EXPLORING DESIGNER'S ATTITUDES AND CHALLENGES IN THE LIFE CYCLE ASSESSMENT OF BUILDINGS IN DENMARK

Aysar Dawod Selman[1], Hans L Heiselberg[1], Peter N Gade[1] and Anne N Gade[2]

[1] *Department of Architectural Technology and Construction Management, University College of Northern Denmark, Sofiendalsvej 60, 9200 Aalborg SV, Denmark*

[2] *Department of Energy and Environment, University College of Northern Denmark, Sofiendalsvej 60, 9200 Aalborg, Denmark*

Requirements on building's carbon footprint are being incorporated into various European countries' legislative frameworks. By 2023 the Danish legislation requires performing Life Cycle Assessments (LCA) for all new buildings. However, studies show that few designers have experience in LCA or are yet equipped to work with it, lacking research on designers' attitudes and experienced challenges in LCA application. Through Activity Theory analytical framework, this study explores designers' attitudes in LCA application, unfolding the perceived challenges. Semi-structured interviews were conducted with six respondents involved in building design, including architectural technologists and engineers with various experiences in LCA. Results reveal that organisations use increased resources in an LCA, as it is a complex and demanding task. The main challenges were lack of LCA experience, lack of information, and data inconsistency. However, results indicate an overall green transition within the organisations, understanding the expected consequences of adapting LCA and the importance of materials choice. Establishing standards to support LCA in building regulations is necessary, designing buildings back wiser.

Keywords: life cycle assessment; building design; challenges; activity theory

INTRODUCTION

Buildings contribute significantly to global resource consumption and environmental emissions from operational energy and material use. Hence, several countries have issued rules for assessing CO2 emissions based on the life cycle assessment (LCA) method (Kanafani *et al.,* 2021). In the EU, increased use of LCA for an environmental performance assessment is evident in the scientific and policy communities. Greenhouse gas emissions must be reduced by at least 55% by 2030, becoming climate neutral by 2050 (European Commission, 2020). Some European countries have included requirements for LCA results to deal with the environmental impacts of buildings (Lützkendorf, 2018).

The Danish political agreement, March 2021, has set CO2 requirements for new construction in Building Regulations by 2023 (BR23) as buildings above 1000 m2

[1] adse@ucn.dk

Selman, A D, Heiselberg, H L, Gade, P N and Gade, A N (2022) Exploring Designer's Attitudes and Challenges in the Life Cycle Assessment of Buildings in Denmark *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 721-730.

must not emit more than 12 kg CO2-equivalent/ m2/ year over a 50-year life span. Also, the climate impact must be calculated for all construction. In BR23, the voluntary sustainability building class requires a maximum CO2 limit of 8 kg CO2-equivalent/ m2/ year (National Strategy for Sustainable Buildings, 2021). Informed design decisions mitigate potential environmental impacts by using LCA in the early project stages (Lykke *et al.,* 2020). LCA is applied in building certification schemes, e.g., BREEAM or DGNB, and for environmental labels (e.g., Environmental Product Declarations (EPD)) to quantify, communicate and manage environmental impacts from buildings (Schlanbusch *et al.,* 2016).

To mitigate CO2 emissions, designers strongly need LCA tools for making informed design decisions (Kanafani *et al.,* 2021). In 2015, the Danish LCA tool LCAbyg was launched under the auspices of Danish building authorities. The LCA database Ökobaudatas was selected as a source for national generic environmental data (Kanafani *et al.,* 2021). Both research and experiences from involved practitioners recognise challenges linked to tools used for sustainable buildings and LCA application. Performing an LCA is complex and time-consuming (Schlanbusch *et al.,* 2016). According to Rasmussen *et al. (*2020), applying LCA in early design phases is a new challenge for practitioners and collecting data for LCA calculations is complex. Actors expect that when LCA becomes a mandatory task, it can add difficulties for organisations with no or minor experience in LCA. Hence, supporting organisations to fulfil CO2 requirements and strengthen LCA application is essential. Thus, this paper aims to explore designers' perceived challenges, attitudes, and experiences with LCA, raising the research question: "What are the attitudes of designers and their perceived challenges when assessing the environmental impact of buildings in Denmark?"

