BRITISH COUNCIL | Newton Fund | INSTITUTIONAL LINKS

International Conference for

Sustainable Design of the Built Environment SDBE 2018

Proceedings

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Setting contextual life-cycle objectives in urban design: requirements for a decision-support method

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Abstract: A variety of building labels and norms exist that set evermore-ambitious environmental and energy performance targets. In parallel, a growing number of building performance evaluation tools are adopting the life-cycle assessment (LCA) methodology to allow verifying if a project, based on its detailed description, reaches these targets. However, such norms and tools seem unsuited to the district scale, where environmental impact considerations are often left out of the urban planning and design process. There specifically appears to be a lack of decision-support instruments that can relate urban-scale performance targets to concrete design choices, taking into consideration the project's specificities (e.g., climatic context), but without requesting design information that is not yet available. This paper presents the first phase of a collaborative research and development project, aiming at developing a novel decision-support method to integrate life-cycle objectives from the masterplanning stage. In this first phase, we investigate barriers and requirements from a practice-oriented perspective in the Swiss context by: (i) exploring urban-scale LCA-based methods and tools, and (ii) engaging with key stakeholders who hold complementary roles in a case study district project, which aims to be low-carbon. These exchanges are conducted in the form of a focus group and a questionnaire to gather qualitative and detailed information. Our findings notably highlight the mismatch between the ambitious objectives set by regulations and labels and the (lack of) means available to practitioners to support them in achieving these objectives. Specifications for a novel tool are derived from the practitioner's feedback, as well as information on relevant design parameters and performance indicators.

Keywords: Life-cycle assessment, building environmental performance, urban planning and design, user requirements, environmental impact targets

Introduction

Regulations and labels regarding life-cycle building performance assessment

In Europe, with the building sector representing the largest single energy consumer (European Commission (EC), 2018), the latest regulation states that all new buildings must be nearly zero energy by the end of 2020 (2018 for public buildings) (European Union (EU), 2010). However, this directive contains no mention of embodied energy or carbon of materials and systems. A revised version, yet to be released, shall among others, *"[create] a clear path towards a low and zero-emission building stock in the EU by 2050 underpinned by national roadmaps to decarbonise buildings."* (EC, 2018). Although it remains unclear whether this revision will specifically put forward a life-cycle assessment (LCA) approach to take into account embodied energy and greenhouse gas (GHG) emissions, it is clear that this issue is of major importance in light of the Paris agreement's objective (UN, 2015), which implies drastic reductions in GHG emissions. In its 2014 report on climate change mitigation, the IPCC notably states that a holistic approach needs to begin at the neighbourhood or city level and must, among others, consider the whole lifespan of buildings – including a life-cycle assessment – to achieve the broadest impact possible (Lucon et al, 2014).

The European Standards "Sustainability of construction works" series (EN 15643) and notably the building-level EN 15978 (CEN/TC 350, 2011), which details an LCA-based environmental performance calculation method, also demonstrate the relevance of this topic. Moreover, the EC published in 2014 an initiative to promote a more efficient use of resources, highlighting the importance of embodied GHG emissions of buildings and the need to consider the entire life-cycle of a building in order to effectively tackle its environmental impacts (EC, 2014).

In addition to these – not yet legally binding – instruments, some voluntary initiatives and labels have integrated LCA considerations within their framework. This is the case for example of the MINERGIE® (-A and (-A/-P)-ECO) building label, which defines a lower and upper non-renewable primary energy target for the construction (embodied) and operational phases. In the case of the -ECO label, these values differ based on the building's usage (or program, e.g., school, housing, office) (MINERGIE, 2014). Similarly, the Swiss Society of Engineers and Architects (SIA) also defines program-specific targets for non-renewable primary energy and GHG emissions related to embodied and operational energy (SIA, 2017). However, for both of the above examples, targets refer to the individual building scale and do not depend on the project's specificities such as its location.

