THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Early Stage Architectural Design Practice Perspectives on Life Cycle Building Performance Assessment

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Gothenburg, Sweden, 2023

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Cover:
Photograph of an architectural practitioner using a life cycle building performance assessment tool in a communicative setting, see Chapter 2 of this thesis.

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“Hvad har vi dog gjort, for at have det så godt?”
- Ragnar Kjartansson, 2023

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Abstract

Architectural practitioners can avoid negative social and environmental impacts of new construction by making decisions supported by impact quantification during design processes. However, most software tools developed for such quantification see little use in practice, especially in early design stages when decisions have the greatest influence. To identify ways for software developers to overcome this situation, a thorough literature meta-review of previously performed tool reviews was combined with interviews applying a practice lens.

The first key finding is that a possible explanation for the low tool uptake in practice could be a missing practice perspective in previous tool development efforts. In a literature meta-review of publications on life cycle building performance tools identifying previously applied perspectives, most previous tool reviews were found to support tool development and selection, while disregarding how tools can be integrated in existing practices and design processes. As a proposed solution, a framework for defining software requirements using a practice perspective was developed.

The second key finding is that a practice perspective could be applied during software development by implementing qualitative methodologies. Nine architectural practitioners in Sweden, Norway and France were interviewed using the interview to the double, a projective technique in which the interviewee is asked to describe their next workday in detail so that their tasks can be assumed by an imagined body double. The design activities described by the respondents were sequenced into user narratives which could serve as starting points for participatory software development processes within the architectural practice.

The outcomes - a proposed framework for practice-centric software requirements, and a proposed methodology for collecting these requirements using a practice lens - indicate a research direction toward software development efforts which aligns with design process, architectural practice, and tool user needs. In the next stage of the research this direction will be pursued through application of the developed methodologies in participatory development case studies in early-stage architectural design practice.

Keywords

Life cycle assessment, Building performance, Architecture, Early design stages, Literature review, Ethnographic interview, Participatory software development

List of Publications

Appended publications

This thesis is based on the following publications:

[**Paper I**] **Säwén, T.**, Sasic Kalagasidis, A. & Hollberg, A. (2023). Critical Perspectives on Life Cycle Building Performance Assessment Tool Reviews. *Submitted to Renewable and Sustainable Energy Reviews*.
Contributions: Säwén designed the research, performed the literature collection and analysis, developed the characterisation framework, and authored the first article draft. Sasic Kalagasidis and Hollberg provided feedback for the research design, and contributed to analysis and writing. In addition, Hollberg initiated the research project.

[**Paper II**] **Säwén, T.**, Sasic Kalagasidis, A. & Hollberg, A. (2023). Early Architectural Design Stage User Narratives - Applying a Practice Lens to Life Cycle Building Performance Software Needs. *Manuscript*.
Contributions: Säwén designed the research, recruited participants, conducted interviews, performed analysis, and authored the first article draft. Sasic Kalagasidis and Hollberg provided feedback for the research design, and contributed to analysis and writing.

Other relevant publications

[**a**] **Säwén, T.**, Magnusson E., Sasic Kalagasidis, A. & Hollberg, A. (2022). Tool characterisation framework for parametric building LCA. *IOP Conference Series: Earth and Environmental Science, 1078*(1), 012090. `https://doi.org/10.1088/1755-1315/1078/1/012090`.

[**b**] **Säwén, T.**, Magnusson E., Sasic Kalagasidis, A. & Hollberg, A. (2022). A Characterisation Framework for Parametric Building Performance Simulation Tools. *E3S Web of Conferences 362*, 03004. `https://doi.org/10.1051/e3sconf/202236203004`.

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And most of all, thank you Henny for your love and patience. You are my greatest inspiration.

