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Findings from a survey on the current use of life-cycle assessment in building design

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ABSTRACT: The built environment is facing environmental regulations more ambitious than ever before. In Europe, a law will lead all new buildings to the Nearly Zero-Energy performance level. However, even if a building does not have any energy consumption for its operation phase, it still has embodied impacts. To that end, Life-Cycle Assessment (LCA) methods have been developed and improved since the 1960s. However, LCAs are still not used as a standard practice among the architecture, engineering and construction industry. This study aims to discover the reasons for the low use of life-cycle performance approaches thanks to a web survey targeting practitioners, and to formulate key recommendations to improve their usability. This research reveals the low penetration rate of LCA software among building designers due to their limited efficiency within the design context. The main reasons for this situation are the cost of use, too heavy for the early design stage constraints, and the functionality, which is limited to the environmental assessment. Indeed, practitioners expect much more design support functionalities (multi-criteria approach, exploration mode, etc.). The survey findings aim to support the usability improvement of new LCA-based methods and the research and development of new tools at early design stages.
KEYWORDS: Life-cycle performance assessment, Survey, Practitioners, Software, Europe

1. INTRODUCTION

The built environment is one of the major contributors to climate change. Since the 1970s and its energy crises, countries have set up regulations to decrease the operative energy consumption of buildings. Their performance targets have been strengthened over the years, and the next generation of regulations will lead to generalizing Nearly Zero-Energy Buildings (*NZEB*) in 2020 within the European Union [1]. Still, the *NZEB* performance level will not be sufficient to reach the objectives in terms of climate change mitigation at the international level. Indeed, the building itself has embodied impacts that need to be considered when assessing its environmental performance. This is specifically the purpose of life-cycle assessments (*LCA*) that will be mandatory in future regulations (e.g. in France), and which are promoted by green building certification systems (e.g. LEED, BREEAM, HQE…).

The *LCA* methodology has been continuously improved since the 1960s, leading to the development of several tools and software. However, *LCA* tools are still not widely used by engineers and architects in the building industry. Therefore, the aim of this study is to better understand the practitioners' needs in terms of Life-Cycle Performance (*LCP*) design support methods. By using *LCP*, the authors would like to voluntarily embrace a wider range of practices that help designers integrate life-cycle targets into the design process, and not limit the scope of the study to the current *LCA* users in the sense of the ISO 14040 [2]. To that end, the present paper summarizes the first results of a survey on the current use of *LCP* tools and methods targeting architects, engineers, and real estate developers on the European scale.

2. REVIEW OF PREVIOUS SURVEYS

To the best knowledge of the authors, there are very few surveys targeting the usability of *LCP* tools so far. Some of the previous studies highlighted theoretical knowledge and practical experiences of the users about *LCA* [3–8]. From these previous works, it is already known that building *LCA* is time consuming, expensive, and problematic in the early design stages [8]. Also, the complexity of the method is identified as one of the main barriers for practitioners [6]. Finally, in North America, a contradiction has been noticed between a large awareness of building *LCA* and its low usage by practitioners, mainly due to a lack of market demand [4]. However, prior researches are limited when it comes to understanding the *LCA* practitioner context and requirements. In addition, none of them targeted the European geographical scope, as they were mainly focused on the US.

3. METHODOLOGY

According to Maguire [9], among several context-of-use methods (e.g. user observation, diary keeping, etc.), the survey of existing users is the one that best fits the aim of our study. It allows us to collect quantitative data and to target a diverse and difficult-to-reach population at the European scale, whereas other approaches describe the context of use by direct observation, making them unsuitable considering the geographical scope of our study. Thus, an online questionnaire was set up thanks to the web-based instrument, Survey Monkey [10]. It was spread via emails to 33'000 European professionals from the Architecture, Engineering and Construction community through the author's network and commercial mailing lists. The professional network LinkedIn was also used to share the survey among green building communities of practitioners using *LCA* tools, or interested by sustainable construction and green label discussions. The survey has been inspired by usability context analysis guidelines [11] and adapted to this study.

