Prospective and retrospective approaches to integrate life cycle assessment in configurators: A multiple case study in the construction industry

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Abstract

This study contributes to the evolving dialog on sustainable practices, emphasizing the strategic integration of life cycle assessment (LCA) in configurators to comply with new regulatory standards and achieve environmental objectives. We investigated the application of configurators integrating LCA through a comparative analysis of two case studies in the construction industry: a prospective approach applied during the early design stages, and a retrospective approach using post-design. Our findings illustrate that prospective LCA configurators can significantly influence early design choices and facilitate preliminary environmental impact assessment. Conversely, a retrospective LCA configuration approach offers more precise and accurate assessments based on finalized designs, enabling detailed LCA reporting and saving significant time and effort. The analysis underscores that the application of these approaches is not mutually exclusive. This suggests that a combined strategy could maximize the potential of these tools. Such a combination would facilitate a more dynamic interaction between the early and later design stages, ensuring that the environmental assessment is thorough and iterative. Additionally, it would help the company gain in-depth insights into the environmental aspects of the design process.

Keywords

configurators, construction, environmental impact, life cycle assessment (LCA), sustainability

1. Introduction

Sustainability is widely recognized as a multifaceted concept encompassing three dimensions: environmental, social, and economic. Notably, the environmental dimension plays a foundational role given its direct influence on socioeconomic elements [1]. In assessing environmental impact, particular attention has been given to the environmental impact of products and services. One of the most widespread methodologies for assessing environmental impact is life cycle assessment (LCA) [2].

In this context, the European Commission has highlighted the urgency of making sustainable products the norm across Europe by setting stricter product design and lifecycle standards [3]. As a result, the increasing focus on assessing environmental performance is evidence of the clear need for digital tools to support this process.

Configurators are a widespread technology that emerged in the late 1970s as decision support systems designed to streamline the specification process during product customization [4]. They allow users to select from various options and configurations of a product, automatically adjusting components and features according to user choices. This technology enhances the decision-making process by providing immediate feedback on potential configurations, thereby significantly improving speed, quality, and efficiency [5].

Additionally, configurators enhance efficiency by automating the creation of crucial documents, such as quotes and bills of materials. This automation ensures accuracy and consistency in documentation; it is particularly valuable in complex configurations, where manual processes are prone to errors [6].

The integration of LCA with configurator technology is quite promising for enhancing sustainable product development. By embedding environmental assessment capabilities in configurators, companies can provide real-time data on the environmental impacts of various product options. This integration can facilitate a more informed design, incorporating environmental consequences alongside traditional factors, such as

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pricing. Furthermore, configurators can enhance the communication of environmental assessment results, a crucial aspect of LCA [7].

Despite the significant potential of this technology, research on the integration of LCA into configurators is still in its early stages. However, over the last five years, this topic has increasingly captured academic interest, as reflected in numerous recent publications [8–19].

Moreover, no research has examined the different implications of LCA in either a prospective or retrospective manner within the context of configurators. This gap in the literature leads to the following research question:

RQ: *What are the implications of a proactive and retrospective of life cycle assessment through configurators?*

We examined two different case studies of companies that have successfully developed configurators with LCA. The first case study involved using this technology during the early design phase to evaluate various design alternatives. The second case study described how a configurator, used over finalized designs, enables precise and accurate LCA. Both case studies pertain to the same sector: the construction industry.

We explored these case studies to assess and compare their impacts, thereby contributing to the research community's understanding of how configurators can be effectively employed to improve environmental development.

The structure of this paper is as follows. In Section 2, we present the theoretical background of LCA typologies in terms of application timing. and we review the academic research conducted on configurators, integrating LCA considerations. In Section 3, we describe the methodology used for analyzing the comparative case studies, and we introduce both case studies. In Section 4, we present the findings from the analysis, and in Section 5, we discuss the implications of the results. Finally, in Section 6, we summarize the key conclusions.