Toivo Säwén, Rörö 13/10 2023

Contents

Acronyms

BIM	Building Information Modelling
BPA	Building Performance Analysis
IttD	Interview to the Double
LCA	Life Cycle Assessment
LCBPA	Life Cycle Building Performance Assessment
MFA	Material Flow Analysis
PEF	Product Environmental Footprint
RIBA	the Royal Institute of British Architects

Chapter 1

Introduction

1.1 Background

There is an environmental crisis caused by anthropogenic emissions, and to deal with it, great transformation is needed in terms of how society is organised in its interaction with planetary ecosystems (Ripple, Wolf, Newsome et al., 2019). This transformation involves adapting the built environment and the processes that produce it, firstly to vastly reduce their negative environmental impact (Röck, Saade, Balouktsi et al., 2020), and secondly to handle the social demands of the rapid transformation (Curtis, Fair, Wistow et al., 2017).

The built environment is indeed responsible for a great portion of humanity's environmental impacts, including material extraction (Krausmann, Lauk, Haas et al., 2018), carbon emissions (Li, Han, Liu et al., 2019), and biodiversity loss (Opoku, 2019). Simultaneously, the built environment is indispensable to provide safety for humans (Zhao, He, Johnson et al., 2015), and its design has a great influence on the wellbeing of its dwellers (Khoshnava, Rostami, Mohamad Zin et al., 2020). Humanity is thus facing a dilemma: humans urgently need the built environment to survive and thrive, but sustaining it is causing great harm to the planetary environment (Hathaway, 2017).

Architectural practitioners (architects, engineers, urban designers, etc.) are at the heart of this dilemma through their professional role of designing the built environment in intermediation between decision-makers and those affected by the decisions (Hillier, 2008; Murtagh, Roberts and Hind, 2016). Transformative practices which challenge established processes and enable the navigation of these paradoxes are emerging among these practitioners, as they are increasingly assuming the responsibility for resolving the dilemma (Soebarto, Hopfe, Crawley et al., 2015; Yu, Gu and Ostwald, 2022). For instance, instead of extracting raw material and converting it to new buildings in resource intensive ways, they are treating the buildings that already exist as raw material in their own right and implementing ways of organising their use more efficiently (Gaspar and Santos, 2015). However, unpredictable social developments require them to also consider the need for new construction for the foreseeable future, such as an ongoing population growth (Churkina, Organschi, Reyer et al., 2020), and uncertain future patterns of migration due to possible disasters triggered by climate change (Lelieveld, Proestos, Hadjinicolaou et al., 2016). Critical urban theorists also note a persistent formulation in the neoliberal regime of the urban environment as a competitive asset, even when confronted with climate change adaptation, rather than as a potential basis for socio-ecological redistribution (Whitehead, 2013).

These developments suggest that the construction of new buildings may stay constant or even accelerate in the near future. To be able to defend this construction of new buildings from an environmental standpoint (Ripple, Wolf, Newsome et al., 2019), the net negative environmental and societal impacts - the ecological and social footprints - of these buildings need to be sharply reduced compared to current standards, or entirely eliminated (Röck, Saade, Balouktsi et al., 2020). Some researchers even argue that a net positive impact should be prescribed for any new construction, referred to as the ecological and social handprint (Malabi Eberhardt, Kuittinen, Häkkinen et al., 2023). This can only be achieved if architectural practitioners have the appropriate means to quantify and evaluate these impacts, allowing them to avoid developing design alternatives which would contribute to the negative impact of the built environment (Hollberg and Ruth, 2016). Life Cycle Building Performance Assessment (LCBPA) is a collection of methodologies which allows such quantification and evaluation.

1.1.1 Tools for life cycle building performance assessment

Methods of evaluating building impacts during design processes include Life Cycle Assessment (LCA), quantifying the environmental impacts of a product during its life cycle (Tillman, Ekvall, Baumann et al., 1994), and Building Performance Analysis (BPA), quantifying the functional performance of a building (de Wilde, 2019). LCA is typically carried out by sustainability experts with backgrounds in fields like industrial ecology or environmental accounting (Hollberg, 2016), whereas BPA is usually carried out by building performance specialists with backgrounds in building physics and technology (de Wilde, 2019). However, some authors argue that these methodologies are interlinked, and that it is both feasible and beneficial to carry out these assessments in conjunction, integrated in design processes (Østergård, Jensen and Maagaard, 2016). In this thesis, the term Life Cycle Building Performance Assessment (LCBPA) is introduced for an assessment workflow which, during an integrated design process, applies a life cycle perspective to the functional performance analysis of buildings, as shown in Figure 1.1. This methodology is studied for the case of its integration in early stage design processes carried out by architectural practitioners in Sweden and other Nordic countries.