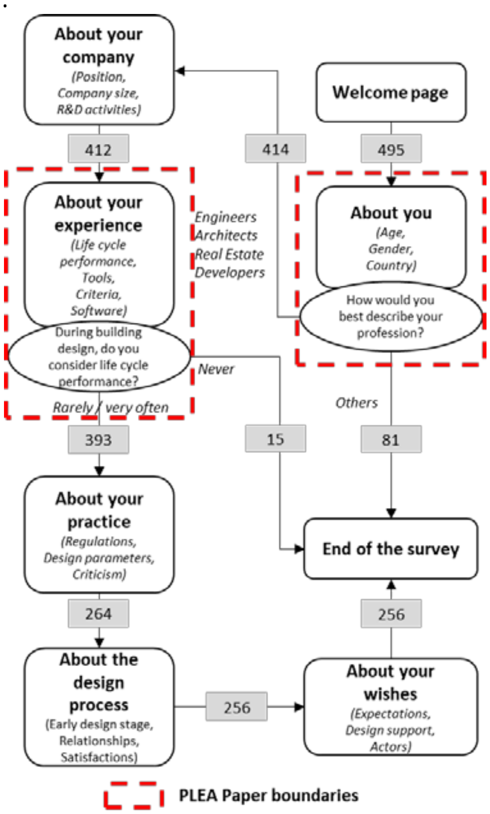

Figure 1: Presentation of the Overall Survey. The parts interpreted in this paper are those within the dashed perimeters. The numbers in the rectangular grey boxes correspond to the number of participants that reached a particular point in the survey.

The overall questionnaire included 40 questions that address two specific topics. The first one is the use and requirements of design practitioners regarding current *LCA* software. It is the purpose of this paper to explore and interpret the results related to this topic. The rest of the survey is concentrated on the context of use of *LCA*, in order to better understand the social environment in which the methodology is used. This part is the purpose of another journal article [12]. Figure 1 highlights the survey perimeter discussed in this paper, which represents 17 questions out of 40. The survey was answered by 495 participants, which is a high population compared to the previous studies [3–8] in which the average number of respondents was below 200. After cleaning the data, 414 of them matched the target population of the survey, i.e. working in geographical Europe, and practicing as engineers, architects or real estate developers. According to their answers, participants were directed differently to other questions, which explains why all questions do not have the same number of answers. Also, some participants quit the survey before the end, but their answers have still been taken into account. Around 400 participants answered specifically the questions addressed in this paper. For more details, each graph interpreting the answers to a specific question will specify its number of respondents.

4. SURVEY FINDINGS

The survey results have been interpreted across the following three subjects.

4.1 About the practitioners in this survey

The survey reaches its ambition in terms of geographical scope: the participants that answered are working in 26 different countries within Europe. However, more than 80% of them are located in the UK, France, Switzerland, Germany, Italy, Spain and the Netherlands - that is to say the Western part of Europe. This might be induced by two factors. First, the author's network is more connected to this part of Europe. Second, participants' feedback in open questions point out that in some countries, economic and social issues have priority over environmental questions. Regarding the profession, 82% of the participants are working as architects, 13% as practicing engineers, and 5% as real estate developers. This fits well with the goal of this survey to target the practitioners working at early design stages.

Within the survey population, it is worth mentioning that most of the practitioners (60%) claimed that they often or very often consider *LCP* during the building design. Only 3.7% (i.e. 15 people) never consider it but agree that they will have to in the future. Looking at the seven countries that represent 80% of the answers, we noticed that the distribution of respondent interest to *LCP* per country was quite stable, varying from 72% in

Spain to 51% in Germany. The robustness of these results must be considered in light of the number of respondent per country, highlighted by the black line in Figure 2 (e.g. only 4.3% of them were coming from Spain). Still, one can deduce that a large majority of the respondents are concerned by the life-cycle performance, which is now of major importance for practitioners. However, the question was very open on purpose, embracing every method that permits a consideration of the *LCP*. Then, if there is no doubt about the awareness of life-cycle performance, the practice behind this notion embraces a large diversity of methods and tools (cf. section 4.2), and probably of *LCP* definitions.