Focusing on the urban district scale, the One Planet Living© (OPL©) procedure defines targets in terms of energy and GHG emissions for embodied and operational energy (Chappaz and Guisan, 2014). However, these targets are fixed and independent not only of the different building programs to be found on the site, but also of the site's context. The DGNB's Urban districts scheme also includes LCA criteria, but does not require individual buildings to be certified for district certification, specifying that *"the assessment focuses on the areas between buildings in a district"* (DGNB GmbH, 2018). Other standards or rating systems, such as BREEAM Communities (BRE, 2017), promote a life-cycle approach and attribute credits to the embodied impacts of materials, but without providing further design guidance.

Integrating environmental performance considerations through an LCA-based approach at the district scale is receiving increasing attention also in research (Lotteau et al, 2015; Mastrucci et al, 2017). Through a review of papers related to LCA at the neighbourhood scale, Lotteau et al (2015) highlighted as an issue the lack of contextualization of the LCA methods to the specificities of the neighbourhoods. They concluded on the need for approaches that remain in line with the data available at the design stages of a neighbourhood development project.

This general lack of contextual and district-scale oriented approaches – in particular for defining sublevel (e.g., building-scale) targets from overarching district-level performance objectives – is a core motivation for the current project, introduced below.

Research context and objectives

This work represents the first phase in a collaborative research and development project (henceforth 'R&D project') between academic and industrial partners, who have come together around a common district renewal project located in Switzerland (henceforth 'district project'). The general goal of the R&D project is the development of a novel method for enabling decision-makers to integrate environmental performance considerations from the masterplanning stage. The motivation notably comes from the fact that, whereas ambitious environmental performance objectives are expected to be set for the whole district, stakeholders have little guidance or tools at hand to translate these site-level objectives into concrete and specific design choices. The lack of information moreover prevents them from

being able to judge how ambitious these targets are regarding architectural possibilities and economical constraints.

The goal of this first phase of the R&D project was thus to explore the research around LCA at the urban scale, as well as LCA in practice from the standpoint of the different stakeholders, to ultimately define user requirements for a novel urban decision-support method. The profile of the industrial partners involved in this study and who hold complementary roles in the urban planning and design process are listed in Table 1. The R&D project is led by two academic researchers (two first authors of the current publication) who are part of the same research group. It is to note that our approach is of a qualitative and in-depth nature, consisting in having regular exchanges with a small but interdisciplinary group of professionals over the one-year duration of the R&D project. As such, we do not aim for quantitative or generalizable findings.

Although the authors have attempted to objectively report the partners' opinions in this paper, the risk of misinterpretations remains. For this reason, and given the early stage of the district project, both the exact location of the project and the identity of the partners are kept anonymous.

The remainder of the paper is structured as follows. A brief review of existing (urban) LCA tools is presented in the next section, followed by details on our approach for gathering information from the project partners. Results are presented in the outcomes section, where we also compare our observations to those of extensive LCA studies recently published.

Table 1. Participants profile and role. Titles within parentheses are used to refer to each participant in the remainder of the paper.

Industrial partners	**Role in district renewal project**
Contracting authority / owner (owner)	Project manager
Urban designer / planner (urban planner)	Consultant during the elaboration of the land-use plan
Consultant specialized in CO2 emissions reduction (CO2 consultant)	Consultant in the elaboration of the district's carbon emissions mitigation strategy
Engineer (engineer)	No role for the moment, possible involvement at a later stage
Sustainable development consultant in a major construction company (construction company)	No role for the moment, possible involvement at a later stage

LCA-based urban scale tools

Conducting an LCA-based performance evaluation is particularly contextual, as it relies on regional/national databases of life-cycle environmental impact values (Kotaji et al, 2003). For this reason, we here focus mainly on methods and tools either developed for or holding the necessary data to be applicable in the Swiss built environment context.

