continue to do so, by stating that a green building is the sum of the environmental improvements of different categories such as water, energy consumption and construction materials. WBLCA takes a systematic approach, integrating all categories in one single analysis. Changing this category type of mindset established by certification systems is gradually shifting to a life-cycle thinking approach.

Only a few interviewees mentioned increasing collaboration between designers and other stakeholders as one of the most important challenges. For instance, it was suggested that EPD developers collaborate to improve and standardize the requirements and improve the EPDs' comparability. Additionally, designers can share pre-defined building assemblies and assessment outcomes in a region-specific collective database. This is especially important in European countries, where architects' formal education is primarily centered on fine arts. Given that engineers retain the quantitative role, there should be increased collaboration between designers and WBLCA analysts. The association between policymakers, academia and industry was also mentioned. In fact, many tools developed in academia get outdated due to the lack of interest from the industry, which in turn is not required to conduct the assessment. However, as mentioned by one of the interviewees, if such obsolete tools had not existed, policymakers might not have included LCA in the agenda.

Making the assessment easier for designers is the least important challenge. Addressing the other issues, such as aligning software tools with BPP, offering WBLCA training or increasing the collaboration with other sectors, will directly make the assessment easier for designers.

5. Discussion and Conclusion

Nvivo, a qualitative data analysis tool, performed a word frequency query on the interview transcripts and on the coded paper's segments extracted from the articles, as illustrated in Figure 4. Only the 50 most frequent words were considered, and stemmed words were grouped. To ensure that only relevant terms were included in the word cloud, words that were expected to be often mentioned, such as LCA, WBLCA, tool, building and design, were excluded from the word frequency analysis. The word frequency is proportional to its font size, and the most frequent words are highlighted in red.

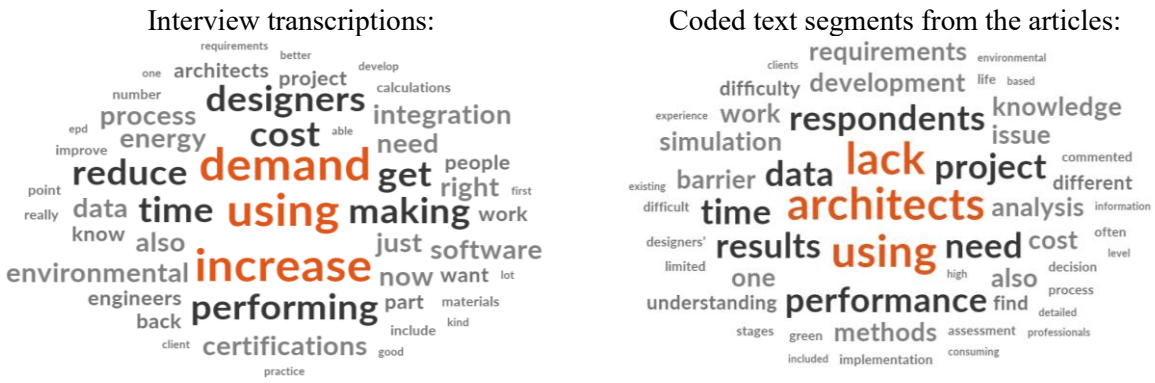

Figure 4. Word clouds

When comparing the two word clouds, identical or synonymous terms appear in the interview transcriptions and literature references, indicating that both software developers and researchers are synchronized. Text segments from the literature bring more negative words compared to the interview transcription, such as "lack", "difficulty", "limited", and "issue". This suggests that the articles selected in the literature review were more concerned about reporting the problem itself instead of finding the solution. This conclusion can also be drawn by looking at the most frequent words highlighted in red. While the references suggested the problem by frequently using the words "lack", "architects", the interview transcriptions had a more optimistic approach to the problem, frequently using the words "increase" and "demand".

As illustrated in Figure 5, the relationship between the challenges is analogue to "peeling the onion" [35]. In other words, to reach the root problem, which is integrating WBLCA with the BPP, there are many layers of challenges that need to be overcome. The first layer, which will unlock all the other challenges, is "increasing WBLCA demand". The most effective way to increase WBLCA demand is by making it mandatory through regulations. Additionally, demand will increase by providing fiscal incentives or increasing the impact of WBLCA performance on the credits given by certification systems.