Rossi *et al. (*2016) identified barriers to implementing sustainable design methods and tools concerning their structure, lack of knowledge and time-consuming efforts. Ipsen *et al. (*2021) reveal that a lack of suitable sustainability tools hinders the sustainability design of buildings. Kanafani *et al. (*2021) argue that to mitigate CO2 emissions, designers strongly need LCA tools to make informed design decisions, especially in the early design stages, where significant sustainability decisions are made. However, the complexity of LCA has often been perceived as a barrier to implementing LCA in building design. Hence, a well-considered tool design can deliver reliable and valid results while keeping the extra workload for LCA implementation in the design process to a minimum. A Nordic survey by Rasmussen *et al. (*2020) showed that designers generally feel professionally committed to applying LCA. However, a primary barrier for LCAs in building design is the perceived lack of incentives, sufficient data and information. Design practitioners perceive a moderate drive for integrating environmental performance assessments, needing to learn what drives and controls a project's results and converting results into understandable data for clients. Also, lack of designer expertise and consuming ample resources are critical barriers.

Schlanbusch *et al. (*2016) showed a growing use and Nordic market demand of LCA in recent years. However, lack of transparency and uncertainty of the inherent data affects the accuracy of LCA results, as an LCA analysis outcome should be the base for optimal decisions. Results revealed the difficulty of finding and collecting data in LCA, finding it resource-consuming. Also, handling the end-of-life phase of buildings in an LCA is challenging. The environmental benefits of recycling, reuse, and energy recovery present a critical knowledge gap in the building sector. The study emphasised the importance of further research on efficient LCA performance in early design. Anand and Amor (2017) consider LCA one of the most complex applications in analysing sustainable buildings due to numerous materials and processes, as the inventory data for LCA of a building highly depends on specific data of building components and materials.

Other challenges are building design, stakeholder criteria, cost, environmental targets, and users. Building inventory data is obtained from building industry databases or EPD. However, product data for LCA lacks environmental feedback for new and old products. In Denmark, Kanafani *et al.* (2021) defined four key areas for successful LCAbyg tool design: default information, flexibility, environmental design feedback, and transparent results. In the UK, Roberts *et al.* (2020) revealed that LCA faces barriers in methods and practice, preventing its ability to guide early-stage design decisions. Generally, it is used late in the design when too late to influence the design significantly. Incorporating LCA with building information modelling (BIM) or life cycle costing has the same challenges as undertaking a traditional LCA.

However, benchmarks, target values, and other information can incorporate life cycle thinking without undertaking a detailed LCA. Nwodo and Anumba (2019) reveal that a building life cycle inventory and LCA phases can be data intensive. Here, BIM-based LCA is suggested to overcome this challenge. Tally, a BIM-based LCA tool in the USA, was incorporated into Autodesk Revit (BIM) as a plug-in. In Denmark, the Department of Construction, Urban and Environment (BUILD) at Aalborg University is developing a BIM-integrated LCA tool using JSON format as a third-party integration in LCAbyg. GRAPHISOFT Center Denmark (2022) developed a BIM-based LCA tool to calculate a building's kg CO2-equivalent/ m2/ year, considering the building's use and materials, requiring Archicad and Excel software. A Finnish LCA software firm developed an LCA tool to reduce LCA workload (One Click LCA, 2022). The industry association DiKon (2022) aim to standardise the BIM model data to reduce manual tasks in LCA.

METHOD

A qualitative method was applied to explore designers' attitudes and perceived challenges in LCA application by conducting six semi-structured interviews (Kvale 1996) with two architectural technologists (A1 and A2) and four consultant engineers (E1, E2, E3 and E4) from middle-size (30-50 employees) and large organisations (>50 employees), selected via purposive sampling. They all support sustainability but have various levels of experience in LCA, evaluated according to the number of cases and years of experience in LCA to capture the controversies and diverging assessments, providing insights into their challenges in LCA.