In terms of tools, we have identified the web platform SMEO for sustainable districts (Riera Perez et al, 2014; Roulet and Liman, 2013), an Excel-based calculation aid for the development of 2000-watt society sites (Intep, 2012; Kellenberger et al, 2013), and City Energy Analyst (CEA), a collection of tools either in stand-alone open-source Python (for

researchers) or GIS plug-in (for planners) format still under development (Fonseca et al, 2016; Fonseca, 2017).

Aside from differences in the level of details regarding user-inputs, the above example tools follow the same workflow: they evaluate a project based on its description as provided by the user. This implies demanding from the user some information that is yet unknown, such as material types, or else making assumptions for instance by setting default code- or label-compliant values. Either way, the evaluation is done for one hypothetical project and iterations, for comparison between project alternatives, must be done manually by the user. This process provides low design support while being time-consuming, two of the main reasons why LCA software are not widely used by practitioners according to Jusselme et al (2018).

Moreover, although conceived for evaluating urban-scale projects, the above tools apply building-level targets to benchmark individual buildings, of the same program, to the same performance objective. They make use of the non-renewable primary energy and GHG emission targets provided in a guiding document published by the SIA (SIA, 2017). As mentioned earlier, these targets are distinct for each building usage and domain (i.e., embodied vs operational energy). Since they are set at the individual building level, the same target will apply e.g., to two residential buildings A and B located on the same site. No contextual specificity is taken into consideration. For example, let's assume that site constraints impose a certain shape for building B that is detrimental to its performance, while building A benefits of a larger design freedom and higher solar exposure. In that case, it might be interesting to capture these characteristics and derive contextual impact targets for each building, that still allow reaching the overarching site-level objective. The SIA itself captures this problem by observing that *"[…] target values cannot be reached for each building. Some initial situations exclude or greatly complicate the achievement of the objectives."* (SIA, 2011) (translated from French). This should be addressed through a method that allows, on the one hand, verifying the feasibility of reaching specific targets given contextual considerations, and, on the other hand, adjusting the targets for each building (or other sublevels of the site) in a way that ensures the whole site can reach its objective.

While the above issues are the core motivations for the current R&D project, this paper first aims at casting light onto the user requirements as a first phase towards developing a novel approach.

Method for identifying needs from target stakeholders

Identifying and specifying the context of use as well as user requirements are the fundamental first steps in the process of developing a new method or tool, in a human-centred design approach (Maguire, 2001). To do so, two complimentary techniques were here used to gather information from the partners: a focus group and a follow-up online questionnaire. The reasons for using and combining these two methods are further described below.

A focus group is a qualitative data collection research method that consists in bringing together stakeholders in a discussion group format (Langford and McDonagh, 2003; Maguire, 2001; Morgan, 1996). In the field of human-centred design, it can be used for identifying requirements and issues to address (Maguire, 2001). Focus groups are often used in combination with other techniques such as in-depth individual interviews or surveys (Morgan, 1996), for which they can provide valuable insight, for instance when defining alternatives for closed-ended questions in a survey (Stewart and Shamdasani, 2015).

In the field of LCA, Saunders et al (2013) conducted two focus groups of respectively 12 and 8 participants including architects, engineers, and contractors to investigate the reasons for the observed lack of whole-building LCA. Their findings then served in the development of a survey that was answered by 250 respondents. Similarly, Meex et al (2018) combined a survey (364 respondents), interviews (5 participants), and a focus group (12 participants) with architects to identify design-oriented user requirements for LCA application. Focusing on how embodied GHG emissions are calculated within industry practice, De Wolf et al (2017) conducted focus groups (48 participants) followed by semi-structured interviews (12 participants). While these examples involved a relatively large number of respondents, possibly in an attempt to derive generalizable findings, the current study does not share this aim, as mentioned earlier. However, the specific feedback gathered from the project partners, which serve to illustrate their point of view, is balanced with the broader findings extracted from the literature review.

The combination of a focus group and questionnaire is particularly useful in the context of this research. The former offers a semi-structured way of gathered qualitative information from the group of participants, exposing in real-time the converging and diverging elements. The questionnaire represents a more structured means of obtaining answers to specific questions that would not have been adapted to the focus group discussion setting. Moreover, some questions already brought up during the focus group can be repeated in order to verify if individual answers differ from the aggregated group answer. More information on how both procedures were conducted are presented below.