In relation to design processes, methods belonging to LCBPA have traditionally been carried out by engineers and sustainability experts during late design stages, mostly for code compliance and certification purposes (Hensen and Lamberts, 2011; Hollberg, 2016). In Sweden, LCBPA requirements have been codified in building regulations for decades: for instance, daylight since the 1960s (Rogers, Tillberg, Bialecka-Colin et al., 2015), operational energy

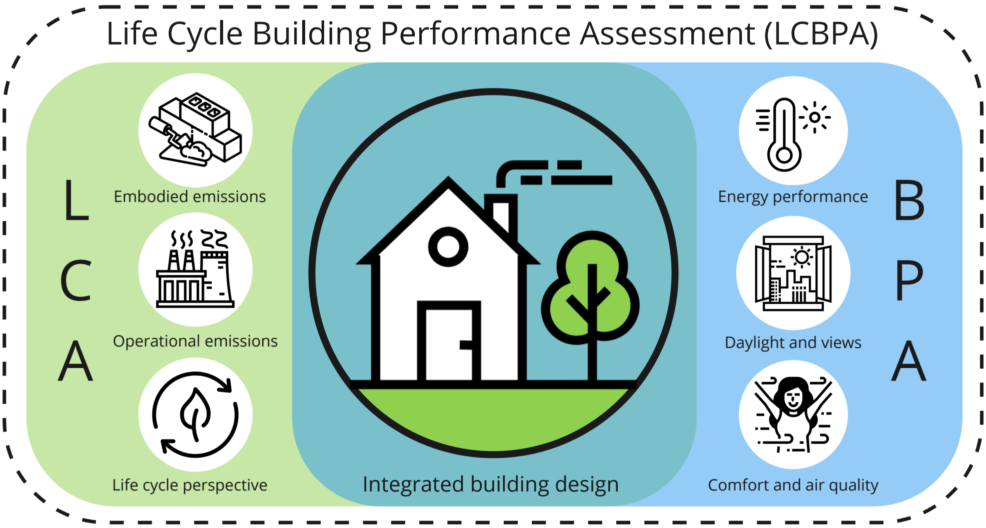

Figure 1.1: Life Cycle Building Performance Assessment (LCBPA) - the application of a life cycle perspective to the functional performance of buildings during an integrated design process. Life Cycle Assessment (LCA) and Building Performance Analysis (BPA) exemplified here through common analysis indicators (Hollberg, 2016; de Wilde, 2019).

since the oil crisis of the 1970s (Legnér, Leijonhufvud and Tunefalk, 2020), and the quantification of embodied impacts since 2022 (Sadri, Pourbagheri and Yitmen, 2022). Environmental certifications have existed since 1990 (Ade and Rehm, 2020), and are growingly being considered drivers of economic value which has accelerated their widespread use (Knuth, 2016).

However, a growing body of research indicates that the greatest benefits of LCBPA can be reaped in early design stages, when the major strokes of the design are determined (Hensen and Lamberts, 2011; Hollberg, Lichtenheld, Klüber et al., 2018; Meex, Hollberg, Knapen et al., 2018). It is argued that, despite the challenges of including quantitative analysis methods in early design stages, such as inherent great uncertainties due to rapid changes to the design (Hollberg and Ruth, 2016), and limited resources available to develop the design (Cross, 1982), the inclusion of these analyses should occur as early as possible, when there is a freedom to select design strategies which eliminate the net negative impact of the building (Basbagill, Flager, Lepech et al., 2013).