Figure 1: Interviewee's job roles

Interviewee role	Architectural technologist and DGNB auditor	Architectural technologist and architect	Engineer	Engineer	Engineer and DGNB auditor	Engineer
Interviewee name	A1	A2	E1	E2	E3	E4
Organisation size	Medium	Medium	Large	Large	Large	Large
Experience in LCA	Medium	Low	Medium	Low	High	Medium

Interview Guide Using the Activity Theory Checklist

An interview guide was designed, following the strategy for semi-structured interviews (Kvale 1996), structured and analysed according to Activity Theory (AT) (Blunden, 2015) and AT checklist (Kaptelinin *et al.,* 1999). The premise of AT is that a collective work activity, with a basic purpose shared by others (community), is undertaken by people (subjects) who are motivated by a purpose or towards a problem solution (object), which is mediated by tools and signs (artefacts or instruments) used to achieve the goal (outcome). The activity is constrained by cultural factors, including conventions (rules) and social organisation (a division of labour) in the immediate context and framed by broader social patterns (of production, consumption, distribution, and exchange). AT provides a conceptual framework to understand the inter-relationship and contradictions between activities, actions, operations and artefacts, subjects' motives and goals, and aspects of the organisational and social contexts in which these activities are framed (Blunden, 2015). The main benefit of AT Checklist is to ensure that human collaborative activity is studied according to the theoretical underpinnings of what constitutes such activities. This helps ensure that all essential aspects of such activities are inquired to give the study scientific rigour. In addition, AT helped achieve a holistic perspective, analysing how activities play out between people, intentions, and technology [17], exploring in-depth actors' perceived challenges and attitudes using LCA.

According to Kaptelinin *et al.,* the AT checklist reflects the AT principles, resulting in four perspectives on the use of target technology to be evaluated (1999): 1: Means and goals: the extent to which the technology facilitates and constrains the attainment of users' goals and the impact of technology on provoking or resolving conflicts between goals. 2: Social and physical aspects of the working environment: integration of target technology with requirements, tools, resources, and social rules of the environment. 3: Learning and cognition in LCA: internal versus external activity components and support of mutual transformations with target technology. 4: Development of LCA: the developmental transformation of preceding components. Based on the four perspectives, interview questions were devised. Interviews were recorded, transcribed, and results were coded according to the answers themes rather than constricted to the checklist's four perspectives.

FINDINGS

According to AT checklist, the results are divided into five areas: The organisation's means and goals, the impact of LCA on designers' work and attitudes, learning with LCAs, LCA development, and insights into the building sector's green transformation.

Organisations' Means and Goals in LCA

Interviewees A2, E1, E2, E3 and E4 declared a significant focus on LCA in their organisations, and their preparations for BR23 are already proceeding, consuming ample time and resources, as also experienced when working with LCA as an essential part of the DGNB certification. In contrast, A1 declared less focus and effort in LCA application. However, they all perceive an increased focus on LCA, expecting an increased client demand, especially when it becomes mandatory to document buildings' CO_2 emissions by 2023. So, actors aim to understand the new CO_2 requirements and advise the clients on the most environmentally friendly decisions, e.g., making variant comparisons on building materials, as a foundation for discussion and decision making.

Furthermore, all interviewees agreed that LCA is an interdisciplinarity task involving building designers, producers, and contractors as they should all participate in a building LCA process, contributing with their area of expertise. In larger organisations, the sustainability department is mainly responsible for conducting an LCA in collaboration with the IT specialist responsible for BIM models and the architect. Various parameters can influence an LCA process, such as conservative actors, lack of fixed and transparent procedures and uncertainty due to lack of consistency in the building model. A2 stated that the ability to influence the input to LCA when the model is developed externally prevents proceeding with the calculations. However, it proceeds well when architects draw in the BIM software Revit. The variables influencing LCA application were explored, revealing that early intervention, defining materials and construction principles are essential. E2 mentioned that much input to LCA is initially estimated due to a lack of detailed material data.

According to E3 extracting quantities works well with BIM software but is challenging with other software or 2D methods. Other challenges are diverse interpretations of how, when, and by whom the building models data must be delivered and the required information level. E3 and E4 stated that DiKon has recently developed such standards. However, results indicate limitations with LCA, lack of experience and exact material data with uncertain estimations, and many manual tasks when importing materials EPDs to LCA, which are unavailable in EPD Danmark's database. E2 stated that this increases resources' use early in the projects, especially when updating and verifying materials and their quantities, revealing the need to automate LCA input. E4 declared that LCA's products database is built very specifically, so it can be challenging to find if, e.g., plasterboard is not explicitly named "Gypsum Gyproc". Also, LCAbyg has a difficult and not standard format (JSON format).