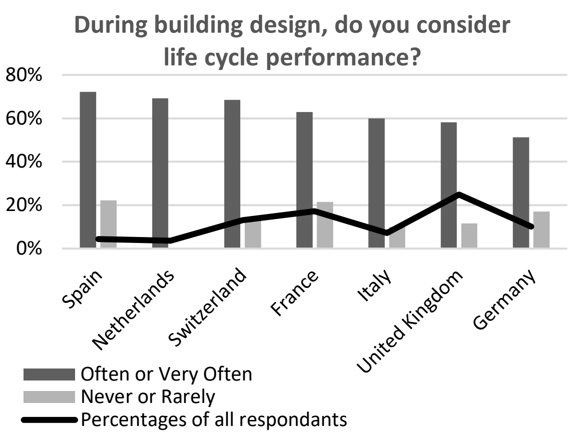

Figure 2: Life-cycle performance considerations, out of 408 answers. Bars represent the respondents of each country that considers LCP, and the line represents the country distribution of 80% of the respondents.

4.2 Practitioners and *LCA* software

The participants mostly work in small architecture companies (<10 employees for 70% of the participants). If this ratio is very low, it is still higher than what is observed in a country like France, where 94% of the architecture offices have less than 10 employees [11]. This segmentation has a direct impact on the skills and tools that are able to handle designers. It has already been noticed in the UK, for instance, that the companies having more than 100 employees used Building Information Modelling on half of their projects while it represents only 17% of the projects for small companies with less than 10 people [13]. Following the same trend, Figure 3 illustrates the very low penetration rate of computer software dedicated to *LCA* among the professionals (27%).

The same phenomenon is observed when looking deeper into the answers, with an equipment rate slightly higher in large companies than small ones. In addition, only 6% of the architects use a *LCA* software, compared to 42% of the engineers. As a comparison, the participants are more likely to use rules of thumb (33%) or guidelines (43%) for instance.

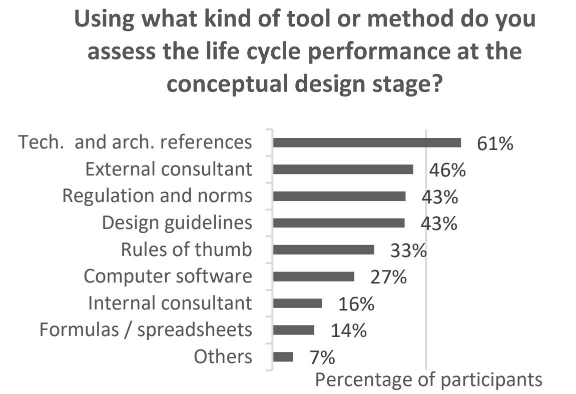

Figure 3: Answers about the tools and methods used to assess life-cycle performance at the conceptual design stage, out of 323 answers.

The most popular approach is the use of technical and architectural references (61%). Indeed, according to Jusselme et al. [14], they are commonly used by designers to feed the iterative design process between problems and solutions. However, considering the still small corpus of reference buildings in terms of *LCP*, the complexity, and the context-dependant specificity of an *LCP* approach, one can wonder about the efficiency of such methods. The complexity of life-cycle thinking is underlined by the fact that 46% of the respondents are working with an external consultant, demonstrating the difficulty of internalizing this competence.

In Figure 4, 38 respondents specified the software they use. It is interesting to note that they use more than 14 different types of software, and the most used (Elodie) concerned no more than 26% of them. This statement has to be moderated according to the country distribution of the survey participants. However, this means that there is no clear leadership of one of the tools, probably induced by country-specific Environmental Product Declaration (*EPD*) databases used to perform the *LCA*. Elodie software, for instance, is dedicated to the French building context, using a French *EPD* database (INIES) and is used in the frame of this survey at 90% by France-located practitioners. Among those who answered “Other,” Brightway, Smeo and a homemade Excel file were mainly cited.