To enable this, a large number of software tools has been developed in the research and software community catering to architectural practitioners active in early design stages (Attia, Beltrán, Herde et al., 2009; Østergård, Jensen and Maagaard, 2016). For instance, the BPA suite Ladybug Tools (Sadeghipour Roudsari and Pak, 2013) is described by its authors as "designer-friendly", and the BIM-integrated LCA tool CAALA (Hollberg, Agustí-Juan, Lichtenheld et al., 2018) claims to "provide meaningful information to architects and clients". However, studies of the architectural design practice reveal that the uptake of these tools and analysis methods remains low in European practice (Mahmoud, Kamara and Burford, 2020), although the interest in the topic is high among architectural practitioners (Jusselme, Rey and Andersen, 2020). In these studies, architectural practitioners state several *sociological* barriers toward tool uptake: a lack of BPA knowledge among architects (Mahmoud, Kamara and Burford, 2020), a lack of interest from clients (Jusselme, Rey and Andersen, 2020), and methodological and epistemological differences between architects and engineers (Bleil de Souza, 2009). However, the solutions offered by the software development community are largely *technological* and emphasise faster, more accurate tools with more streamlined interoperability (Attia, Hensen, Beltrán et al., 2012). The perspective of the practitioner using the tool in design processes is rarely, if ever, applied (Jusselme, Rey and Andersen, 2020). Without this perspective, it appears that currently available LCBPA tools fail to address the problems faced by practitioners and effectively add to their value proposition (Tucker and Bleil de Souza, 2017). If the hypothesis holds that the early stage integration of analysis tools would benefit life cycle building performance outcomes in the final design, it is crucial for software developers to apply new perspectives which deal with the concerns of the end users in the architectural practice in order for tools to gain a greater uptake. These perspectives are explored through Research Question I of this thesis:

Research Question I: how can critical perspectives that identify practitioner needs be applied by software developers to allow them to define software requirements which meet these needs?

1.1.2 Critical perspectives in software development

In order to propose new, more practice-oriented software development methodologies, a look at the practice of software development itself is needed. Software development is, in essence, the art of meeting the needs of potential software users in a practice by facilitating their work through software integration (DeBellis and Haapala, 1995). Similarly to design processes, software development processes begin by collecting software requirements which are then iteratively developed during the development and used as benchmarks for whether the developed software fulfils its intended purpose (Comino, Manenti and Parisi, 2007). There is an entire research field dedicated to the development, implementation and evaluation of software requirements (Franch, Palomares, Quer et al., 2023). However, the resources and structures needed for a stringent, requirements-driven software development process are often missing during the development of LCBPA tools, as much of the development is carried out within the practice and spearheaded by practitioners themselves (Säwén, Magnusson, Sasic Kalagasidis et al., 2022a). Due to limited resources available for software development, these practitioner-developers need methodologies which can seamlessly integrate with practice and solve its problems without massive, overly robust software architectures. In such *user-centric innovation* processes, the success of a software is determined by its ability to first meet the needs of the developers themselves. After that, market expansion can take place (Comino, Manenti and Parisi, 2007).

User-centric software development has emerged in the past decades as a methodology which first and foremost considers the needs of the software operator - the user - and not the detailed formalisation of the process intended to be facilitated through the use of software (DeBellis and Haapala, 1995). This development paradigm offers a number of methods for identifying user needs. One common approach applied in agile methodologies is representing user needs in terms of *user stories*, normally of the format "as a <user>, I would like to <perform action> so that <benefit>" (Amna and Poels, 2022). Developing and interpreting these stories allows the software developer to gain an understanding of the user, what they want to achieve, and why (Lucassen, Dalpiaz, Werf et al., 2016).