2. Theoretical background

2.1. Prospective and retrospective LCA

The use of LCA is subject to different contexts and can be driven by distinct aims and goals. In terms of the time perspective, LCA can be divided into two primary categories [20, 21]. On the one hand, *retrospective* LCA is aimed at assessing the effects of something that occurred; on the other hand, *prospective* LCA is a forward-looking approach [20, 21].

Retrospective LCA evaluates the environmental impacts of existing products based on actual data. It helps to understand and improve the environmental performance of current technologies [20, 21].

On the other hand, prospective LCA evaluates the potential environmental impacts of products before they are implemented. It is used to guide decision-making during the development phase by predicting future impacts [20, 21].

2.2. Configurators and sustainability

The increasing focus on environmental considerations in the use of configurators has become a significant area of interest over the past five years. This trend is noticeable in the academic community and across various industries. For instance, standard product configuration software applications such as Tacton CPQ are developing their environmental impact assessment capabilities by incorporating LCA features into their applications [22].

Various researchers have also turned their attention to this subject in the academic sector. Given the novelty of the topic, the range of issues discussed in these studies regarding the integration of LCA and configurators is quite diverse, demonstrating the broad scope of the field.

Hankammer et al. [13] extensively reviewed over 900 configurators, providing valuable insights into enhancing sustainability features across sectors. Responding to the need for streamlined LCA assessments, Spreafico et al. [8] introduced I-Tree, a tool that leverages real-time data for efficient eco-assessment. Similarly, Rousseau et al. [10] explored the impact of environmental indicators in configurators, focusing mainly on sustainability enhancement in 3D printing.

To address the nexus between product variety and sustainability, Medini et al. [9] proposed a comprehensive framework, while Wiezorek and Christensen [14] focused on refining configurator architectures to enable better sustainability data communication. In consumer electronics, Hankammer et al. [11] found that default sustainable options significantly influence consumption patterns. Campo Gay et al. [18] analyzed the successful integration of LCA into configurators, guiding users toward sustainable choices. Focusing on sustainability integration, Christensen and Wiezorek [12] aligned configurators with ISO 14040 standards, while Campo Gay and Hvam [17] demonstrated the transformative impact of sustainability-focused configurators, particularly in construction.

Regarding configurators' development, Piroozfar et al. [16] discussed solutions tracking environmental impact, while Helo et al. [15] introduced software streamlining environmental assessments in supply chains. Moreover, Jakobsen et al.'s [19] call to redesign product configuration systems for better sustainability integration tied these efforts together, portraying a concerted push toward deeper sustainability considerations in configuration processes across sectors.

All of these efforts highlight a strong trend toward deepening sustainability considerations within configuration processes.

3. Methods

Given that the advancement of configurators incorporating LCA is still at an early stage, elucidating their full potential and application is a notable challenge. To address this gap, we conducted a qualitative case study analysis comparing two distinct applications of configurator systems within the construction industry. Our objective was to delve deeply into their utilization of LCA and compare their effectiveness to gain in-depth insights.

As highlighted by previous research [23,24], case studies are essential for understanding the key variables, the connections between them, and the reasons behind these relationships.

We identified two case companies using configurators for environmental impact assessment, employing standard LCA methodology. These companies operate within the construction sector in Sweden.

The main reasons are first, that, according to the United Nations Environment Programme (UNEP), the building and construction industry stands as the most polluting industry sector, responsible for 38% of all energy-related CO2 -eq emissions [25]. Consequently, the construction sector has played a pioneering role in shaping standards and regulations, as exemplified by the European standard EN 15804 for environmental product declarations [26], aligned with international LCA methodology standards ISO 14040 and ISO 14044 [7,27].

Second, Sweden has been a leading country in terms of introducing new policies and regulations for the construction sector. Currently, it is compulsory to declare an LCA on new buildings, and beginning in 2025, new projects must adhere to statutory limits on CO_2-eq emission per m2 per year across the life cycle [28].

Consequently, all these factors motivate the construction sector in Sweden to seek out new tools and solutions to support their initiatives and make the studied companies ideal case studies.

3.1. Data gathering

To analyze the first case company, we conducted a series of systematic observations of the configuration process. We evaluated the experiences of the primary configurator implementor involved in the project over a period of four years.