Impact of LCA on Designers' Work and Attitudes

Interviewees agreed that LCA work creates a change of attitude and adds greater knowledge to organisations. Overall, interviewees expressed that the actors have become more aware of the choice of materials in construction. Thus, materials are now considered more carefully. A2 stated that designers recommend building materials with lower CO2 impact, facing some client resistance, being a wake-up call for those who do not accept untraditional materials. It is revealed that LCA highly impacts architects in design limitations, forcing them to use new solutions. Also, materials origin must be considered when selecting products. Here, the economy plays an essential role, e.g., higher cost of energy used for materials production. Specifically, wood construction is considered, recognising its environmental benefits. Along these lines, A2 argued for an increased awareness of using less concrete. Generally, the awareness of material choices has spread among other professionals as there is a significant focus on this from all manufacturers, adding that leaders must promote sustainability and ensure it by raising competencies and specialists. A2 stated that LCA work is becoming more structured since they first started using it, and cooperation between involved actors is the best way to achieve satisfying LCA work processes. E2 revealed that certain building parts are not included in the LCA. Thus, an LCA can hide specific facts.

E4 declared a significant contradiction reflecting on LCA experts' workload: "The process towards providing complex decisions should be simpler. It cannot be right that our sustainability experts spend 80 percent of our time finding information and only 20 percent on creating a more sustainable building". Buildings' design is getting more complex, as many decisions must be made earlier than usual, which is challenging when the rest of the project is not geared towards it, creating the risk of some late design changes and adding economic challenges. Moreover, working with LCA has significantly affected project documentation work and data delivery, changing design processes, revealing that the LCA should run the design process, requiring an earlier and greater flow of information than usual.

E4 stated: "I often see that an LCA is used as a documenting tool rather than a real design tool...it is improving, and I can feel the paradigm shift towards using it as a real design tool". On the other hand, the interviewees confirmed a positive impact of LCAs. Besides the environmental benefits documented and visualised via LCA, focusing on building materials generally provides a better understanding of materials and their properties, e.g., less degassing from materials will provide healthier buildings. LCA also provides extra quality assurance by detecting incorrect quantities via LCA calculations in the early design stages. In addition, it generally provides greater knowledge of a building and opens a discussion about materials' lifetime, maintenance, and potential for circular strategies at the end of life.

Reflections on Learning with LCAs

The interviewees were asked whether learning LCA calculations require an excessive investment of time, effort and resources. A1 admitted the need for more extensive investment in learning and developing in LCA as they have not reached the desired level of expertise. Despite spending much time on it, admitting that smaller organisations might not be able to lift the task at the same level as larger organisations. Similarly, all interviewees declared that ample time was consumed in learning LCAs. Also, A2 revealed a learning period for the first projects before one gets self-driven.

E1, who works in a larger organisation, does not perceive LCAbyg as a difficult tool. They have a sustainability department with LCA specialists. However, he admits challenges in the work process, e.g., how the information is obtained, disclosed, and communicated, adding that learning is iterative. E2 stated that exchanging experiences with LCAs is a prerequisite for learning and expanding specialists in this area. Furthermore, the learning process in LCA involves communicating with all interdisciplinary specialities and pulling resources from other departments across the organisation. According to E3, learning LCA requires regular use and strategical work via a specialised sustainability department.

The interviewees were asked whether any activities in LCA work have changed over time since they started working with it. A1 revealed a higher focus on influencing the project in the early phases. According to A2, LCA work is getting more structured, and the process has become more standardised with fewer templates. E1 mentioned: "It is generally easier for larger organisations to control quality and share knowledge between organisations' branches". E2 stated that they learn fast from their own mistakes, doing things smarter, especially when working with new aspects: "I have certainly learned something, but mostly how I can optimise my processes" E2. According to E4, some tasks became simpler; others are still complex, e.g., requirements for expanding the building model's data with materials and their parameters, revealing that a digital platform (Dalux) is used to share LCA results. The interviewee's capability to master the tools they needed in LCA work was explored.