However, as Orlikowski (2007) argues, applying the human-centric or the techno-centric perspectives in isolation is not enough to understand practice - investigations are needed of the entanglement of social constructs (the design process) and technology (the design support tool). In the case of LCBPA, it is not only the software which needs to change to better support user needs. As previously noted, the entire architectural practice needs to be transformed to be able to overcome the challenges in the built environment. While the user-centric software development methodologies can serve as a starting point for a new development paradigm, a look at the wider practice and how software can be integrated in it is needed. Practices which aim to change how design processes are being carried out need to be identified; especially those that aim to ensure that the building design does not contribute to net negative environmental and social impacts, such as LCBPA (Röck, Saade, Balouktsi et al., 2020). If these practices are being hampered by inefficient, ineffective, or missing software, the research and development community needs to shift to providing software solutions which accelerate them in a way that makes sense to software users in the design process, allowing for widespread adoption. To do this, methodologies are needed which allow observing the practice to identify these transformative activities.

In organisational studies stemming from the social sciences, such methodologies of applying a *practice lens* have been developed and widely applied since the turn of the millennium (Brown and Duguid, 2001). These methodologies have also been proposed to be useful in studying design practice (Kimbell, 2012). In organisational studies, the development of the practice lens as applied to understand complex organisations has been presented by Nicolini (2009), describing it as a methodological toolbox. There are clear overlaps between some of these methodologies and those applied in user-centric software development, as shown in Figure 1.2. The left box shows the representation of practice retrieved using the interview to the double (Nicolini, 2009). The two right boxes are examples of user stories as used in a user-centric software development process (Amna and Poels, 2022). There is a common question about observing situated, in-practice doings and making sense of these doings to enable organisational change: in the social sciences, to understand how organisations operate and grow as networks of human actors; in software development, to understand technological needs of the actors in the organisations on a user and practice scale.

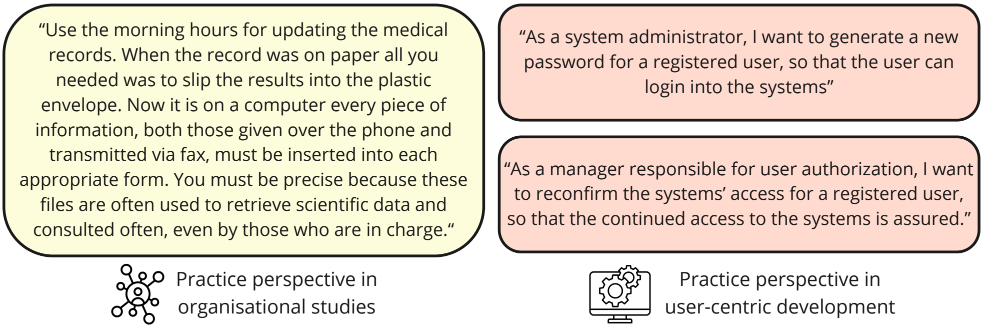

Figure 1.2: The representation of the practice perspective in organisational studies using the interview to the double (Nicolini, 2009), and in user-centric software development using user stories (Amna and Poels, 2022).

Due to this overlap, the application of methods developed in organisational studies are useful to enable communication between software developers and potential users. One way of "realising the critical potential of the practice lens" (Nicolini, 2009) could be using it to identify opportunities for integrating technologies like LCBPA in early stage architectural design processes. This is investigated through exploring Research Question II of this thesis:

> *Research Question II: how can applying a practice lens during software development help identify opportunities for integration of life cycle building performance assessment software?*

1.2 Problem statement and objective

As indicated in the previous section, the integration of Life Cycle Building Performance Assessment (LCBPA) in early design stages is beneficial both to design outcomes and resource use during the design process. A great number of LCBPA tools are available for this purpose, but they are seldom used in practice. One of the reasons for this situation is a missing perspective from developers on how the tools can be integrated by practitioners in real design processes.

The objective of this thesis is to propose an approach which applies practitioners’ perspectives of software integration in design processes during software development. To achieve this aim, two research questions are investigated: firstly, how software developers can apply perspectives on practitioner needs that are necessary for software requirements to be useful; and secondly, how these needs can be identified through the application of a qualitative practice lens.