Focus group

A kick-off meeting was organized by the academic leaders to launch the R&D project. An overview of the project's general motivation, context, and goals was first presented. The focus group discussion then took place. The entire session lasted about two hours and was audio-recorded. A list of questions developed prior to the meeting and presented in Table 2 was used as a guide during the focus group. Since exchanges with the participants began from the inception of the meeting (i.e., during the introduction presentation), the whole content of the audio-recording was subsequently transcribed and analysed. This engagement from participants also had the effect of naturally guiding the discussion, reason for which the guide was only loosely followed and additional spontaneous questions were raised by the moderators. The analysis was done by extracting from the transcript the key points and structuring them according to themes as well as partner roles. Excerpts in the form of quotes are presented in the outcomes section. To plan and subsequently analyse the focus group, and since the project does not involve a social scientist, references on the subject were consulted to extract guidelines (Langford and McDonagh, 2003; Morgan, 1996; Stewart and Shamdasani, 2015).

Questionnaire

As a complement to the focus group, an online questionnaire was developed and sent to the partners three weeks later. It included questions for gathering: the knowledge and satisfaction level of participants regarding specific software; their perception concerning barriers to the consideration of environmental performance objectives; the types of design parameters and performance indicators of interest (i.e., potential inputs and outputs of a tool); and general information on the phases during which they intervene over the

development of a new district. Some of these questions and their answers are presented in the next section.

Instructions sent along the questionnaire informed the partners to answer only the questions which were relevant to their professional activity. As such, the response rate for each question varies. Moreover, one participant (the owner) did not fill in the survey likely due to self-exclusion given their background and actual role in the project.

Table 2. Sample of focus group guide, loosely followed during the discussion.

Today in your practice, do you encounter life-cycle performance objectives for the projects on which you work?
If so: Where do these objectives come from? Are there legal obligations? How often are such objectives present? If not: How come? Because there is no requirement/demand? Because there are no tools?
According to you, how critical are environmental performance objectives for a project?
When working at the urban scale, which type of tools do you use? Are they well-suited to your needs?
Do you know these existing tools? *[referring to example tools such as those presented in the Introduction of the paper]*
How do environmental performance criteria influence the design / the evolution of a project?

Outcomes from investigation

General findings

From the very start of the meeting with the partners, questions arose regarding the meaning of terms such as zero/low carbon and zero/low energy (buildings or in this case districts), and in particular the evaluation scope (or boundaries) for each concept (e.g., including or not energy related to materials and mobility). The definition of these terms is out of the scope of this paper and covered in multiple publications (e.g., Marszal et al, 2011; Sartori et al, 2012). While such confusion about definitions and boundaries, and their divergence, is commonly encountered and highlighted in the literature around LCA (De Wolf et al, 2017; Saunders et al, 2013), it appears clear that including the often left-out embodied energy/carbon and explicitly communicating the evaluation boundaries are essential requirements. These needs are also recurrently highlighted in the literature (Lotteau et al, 2015; Mastrucci et al, 2017; Meex et al, 2018).

This initial questioning has as a result that practitioners who approach the topic immediately face a difficulty, as expressed by the urban planner: *"If someone asks us a zero-carbon district, we won't really know how to proceed. We are rather lacking in methods. We fall back on our common methods [e.g., bioclimatic principles], which work fine, but are not necessarily up to our ambitions. I would find interesting to see how we can, throughout the masterplanning process, already get to suggestions that allow to be intrinsically more economical [in terms of energy, emissions]."*

This quote also highlights a lack of means to integrate environmental performance assessment early on during the masterplanning stage, when there remains a large freedom in the design choices, among which choices that can strongly affect the performance (Kohler and Moffatt, 2003; Lechner, 2009). This lack of means was actually expressed by the CO2 consultant: *"There are labels and objectives, but nothing that says how to achieve them before the end of the project's realization phase. I see the utility of a tool at the very beginning of the project, to figure out how to design my project so that it can fulfil a given label."*

These statements also point to the limited guidance provided by existing instruments (e.g., standards, labels) and evaluation tools when it comes to supporting practitioners in their decision-making process.