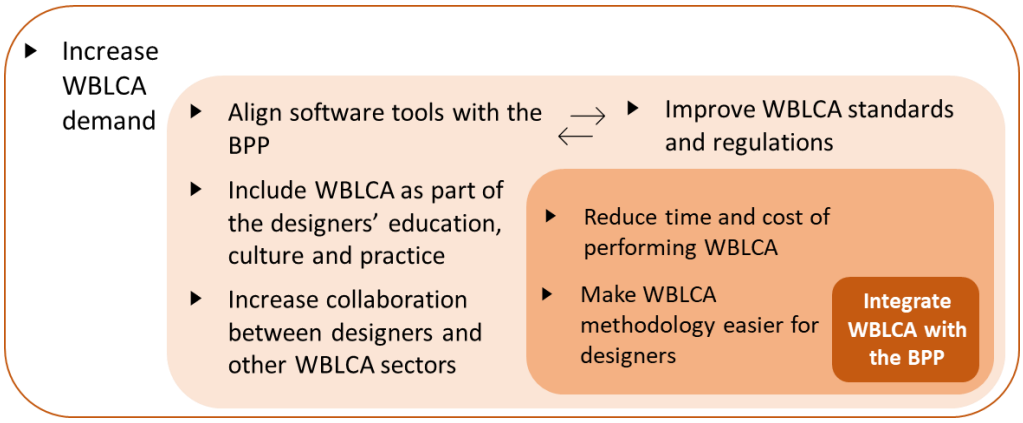

Figure 5. Schematic representation of the challenges

When demand increases, the second layer is reached, when the construction industry will find ways to adapt to the new status quo. For instance, designers will search for courses or training related to this topic, and universities will update the course curriculum to include LCA requirements. This process is already underway, particularly in the countries where WBLCA will soon become mandatory. As designers request more efficient simulation tools, developers will improve the integration of their

software into the BPP flow. This integration will happen easier if there is a collaboration between other WBLCA sectors, such as architects, engineers, manufacturers, academia, software developers and policymakers. This open line communication among the construction sector will ensure the reliability of the database and underlying reasoning and assumptions. One of the participants mentioned the relevance of improving WBLCA standards and regulations, which was not particularly mentioned in the literature review. In fact, software companies and policymakers can develop a working relationship and establish an agreement to share resources [36].

Reducing the time and cost of performing WBLCA and making the methodology easier for designers are represented in the third layer of the graph. In other words, making the assessment cost-effective and feasible for designers are consequences of overcoming all the other challenges previously discussed. Finally, after addressing all these challenges and peeling all the layers, the integration of WBLCA with BPP will be more efficiently reached.

The outputs of this study are intended to benefit software developers and policymakers to understand how to tackle the challenges of integrating WBLCA with design. A survey with WBLCA software users is in progress. This subsequent survey will identify what part of the assessment should be improved and what type of outputs are more suitable for each BPP stage. This will assist software companies in creating tools more suitable for designers, so they can use the simulation results to make more sustainable decisions. For future research, consideration of the construction product industry stakeholders will aid understanding of how to overcome the challenges of performing WBLCA for decision making.

Acknowledgement
This research was supported by Building 4.0 CRC (Cooperative Research Centre).

References

[1] IPCC 2021 Synthesis Report of the Sixth Assessment 2021 Available from: https://www.ipcc.ch/ar6-syr/
[2] IEA 2018 Global Status Report: Towards a zero-emission, efficient and resilient buildings and construction sector
[3] LETI 2021 Client Guide for Net Zero Carbon London p 108
[4] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings
[5] EU 2021 Energy efficiency: Revision of the Energy Performance of Buildings Directive Available from: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive_en
[6] Sartori T, Drogemuller R, Omrani S, Lamari F 2021 A schematic framework for Life Cycle Assessment (LCA) and Green Building Rating System (GBRS) *Journal of Building Engineering* **38**:102180
[7] ISO 15978: 2011 Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method2 p 64
[8] AIA 2007 Integrated Projetct Delivery: A Guide
[9] Roberts M, Allen S, Coley D 2020 Life cycle assessment in the building design process – A systematic literature review *Building and Environment* 107274
[10] Lamé G, Leroy Y, Yannou B 2017 Ecodesign tools in the construction sector: Analyzing usage inadequacies with designers' needs *Journal of Cleaner Production* **148**:60-72
[11] Bach R, Hildebrand L 2018 A comparative overview of tools for environmental assessment of materials, components and buildings. Sustainable and resilient building design: approaches, methods and tools