The importance of several criteria according to *LCA* software users have been characterized and illustrated in Figure 5. Among the three first-ranked criteria, the time spent conducting a *LCA* and the interoperability with *CAD* tools are both related to a willingness to reduce and lighten the time consumption of filling in input data or more generally using the software. Indeed, architects and engineers spend most of their time managing existing information [15], rather than creating new information.

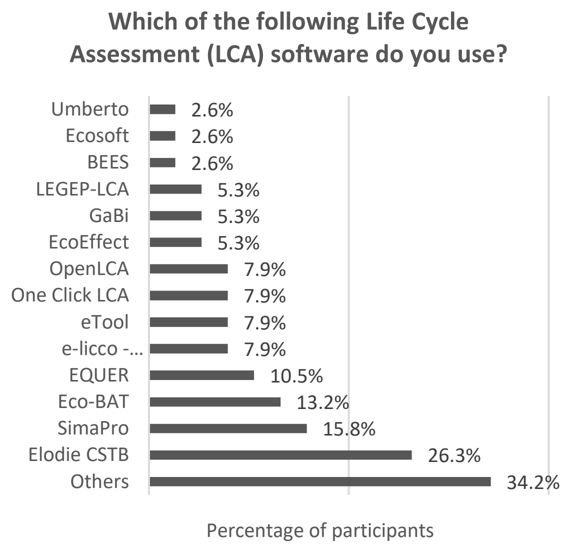

Figure 4: LCA Software distribution, out of 38 answers.

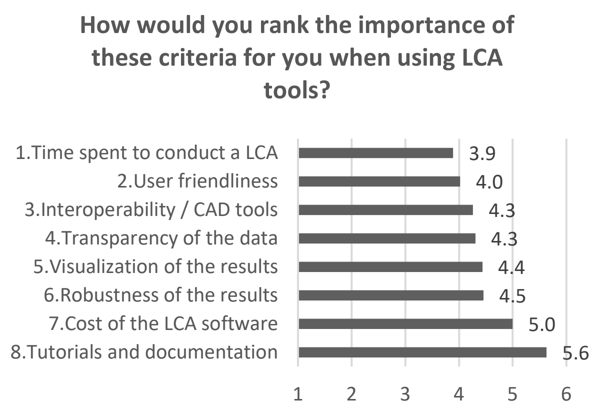

Figure 5: Average ranking of several criteria when using a LCA software, out of 46 answers (1=highest importance; 8=lowest).

The user friendliness is also a major concern, which might be related to the desire for an easier interpretation process. This could be improved with the use of data-visualization techniques of the results as suggested by Jusselme et al. [16].

These criteria have also been rated in terms of satisfaction levels thanks to a Likert scale with five levels from "not at all satisfied" (1st level) to "completely satisfied" (5th level). The weighted average of the answers highlight that users are satisfied with criteria two and four to eight in Figure 5 with an average score of between 3 and 3.11 on the Likert scale. However, criteria one and three, namely the time spent and the interoperability have a lower satisfaction with a score of 2.84 and 2.49, respectively.

Overall, a major issue regarding the use of life-cycle tools is their cost of use, which is too high for practitioners. This is also clearly reported in several open answers. This survey also found out the *LCP* is a voluntary approach for 71% of the practitioners, while it is a client's requirement for only 41%. In this context, and especially with the early designs, the engineering fees might fail to make up for the time consumption of current software.

Figure 5 also highlights a lower emphasis on the importance of tutorials and documentation. This is paradoxical, as the survey shows on another note that they are used by 82% of the respondents, while 44% are helped by colleagues, and 38% have internal or external training courses. Thus, tutorials are highly popular, but are probably considered a basic feature of the software compared to the other criteria.