Practitioners also expressed a feeling of being somewhat trapped between on one side, pressures and demands from the market, i.e., having to ensure market competitiveness, and on the other side, growing awareness and expectations surrounding sustainability-related measures and objectives. They mentioned perceiving a (lasting) conflict between the financial market and sustainability in today's reality. As such, what came out as a crucial requirement is the need for a method that can allow verifying if a project can be high-performing (in terms of operational but also embodied energy over its lifetime), without compromising its competitivity on the market. That is to say, professionals would like to be able to know well in advance the relationship between performance level and costs, and extract arguments from this information when communicating with other stakeholders.

Barriers to environmental performance consideration

The main barriers to considering environmental performance objectives, as perceived by the respondents, are presented in Figure 1. The number one barrier differs among the partners; the lack of legal obligation was identified as the prime obstacle by the urban planner and engineer (and was rated barrier number three by the CO2 consultant), whereas the CO2 consultant selected the lack of interest from the client (also the engineer's barrier number five), and the construction company representative pointed to too high costs (barrier number four of the CO2 consultant). Lack of information / knowledge was selected by all respondents except the engineer as the second most important barrier, while the lack of decision-support tools was identified as barrier number three for the urban planner and construction company, and barrier number six for the CO2 consultant.

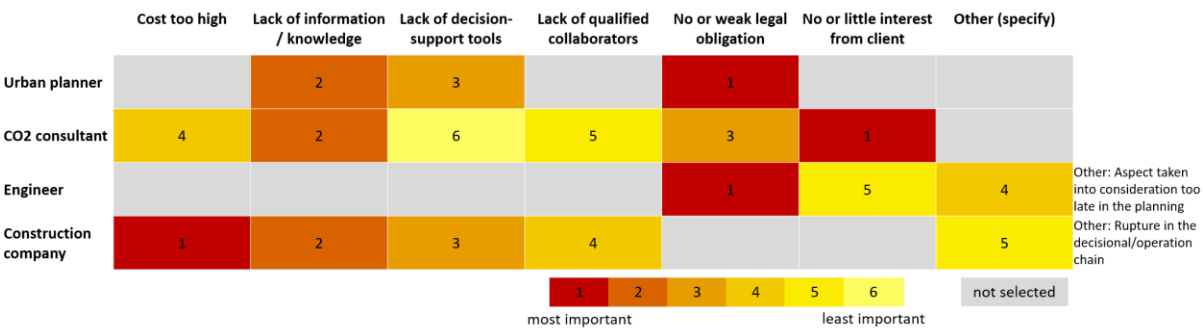

Figure 1. Survey responses to the question *"What barriers do you perceive to the consideration of environmental objectives?"* and *"Please rank these barriers in order of importance (1=most important)"*.

All barriers in the provided list of options were selected at least twice, and two additional barriers were specified: that environmental objectives are taken into account too late in the planning process (engineer), and that their consideration disrupts the chain of decisions (construction company). We can speculate that these two aspects are partially caused by the lack of adequate methods and tools to seamlessly integrate such considerations during the planning and decisional process.

Our main results notably match those of Saunders et al (2013) and Olinzock et al (2015) who investigated, respectively through focus groups and a survey, the experience of members of the architecture, engineering, and construction community with LCA. They identified as main barriers the cost and time requirements of conducting an LCA, and the lack of demand

from clients, of government incentives, of data, and of understanding of LCA. Saunders et al (2013) highlighted the following question representing a barrier to the validation of LCA: *"How do you prove sustainable options are a must to clients?".* We could relate this question to the position of our participants regarding the market competitivity as discussed earlier, for which they need "proof" that sustainable options can be financially viable.