Responses varied, as engineers indicated that using LCAbyg is easier for them while roles with a more general function (A1 and A2) find it extremely difficult. According to A1, it is difficult to have control over LCAbyg, considering it frustrating as it is challenging to navigate the data, understand it, and further communicate the results. E1 declared that it is getting easier after consuming many hours with LCA. E2 mentioned that the tool is simple, but understanding its mechanisms is challenging, as it can be relatively complex. They seek help internally from colleagues and externally by referring to BUILD and their network. A2 stated that LCA methods develop continuously, e.g., considering the building's renovation phase, which requires continuous learning. However, results reveal some uncertainty about the voluntary sustainability class. E1 declared a lack of knowledge in defining the transport in the construction phase. A1 mentioned that they learn from competitors in finding practical ways to convey and present LCA results. A2, E1 and E2 clarified that they have a library to save previous LCA work and variant studies as a benchmark to compare.

E1 and E2 proposed that the manual work of defining quantities must be automated, requesting requirements for defining quantities in the tender phase. Generally, responses showed that it is imperative to reduce resource consumption when performing LCA analysis. However, A1, who lacks experience in LCA, requests to consume more resources to learn more about LCA, taking the challenges more seriously. All interviewees indicate the need to work with more practical and user-friendly tools. E2 stated that LCA results must include all environmental indicators, though the CO2 global warming potential is the most critical, adding that a reference period of 50 years is defined in LCA, which can be optimised. It was indicated that LCA users prefer to be less dependent on other disciplines in collecting data. Also, E1 requested a synergy between the Danish buildings' energy calculation tool (Be18) and LCA. E3 proposed developing methods of working with LCA, such as visualising the results with the building model and developing a drag and drop function.

All interviewees agreed that the available tools do not fully support users' needs. LCAbyg is too complex, requesting further improvements due to extensive manual work and a lack of integration between the data in the programs used. LCA users require a plug-in for Revit to automate the data flow between Revit and LCAbyg or import materials quantities from Excel into LCAbyg. E4 argue that it is troublesome to use JSON format raising technical challenges. Other aspects relate to the export and import of EPDs into LCAbyg, as it works well when choosing products from EPD-Denmark database but is challenging with other EPD databases. Finally, the satisfaction of available LCA standards was discussed. Here, E4 mentioned: "despite adequate standards for LCA, many uncertain areas still lead to confusion and incorrect calculations, which should be clarified". A1 stated that it is unclear which life cycle phases are included in BR23 CO2 requirements. E2 specified the need to clarify which building components to include in an LCA. Moreover, E3 and E4 pointed out the lack of standards for methods to present LCA results, as they can vary among projects and users.

The interviewees were asked about their insights into the building sector's expectations regarding the LCA progress. They shared similar visions in developing methods to make LCAbyg more operational and user-friendly with an automated link between Revit models and LCAbyg, along with standardised output from LCAbyg. Moreover, interviewees expect the development of a broader range of EPDs. The interviewees suggest improving actors' attitudes, accepting various approaches with increased LCA recognition, and integrating LCA early in the design process. According to E3, LCA application will be a more competitive parameter in the future than it currently is, and it will be relevant to evaluate and optimise their work with LCAs. E4 expects BR23 CO2 limits to include all buildings, not only buildings over one thousand square meters. Also, expectations for more explicit specifications on which building parts will be assessed in an LCA. Finally, E3 stated that smaller organisations would likely need to hire external consultants for LCA, at least in the short term, until they adjust and fit into the LCA demands. E4 argued that this would be a considerable challenge, leading to increased expenses, while larger organisations can easier adapt to these changes.