For the company described in the second case, we began with an initial semistructured interview based on the main research question. This was followed by six semistructured interviews to understand the company's working processes and configuration systems. We finalized our analysis with a review of the results by one of the main configurator developers at the company.

3.2. Case company 1

The company is a subsidiary of a large international corporation that operates in Sweden and has approximately 350 employees. It specializes in developing, manufacturing, and marketing cement for infrastructure, such as roads, tunnels, bridges, and residential, commercial, and industrial buildings.

Recognizing the upcoming regulations that will take effect in 2025, which impose limitations on new construction projects, the company saw the need for an early design tool to assist in this process. They developed an LCA configuration to facilitate and promote environmentally friendly design options in the initial stages of projects when decisions are more flexible and have fewer resource implications. This tool assists users in the educational process, encouraging the consideration of less conventional options and more environmentally sustainable solutions.

Given the high level of uncertainty in decision-making during the early design phase of projects, a preliminary LCA was performed. In addition to serving as a decision support tool to address the complexity of environmental and technical requirements, the tool was modeled to quantify LCA to determine the margin of safety concerning maximum statutory limits.

The company has collaborated with external consultants over the past four years to develop this tool, reaching the final testing phase in the first quarter of 2024. Ownership of the tool was transferred to the company during the second quarter of 2024, with full integration into the company's workflow scheduled for completion by June 2024.

3.3. Case company 2

The company is a small enterprise that has been based in Sweden since 2018 and employs 35 people. It specializes in designing and planning the construction aspects of projects. The company uses a configuration system approach to streamline its building design process, which optimizes the overall process.

In response to new regulations requiring LCA declarations for construction projects since 2022, the company has integrated LCA evaluation into its established configurators. To facilitate this, the company uses a commercial solution named *One Click LCA*, a leading cloud-based software solution for

Table 1
Company Case 1: Early Design Stage Configurator Usage (Prospective)

Aspect	Description
Stage of use	Used in the very early design stages for planning
Main purpose of the LCA integration	To make environmentally conscious decisions and compare different solutions
LCA approach	Prospective, integrating LCA from the start of a design
Output	Overview of environmental impacts and technical aspects
Required configuration inputs	Preliminary technical requirements and environmental priorities
LCA integration kind with the configurator	During the configuration.
Impact on the design process	Significant influence over the design approach
Environmental focus	Screening LCA, preliminary impact assessments
Suitability for Projects	New projects with undefined design parameters

creating Environmental Product Declarations (EPDs) and LCA reports for building materials and products.

Consequently, the company has updated its configuration system to automatically generate a comprehensive material list with detailed material quantities in kilograms. These data can then be seamlessly processed by One Click LCA and integrated into the company's database to produce comprehensive EPDs.

4. Results

First, we characterized how each application on the configurator integrating LCA capabilities works and impacts the building design process, focusing on when they are used, what outputs they produce, and their ultimate influence on design decisions and environmental assessments.

Table 1 illustrates the case of Company 1. The application is employed during the early design stage of the building process, representing a prospective approach.

Table 2
Company Case 2: Post-Design Specification of Configurator Usage (Retrospective)

Aspect	Description
Stage of use	Used after the building design is finalized
Main purpose of the LCA integration	To create detailed LCA reports
LCA Approach	Retrospective, LCA applied to finalized designs
Output	Detailed environmental impact reports based on specific materials used and their quantities
Required configuration input	High-level drawing specifications
LCA integration kind with the configurator	After configuration, based on the automatic generation of specifications (i.e., a part list with quantities), the LCA is performed through an external tool (One Click LCA).
Impact on the design process	No or minimal impact on the design.
Environmental Focus	Detailed LCA, focusing on the quantifiable impacts of materials
Suitability for Projects	Projects with set designs needing LCA reflection

In contrast, Table 2 presents the case of Company 2, where the application is used after the design has been finalized, adhering to a retrospective approach.