4.3 Practitioners' wishes

Regarding the services expected by the participants, more than 50% of the practitioners are willing to perform the following: (a) to check the compliance of the project with the objectives; (b) to assess the performance of the building project; (c) to evaluate the sensitivity of the design parameters; (d) to know what would be the optimum in terms of sustainability; (e) to explore which design alternatives fulfil the objectives; and (f) to compare the performances of different building design alternatives. While current software is able to meet requirements (a) and (b), this is commonly not the case for the others, which highlights a major gap with practitioner's needs that expect much more than a simple life-cycle performance assessment. Indeed, if the compliancy of a project with a specific environmental target is a fundamental need, it does not efficiently support the design process and its iterations. On the other hand, the sensitivity analyses of design parameters and design alternative explorations, for instance, are much more powerful [14,17]. When focusing specifically on early design stages, 59% of the respondents agreed to use simplified performance assessment to handle the low resolution of details of these stages (Figure 6). However, the exploration of a gallery of possible design options is acclaimed by 48% of them, with a higher rate among the engineer's sub-population (62%).

The survey also reveals a strong willingness to perform multi-criteria assessments as most of the respondents also take care of acoustics, lighting, thermal comfort and energy consumption. This finding is in line with the need for interoperability compliancy of *LCA* software, and it demonstrates the will to have more holistic tools to integrate the complexity of multiple performance targets into the design process.

Regarding the design parameters, Figure 7 highlights that more than 80% of the practitioners consider the building shape and the building orientation at the conceptual design stage. If the building shape has a direct incidence on the embodied impacts of a building, this is not the case for the building orientation, which affects exclusively its operational impacts. This strengthens the need to develop *LCA* tools that also evaluate the energy consumption and then the life-cycle efficiency ratio as developed by Brambilla et. al [18], in order to balance the operational and embodied impact of a design parameter.

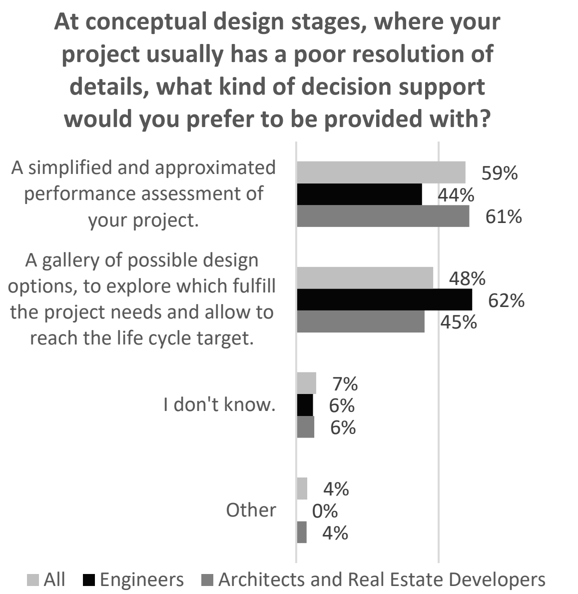

Figure 6 Comparison of exploration and assessment approaches, out of 256 answers.

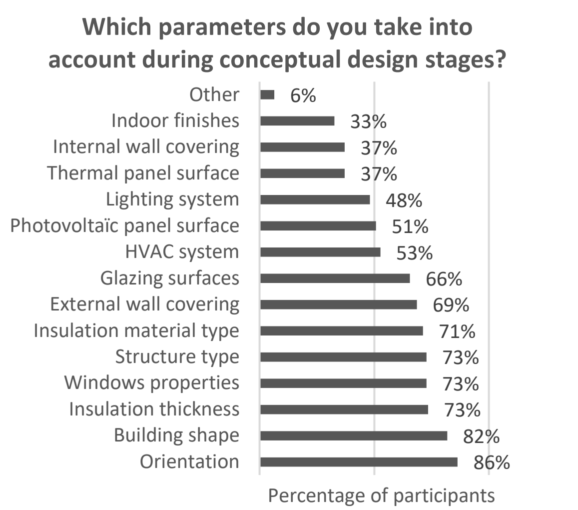

Figure 7: Consideration of design parameters at conceptual design stages, out of 263 answers.