It is evident from the analysis of interviews that building practitioners perceive an increased focus and demand for LCA applications. Preparations for the upcoming CO2 requirements are proceeding, expecting an increased demand for it when it becomes mandatory in 2023, considering it a competitive parameter. The BR23 CO2 requirements will accelerate the adoption of LCA. Results show a knowledge gap perceived among LCA users, reflecting the complexity of LCA and the need for knowledge exchange. LCA specialists in larger organisations have adequate knowledge of LCA and are more confident with their experiences. In contrast, designers in organisations with fewer experiences are eager to learn more and request more investment from the leaders' side in increasing the organisations' competencies to catch up with the rapid development. Thus, leaders have an essential role in boosting LCA application. Results from interviews and research by Rasmussen *et al. (*2020) agree that LCA is an extensive task with many manual activities and increased resources. It starts early in the design phase and runs until the building is handed over. Moreover, it is an interdisciplinarity task, requiring collaboration and extra resources in the design team and among other professionals. Results revealed that various challenges influence LCA work, such as conservative actors, lack of experience, lack of fixed and transparent procedures, lack of materials data and uncertainty due to lack of consistency in the BIM model. Schlanbusch *et al. (*2016) defined issues related to inconsistency, transparency, comparability, and data quality and availability, affecting LCA results accuracy. Interviews results declared the difficulty of influencing LCA's input when the building model is developed by various tools and lack of exact material data with uncertain estimations and many manual tasks when importing materials EPDs to LCAbyg.

Kanafani *et al. (*2021) argued that a well-considered tool design could deliver reliable and valid results while keeping the extra workload for LCA implementation in the design process minimum. According to Ipsen *et al. (*2021), more holistic assessment methods and tools are lacking in considering sustainability from a broader definition. Roberts *et al. (*2020) exposed that LCA is generally used late in the design process when too late to influence the design significantly. This study confirmed that several factors impact designers' work and attitudes toward LCA. Here, the choice of materials in buildings is crucial; designers have become more aware of it, indicating the building sector's positive green transition and willingness to change its traditions. Clients got a wake-up call to choose new materials. There has been a significant architectural upheaval, impacting architects to design buildings more flexibly, considering untraditional building materials like using more wood instead of concrete, reflecting that buildings design is getting complex. Many decisions must be made significantly earlier than usual, with a greater flow of information, which is challenging when many design aspects are estimated, leading to the risk of late design changes. Thus, an LCA tool must be used as a design tool to document the environmental impact of buildings, designing buildings back wiser. The economy is also a key factor when choosing materials with lower CO2- emissions, as they can be costly. Moreover, LCA work has positively affected practitioners. Their work has become more structured and standardised using their own templates with improved collaboration between actors. LCA also provides extra quality assurance by detecting faulty materials quantities and gaining a more profound knowledge of a building, such as materials' lifetime, maintenance, and potential for circular strategies at the end of life. However, Schlanbusch *et al. (*2016) found that handling the end-of-life phase of buildings in LCA is challenging, and the environmental benefits of recycling, reuse, and energy recovery represent a critical knowledge gap in the building industry.

Also, learning and working with LCA requires much effort and resources. Interviewees, challenges in LCA mainly exist in the work process itself, e.g., how the information is obtained, disclosed, and communicated, rather than the LCAbyg tool itself. Generally, it is less challenging for larger organisations with higher experience and options to exchange knowledge internally than smaller organisations with less or almost no experience who most likely need to hire external LCA consultants, leading to higher consultation costs. Moreover, learning about LCAs requires exchanging experiences across the building sector. Actors learn faster by making mistakes and regularly working with LCA. Generally, engineers are more capable of mastering LCAs. Actors requested a more user-friendly tool to reduce manual work in LCAbyg, and an automated process by incorporating BIM to LCA and developing LCA standards to clarify uncertainties. These results aligned with Nwodo and Anumba (2019) and Rasmussen *et al. (*2020). BIM must go in hand with LCA application early buildings design to eliminate the risk of extra resources, requesting common standards for LCA-based tools for early design stages. Other LCA development potential involves expanding the materials in the Danish EPD database, including all environmental indicators in LCA, and defining other reference periods than 50 years. Finally, using AT assisted in a holistic analysis. Despite the limited number of interviews, answers gave valuable insights into the designer's LCA work.

CONCLUSION

To mitigate CO2 emissions, building designers use LCA tools for making informed design decisions. Previous research has highlighted several challenges in LCA application. Thus, this study aimed to explore designers' attitudes, perceived challenges, and benefits in LCA. Based on interviews with LCA practitioners, the results showed that LCA creates a change of attitude as actors have become more aware of the choice of materials in construction. LCA is an interdisciplinary task and must start in the early design stages. The main challenges involve extensive use of resources in LCA work, lack of experience, lack of exact material data, and lack of standards in methods to extract data from building models and formats to present results. Regarding LCA development potential, actors demand automation efforts between BIM and LCA, supplemented by common standards for LCA-based tools for early design stages. The study contributes to research and development in LCA application, aiming to support actors in increased understanding and use of LCA, indicating the need for more effective tools for sustainable buildings assessment.