Subsequently, we examined the implications of choosing either a prospective or a retrospective approach to how a new company's resources, design process, and overall strategy for sustainability are impacted. This should help in understanding the strategic differences between these two approaches.

Table 3 outlines the considerations for a prospective approach, whereas Table 4 details the considerations for a retrospective approach when LCA is integrated into configurators. It is important to note that retrospective design is considered viable only for companies that have already implemented configurators. Implementing a retrospective approach without pre-existing configurators would be significantly costly and inefficient.

Table 3
Considerations for a Prospective Approach to Configurators Integrating LCA

Feature	Evaluation	Explanation
Iterative design	Yes	Facilitates iterative design adjustments during early stages
Approach to design	Prospective	Used to influence initial design choices and integrate LCA
Accuracy	Low	Estimates are broad and based on preliminary data
Influence in design	High	Can significantly alter design outcomes
LCA is the main aim of the configurator	Yes	The primary aim is to guide environmentally conscious design
Further integrations	No	Standalone use for initial design stages
Resource investment in developing the configurator	High	Requires the development of a LCA focused configurator
Cost	Medium/High	Licenses and running cost of configurator tool

Table 4
Considerations for a Retrospective Approach to Configurators Integrating LCA

Feature	Evaluation	Explanation
Iterative design	No	The LCA evaluation occurs once the configuration is finalized
Approach to design	Retrospective	Used after design choices are made
Accuracy	High	Calculations are detailed, based on precise information
Influence in design	None or minimal	The LCA is carried out to reflect on the design rather than modify it
LCA is the main aim of the configurator	No	LCA is secondary and happens thanks to the configuration
Further integrations	Yes	Requires integration with One Click LCA
Resource investment in developing the configurator	Low	Utilizes existing configurator
Cost	Medium/High	While the configurator is in place, there are costs for licenses on external LCA databases.

5. Discussion

A prospective approach in configurators integrating LCA allows for the early detection and mitigation of environmental impacts. In contrast, a retrospective approach ensures that these mitigations are based on precise, real-world data, ultimately enhancing the accuracy and reliability of environmental assessments.

Despite the benefits of a prospective configurator integrating LCA, the higher cost and resource requirements associated with developing and maintaining configurators must be considered. The investment in licenses and running costs of configuration applications can be substantial, but the long-term benefits of reduced environmental impacts and alignment with policies and requirements can compensate for initial costs.

On the other hand, a retrospective approach is highly dependent on completed project design specifications. This approach prevents the flexibility needed to make environmental improvements once the design is finalized. Moreover, while LCA reports on the same product should be comparable and provide precise environmental impact data, the exceptional detail provided by a configuration translates into outstanding detailed LCA reports, which differ from standard LCA reports. For example, this configuration approach could include the consideration of even the smallest details, such as the weight of bolts in a multifamily building construction. Such detailed LCA assessments can result in a misleading comparison between products using the same LCA database, where one report is very detailed (enabled by the configurator), and others are less detailed.

Therefore, the application of prospective and retrospective configurators integrating LCA should not be regarded as mutually exclusive. Incorporating both approaches into a project could substantially streamline efficiency in embracing environmental considerations and reporting LCA. Moreover, such dual applications could enable more dynamic interaction between the early and later design stages, ensuring that the environmental assessment is comprehensive and iterative.

Comparing LCA results from an early design stage with those derived from detailed data collected later in the same project can provide significant insights into product design. This comparison could help companies identify major environmental impact drivers and offer opportunities to reduce environmental assessment uncertainties.

6. Conclusions

The integration of LCA into configurators presents a promising path for enhancing sustainable production practices. We explored the use of configurators integrating LCA at different stages of the design process through two contrasting case studies, a prospective and a retrospective LCA approach in the construction industry.

By employing prospective and retrospective LCA tools, companies can achieve a more thorough understanding of environmental impacts at different project stages, leading to more informed decision-making. This approach not only aids in achieving compliance with evolving regulatory standards but also aligns with broader corporate sustainability goals.

Future research should continue to explore the development and application of these tools across different sectors to fully realize their potential in driving sustainable development.

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