Specifications

The outcomes from the focus group and questionnaire have been consolidated into the list of user requirements presented in Table 3, which can then serve to inform the development of a novel decision-support method (this step, out of the main scope of the current paper, is briefly discussed in the conclusion section).

Table 3. Summary of user requirements ("wish list") as extracted and interpreted from the focus group discussion and survey results. Soft requirements (less critical, "nice to have") are italicized.

General / Purpose	
Needs	Clear methodological approach Simple quantification tool, adequate for usage as early as the start of the project Support dialogue between project actors in real-time (e.g., during collaborative sessions) *Dynamic tool that incorporates new technologies (e.g., in constructions) as they emerge, enabling an up-to-date and long-term follow-up of a project*
Types of analyses and uses	Assess impact of masterplanning decisions on environmental performance Quantify the sensitivity of the environmental performance to the different decision parameters (see also Figure 2) Identify decisions that could compromise project's ability to achieve goals or constrain downstream decisions (sort of risk assessment) Assess impact of specific financial investments in relation to environmental performance *Quantify added-value in terms of market competitivity related to achievement of performance labels* *Propose construction mode according to project location (based on nearby resources)* *Identify synergies at site level (e.g., between buildings)* *Provide guidance regarding existing buildings (to protect/maintain or deconstruct/rebuild)*
User-inputs (see also Figure 2)	
Quantity and nature	Relevant/in line with masterplanning stage Interest for being able to anticipate the impact/weight of upstream design parameters but without having to provide information yet unknown about such parameters
Evaluation	
Scenarios	Facilitate the evaluation and comparison of multiple project scenarios and design options (in terms of their impact)
System boundaries and methods	Clear delimitation and communication of the evaluation scope (what is considered and not, the physical and temporal perimeters, etc.) Clear positioning of the method with respect to definitions (e.g., low-carbon, zero-energy), local/national legal frameworks, labels, etc., and (reliable/recognized) data sources.
Outputs	
Target definition and benchmarking	Allow comparing scenarios to site-level performance objectives Provide options for the frame of reference which sets these overall site-level performance objectives
Indicators	Cost, greenhouse gas emissions, primary energy (global and non-renewable part), feasibility indicator (see Figure 3)
Visuals	Adequate to support the different types of analyses (see top of table) and facilitate communication with other actors

We notably observe a need for a quantification tool that is adequate for real-time and early usage during the typically collaborative planning phases of a project. The different types of analyses that users would like to be able to conduct include assessing the sensitivity of the environmental performance to different parameters (e.g., choice of construction material), and anticipate the costs related to different scenarios by knowing the relationship between design decisions and associated construction costs.

To infer on the types of user-inputs that may be the most relevant to the potential users, the survey included a question on the types of parameters with which each partner typically works during a district project, and at what level (or scale) these are specified. For example, specifying the window-to-wall ratio at the site level would mean that the same ratio is applied to all buildings on the site. Answers to these questions, shown in Figure 2, bring us information regarding the fundamental versus secondary/too detailed parameters. The former includes the building program and the grid orientation, which could thus seamlessly be part of the user-inputs and exploited to contextually delimit the evaluation. However, parameters that were not selected by the respondents but that may still influence the different performance indicators should not be neglected. A proper method will have to be defined to reconciliate the need to take such parameters into account with the fact that they are not relevant to the decision-maker at the targeted design stage. Indeed, one of the desired analysis is to be able to identify decisions that could compromise the project's ability to reach its objectives. This implies being able to anticipate the effect of downstream design decisions.

In terms of outputs, our partners have unanimously selected costs and GHG emissions as the main indicators of interest, followed by primary energy and its non-renewable part, and a feasibility indicator. The latter would inform on the technical and architectural feasibility of reaching the performance goals, given the project's characteristics (Figure 3).