REFERENCES

Agreement of National strategy for sustainable buildings (2021) Available from: https://im.dk/Media/C/4/Endelig%20aftaletekst%20-%20B%C3%A6redygtigt%20byggeri%20-%205.%20marts%202021.pdf aftaletekst - Bæredygtigt byggeri - 5 marts 2021 [Accessed 1 July 2022].

Anand, C K and Amor, B (2017) Recent developments, future challenges and new research directions in LCA of buildings: A critical review, *Renewable and Sustainable Energy Reviews*, **67**, 408-416.

Blunden, A (2015) *Engeström's Activity Theory and Social Theory*, Available from: https://www.ethicalpolitics.org/ablunden/pdfs/Engestrom.pdf [Accessed 30 June 2022].

DIKon (2022) DiKon vil harmonisere 3D-modeldata for livscyklusvurderinger i byggeriet**,** Available from: https://www.dikon.info/dikon-vil-harmonisere-3d-modeldata-for-livscyklusvurderinger-i-byggeriet/ [Accessed 30 June 2022].

European Commission (2020) *Stepping Up Europe's 2030 Climate Ambition Investing in a Climate-Neutral Future for the Benefit of Our People***,** Communication from the commission to the European parliament, the European economic and social committee and the committee of the regions, Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0562 [Accessed 30 June 2022].

GRAPHISOFT Center Danmark (2022) Available from: https://graphisoft-danmark.dk/ [Accessed 30 June 2022].

Ipsen, K, Lambrecht, Pizzol, M, Birkved, M and Amor, B (2021) How lack of knowledge and tools hinders the eco-design of buildings-a systematic review, *Urban Science*, **5**(1).

Kanafani, K, Zimmermann, R K, Rasmussen, F N and Birgisdóttir, H (2021) Learnings from developing a context-specific LCA tool for buildings - The case of lcabyg, **4**, *Sustainability*, **13**(3), 1-23.

Kaptelinin, V, Nardi, B A and Macaulay, C (1999) Methods & tools: The activity checklist: a tool for representing the space of context, *Interactions*, **6**(4).

Kvale, S (1996) *Interviews : An Introduction to Qualitative Research Interviewing*, London: Sage Publications.

Lützkendorf, T (2018) Assessing the environmental performance of buildings: Trends, lessons and tensions, *Building Research and Information*, **46**(5), 594-614.

Lykke, N, Nygaard, F, Borgestrand, T and Kathrine, A (2020) Holistic sustainability: Advancing interdisciplinary building design through tools and data in Denmark, *Construction Economics and Building*, **20**(2).

Nwodo, M N and Anumba, C J (2019) A review of life cycle assessment of buildings using a systematic approach, *Building and Environment*, **162**, 106290.

One Click LCA (2022) Available from: https://www.oneclicklca.com/ [Accessed 30 June 2022].

Rasmussen, F N, Malmqvist, T and Birgisdóttir, H (2020) Drivers, barriers and development needs for LCA in the Nordic building sector - a survey among professionals, In H. Wallbaum, A. Hollberg, L. Thuvander, P. Femenias, I. Kurkowska, K. Mjörnell, & C. Fudge (Eds.), *Conference Proceedings: World Sustainable Built Environment online conference BEYOND 2020 : 2- 4 November,* IOP Conference Series: Earth and Environmental Science, **588**.

Roberts, M, Allen, S and Coley, D (2020) Life cycle assessment in the building design process - A systematic literature review, *Building and Environment*, **185**, 107274.

Rossi, M, Germani, M and Zamagni, A (2016) Review of ecodesign methods and tools Barriers and strategies for an effective implementation in industrial companies, *Journal of Cleaner Production*, **129**, 361-373.

Schlanbusch, R D, Fufa, S M, Häkkinen, T, Vares, S, Birgisdottir, H and Ylmén, P (2016) Experiences with LCA in the Nordic building industry - challenges, needs and solutions, *Energy Procedia*, **96**, 82-93.