As seen in Figure 7, there is a decreasing interest of the design parameters from macro (building shape and orientation) to micro (indoor finishes and internal coverings). However, all proposed parameters are considered by more than 30% of the participants, which is counter-intuitive at the early design phase. In fact, life-cycle performance assessments consider all the building components in their calculations. This means that using a low performing structure will perhaps lead to a decrease in design options by choosing only the best products in terms of indoor finishes. Vice-versa, if the client's brief specifies low performing indoor finishes, this may have an impact on the building shape or structure possibilities. In that sense, it is interesting to note that designers want to understand the consequences of design choices commonly made at early stages, on details with high environmental impacts that will be fixed in later phases.

5. OUTCOMES AND DISCUSSION

The major finding of this survey is the important gap between the *LCP* issue awareness among practitioners, and the low equipment rate of these professionals with a dedicated *LCA* software. On the one hand, the present survey clearly confirms that life-cycle performance is a question placed high on the agenda of practitioners. There is no doubt there is an awareness of the topic, even if there might be a bias inherent to the survey, as those that answered were plausibly already interested in the survey subject. On the other hand, only 27% use computer software, which is a very low rate considering the difficulty of reaching meaningful and robust conclusions with any other approach.

This underutilization of *LCA* software is explained by their low efficiency, i.e. a high time investment for a low satisfaction. Software mismatches the design process and its context. Indeed, current tools are mainly limited to the assessment functionality, and should propose many other benefits such as sensitivity assessment, exploration mode, etc., to fit better with the design iterations. These iterations are currently fed by the use of architectural references, which are highly popular among architects and engineers during the iterative design process, but are very limited from the author's point of view when it comes to the *LCP* issue.

LCA software should also be more interoperable with CAD tools in order to decrease their cost of use, i.e. the time for processing the input parameters and interpreting output data. Indeed, the time spent in conducting a *LCA* is judged too high while in most of the cases, the clients do not require them, with probably no engineering fees for these specific assessments. This compatibility with the BIM environment might extend the boundaries of current *LCA* software with more functionalities. Indeed, the increasing performance-oriented trend of design briefs calls for designers to adopt a multi-criteria approach, assessing other metrics such as energy, lighting, acoustics, etc. In addition, the life-cycle approach should include all building components in its perimeter, leading designers to an anachronistic situation where design parameters usually discussed at detailed phases, which have heavy environmental impacts, can actually influence the early stage design options.

6. CONCLUSION

Thanks to 414 valid responses from 26 different European countries, this survey aims to accurately depict the situation of practitioners regarding their use and understanding of life-cycle performance (*LCP*). Given the current lack of knowledge regarding this field, particularly in Europe where the regulation context is ambitious, the idea was to target the design community at large. Indeed, by focusing on practitioners who are already *LCA* software users, the consequence would have been to exclude from the survey those interested in *LCP*, but not equipped yet.

In a few words, it is suggested that *LCA* software developers should focus their future work on the following contradiction. First, to decrease the cost of use of the software with more interoperability and user friendliness. Second, to increase the design support added-value by coupling more interpretation techniques of the assessments, extending the scope of analysis to other metrics, and including all building components starting from the early design phases.

This challenge might feed further research as the resulting answer would be to increase the complexity of *LCA* assessments and associated analysis, and in the meantime to spread the methodology among a wider community, that have probably fewer skills than the early adopters, who were mostly specialist consultants. These objectives might be achievable with the coupling and implementation of the latest findings in research. The data-collection should be easier with the increasing BIM industry. *LCA* should also better use data-science techniques to increase its usability thanks not only to higher computational power (e.g. cloud computing), statistical analysis (e.g. sensitivity analysis), but also data-visualization techniques that interpret multidimensional and heterogeneous *LCA* inputs and outputs.

The highlight of current *LCA* software weaknesses along with the practitioner's wishes and situation might be useful to further work led by developers and researchers towards new tools with higher usability.

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