Comparing our results with those from Meex et al (2018), who compiled a series of user requirements for LCA-based assessment tools for early stage building design, we observe a general agreement. One notable difference, aside from the targeted scale of evaluation (district vs building) and their intradisciplinary pool of architects, is their finding that architects are more interested in an aggregated single score than various environmental indicators. Within our panel of stakeholders, this choice of output received only one vote.

Conclusion

This paper is based on the hypothesis that life-cycle environmental performance regulations will imminently become compulsory, leading to the need for urban-scale methods and tools supporting the integration of these constraints into the urban planning and design process. To define the specifications for a novel decision-support tool, we have explored the current state of LCA-based urban-scale project assessment both from the research and practice side in the Swiss context.

Adopting a user-centred design approach, we have engaged with key stakeholders having complementary backgrounds around a common district project, chosen for its ambitious environmental targets. Current barriers as well as user requirements were identified through a focus group discussion and follow-up survey. A major barrier, highlighted both in the literature and by the interrogated partners, is the fact that practitioners perceive little pressure to integrate environmental performance criteria into their activity. This demonstrates that the objectives and ambition set at the European and national levels have yet to become legally binding and embedded into the daily practice of the practitioners.

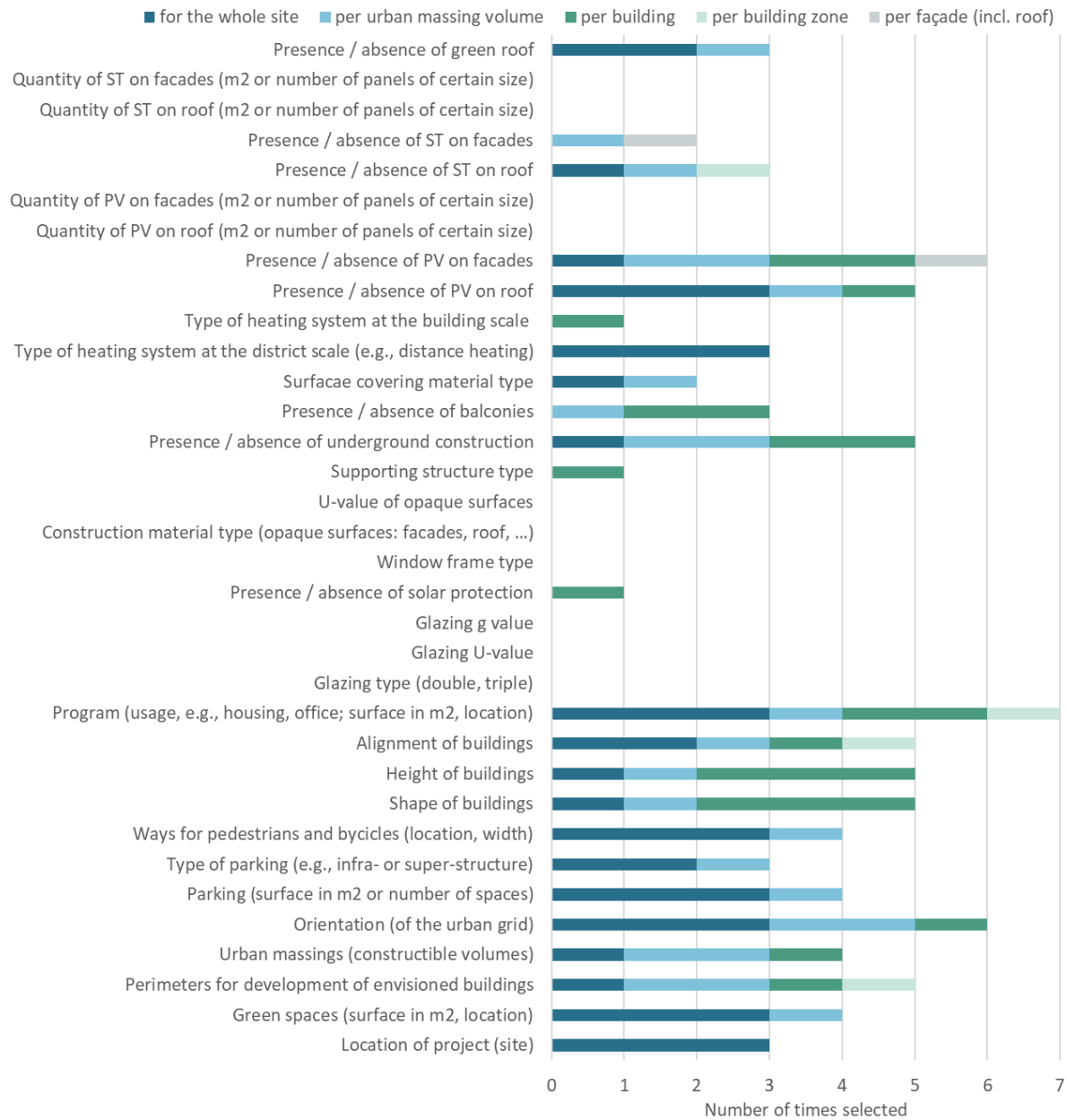