[12] Potrč Obrecht T, Röck M, Hoxha E, Passer A 2020 BIM and LCA Integration: A Systematic Literature Review *Sustainability* **12**(14)
[13] Crippa J, Araujo Aline MF, Bem D, Ugaya Cássia ML, Scheer S 2020 A systematic review of BIM usage for life cycle impact assessment *Built Environment Project and Asset Management* **10**(4):603-18
[14] Soust-Verdaguer B, Llatas C, García-Martínez A 2017 Critical review of bim-based LCA method to buildings. *Energy and Buildings* **136**:110-20
[15] Azizkhani M, Haberl J 2020 Assessment and discussion of the level of the application of passive/natural systems and daylighting systems by practitioners in the US *Science and Technology for the Built Environment* **27**:4 509-523
[16] Jusselme T, Rey E, Andersen M 2020 Surveying the environmental life-cycle performance assessments: Practice and context at early building design stages *Sustainable Cities and Society* **52**
[17] Xie X, Gou Z 2020 Obstacles of Implementing Green Building in Architectural Practices. Green Energy and Technology p 33-47
[18] AIA 2019 Architect's Guide to Building Performance: Integrating performance simulation in the design process p 91
[19] Bruce-Hyrkäs T, Pasanen P, Castro R 2018 Overview of Whole Building Life-Cycle Assessment for Green Building Certification and Ecodesign through Industry Surveys and Interviews *Procedia CIRP* 2018 **69**:178-83
[20] Meex E, Hollberg A, Knapen E, Hildebrand L, Verbeeck G 2018 Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design *Building and Environment* **133**:228-36
[21] Meex E, Knapen E, Verbeeck G 2017 A framework to evaluate the architect-friendliness of environmental impact assessment tools for buildings *eCAADe* 289-98
[22] Schlanbusch RD, Fufa SM, Häkkinen T, Vares S, Birgisdottir H, Ylmén P 2016 Experiences with LCA in the Nordic Building Industry – Challenges, Needs and Solutions *Energy Procedia* **96**:82-93
[23] Olinzock MA, Landis AE, Saunders CL, Collinge WO, Jones AK, Schaefer LA, et al. 2015 Life cycle assessment use in the North American building community: summary of findings from a 2011/2012 survey *The International Journal of Life Cycle Assessment* **20**(3):318-31
[24] Saunders CL, Landis AE, Mecca LP, Jones AK, Schaefer LA, Bilec MM 2013 Analyzing the Practice of Life Cycle Assessment: Focus on the Building Sector *Journal of industrial ecology* **17**(5):777-788
[25] Lasvaux S, Gantner J, Schiopu N, Nibel S, Bazzana M, Bosdevigie B, et al. 2013 Towards a new generation of building LCA tools adapted to the building design process and to the user needs *Proceedings of the international conference on sustainable buildings, construction products & technologies*
[26] Bleil de Souza C 2012 Contrasting paradigms of design thinking: The building thermal simulation tool user vs the building designer *Automation in Construction* **22**:112-22
[27] Gantner J, Saunders T, Lasvaux S 2012 EeBGuide: D43 Requirements for building LCA tool designer p 46
[28] Weytjens L, Attia S, Verbeeck G, De Herde A 2011 The 'architect-friendliness' of six building performance simulation tools: A comparative study *International Journal of Sustainable Building Technology and Urban Development* **2**(3):237-44
[29] Lawson B 2005 How designers think: the design process demystified 4th ed Amsterdam: Elsevier/Architectural Press
[30] European C 2022 Construction Products Regulation (CPR) Available from: https://ec.europa.eu/growth/sectors/construction/construction-products-regulation-cpr_en
[31] ISO 15804:2012+A1:2013 Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products p 70

[32] ISO BE 21930: 2017 Sustainability in Buildings and Civil Engineering Works—Core Rules for Environmental Product Declarations of Construction Products and Services Geneva, Switzerland
[33] Sartori T, Drogemuller R, Omrani S, Lamari F 2020 Analysis of Whole Building Life Cycle Environmental Impact Assessment (EIA) Tools *37th International Conference of CIB W78* online p 453-64
[34] Helbling T 2020 Externalities: Prices do not capture all costs Available from: https://www.imf.org/external/pubs/ft/fandd/basics/external.htm
[35] Connolly M, Harms L 2011 Onion-peeling theories. Social Work: From Theory to Practice Cambridge: Cambridge University Press p 73-100
[36] Moore T, Moloney S, Hurley J, Doyon A 2017 Implementing sustainability in the built environment