Figure 2. Parameters selected to the questions *"Which are the parameters with which you work in the context of a district project?"* and *"At which scale do you specify these parameters?"*.

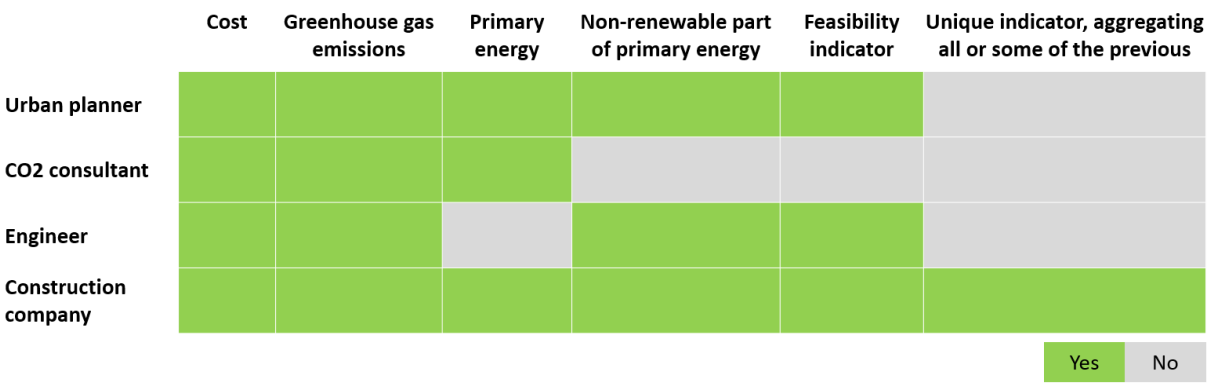

Figure 3. Survey responses to the question *"What would you like to be able to get as output data (results) from a decision-support tool?"*.

Environmental performance is still often reduced only to the operational energy and biodiversity aspects, which are moreover treated as non-critical and secondary issues and hence do not exert much influence on the project. Practitioners also raised shortcomings of existing targets set by norms and labels, which do not translate into solutions that exist in terms of design and construction choices.

The outcomes indicate a need for a contextual target-cascading method, i.e., a decision-support instrument that can convert a district performance objective (e.g., 2000-watt society targets) into specific sublevel targets (e.g., per building or component), while considering the site's properties (e.g., climatic context). This method shall also allow identifying trade-offs between environmental impacts and economic indicators across distinct project scenarios involving different design choices. Building upon this study's findings, including our analysis of the literature and of the exchanges with the stakeholders, the next step of the project will be to translate user requirements into a method towards the development of a novel decision-support tool.

Acknowledgements

This research is conducted at the Ecole polytechnique fédérale de Lausanne (EPFL) and co-financed by the NPR program of the state of Fribourg (project number PC-2017-03) and the COGENER SIG fund. We would like to thank the partners of this project for their collaboration and the rich exchanges that have made this study possible.

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