1.3 Scope and research context

This thesis contributes to research into the development of software which supports LCBPA performed by architectural practitioners in early architectural design stages, through the development of critical, participatory approaches. The study investigates the case of the practice in Sweden and other Nordic countries.

This section provides the definitions for the terms outlining this aim and the intended beneficiaries of the research presented in thesis, as well as previous research directions in the related fields. The approach in this thesis to resolving the global issues is the empowerment of architectural practitioners to engage in practices which improve design outcomes in terms of social and environmental impacts. This is done by proposing methodologies for software developers which allow them to learn more about and support these practices.

Table 1.1: The approach selected in this thesis to achieving the end goal of an improved life cycle building performance, and a selection of potential other approaches including references pursuing these research directions.

Level of inquiry	Approach in this thesis	Alternate research approaches
Stakeholders	Architectural practitioners (Yu, Gu and Ostwald, 2022)	Policymakers (Sadri, Pourbagheri and Yitmen, 2022) Design project clients (Haapio and Viitaniemi, 2008)
Assessment method	LCBPA (Hollberg, 2016; de Wilde, 2019)	Environmental certification systems (Wallhagen, Glaumann, Eriksson et al., 2013) Social LCA (Somanath, Hollberg and Thuvander, 2021)
Design stage	Early architectural design stage (Østergård, Jensen and Maagaard, 2016)	Feasibility studies (Larsen, Tollin, Sattrup et al., 2022) Code compliance (Xie, Tyler, Huckett et al., 2023)
Tool paradigm	Digital tools (Negendahl, 2015)	Analog design tools (Peters, Loke and Ahmadpour, 2021) Design standards (Kuittinen and Häkkinen, 2020)
Tool development approach	Improved software requirements (Johansson and Messeter, 2005; Lucassen, Dalpiaz, Werf et al., 2016)	Improved analysis method (Qavidel Fard, Zomorodian and Korsavi, 2022) Interface usability (Nisztuk and Myszkowski, 2018)

As shown in Table 1.1, there is a wide range of approaches in research to reducing the environmental and social impact of the built environment. The present research emphasises the work of architectural practitioners applying life cycle building performance assessment in early architectural design stages through the implementation of digital tools and workflows. This is done by identifying ways to improve the definition of software requirements for software developers with architectural practitioners as target users, by applying a practice perspective.

Below, the scope of the thesis is elaborated through definitions for the included terms. More detailed explanations and an elaboration on previous research related to each term is provided in Chapter 2.

Life cycle building performance assessment (LCBPA) - is a combination of Life Cycle Assessment (LCA) and Building Performance Analysis (BPA) into a holistic workflow for quantitatively evaluating the functional and environmental performance of a building over its entire life cycle.

LCBPA tools - are defined in this thesis as software tools for LCBPA, composed of a front-end with which the user interacts, and a back-end which stores information supplied by the user and runs analyses.

Software developers - may refer both to the companies and groups that develop software, the specific practitioners designing and implementing them, or architectural practitioners developing tools themselves to meet their needs in design processes.

Architectural practitioners - refers to people responsible in design processes for research, modelling, analysis, and communication, which serves to develop a design proposal. This includes architects, engineers, urban designers, sustainability experts, and other consultants. It excludes other stakeholders in design processes such as policymakers, clients, land owners, and end users.

Early architectural design stages - refers to the first stages in which an architectural design is developed, including definition of the project brief, and development of the initial architectural concept. That excludes the preceding prestudy phase where a decision on project initiation is made, and the following phases where a detailed design model is developed followed by construction.

1.4 Research design

To meet the aim of proposing methods for software developers to identify practitioners' perspectives on LCBPA tool integration in early stage architectural design processes, the research is conducted in two phases, each included as a study in this thesis, as shown in Figure 1.3. The first phase, described in this thesis as Study A, aims to understand existing approaches to characterising and developing tools through a critical literature study, combining *literature meta-review* and *conceptual framework analysis*. The second phase, described as Study B, aims to propose a new, more practice-oriented approach to defining software requirements through an interview study, combining the *interview to the double* with *narrative analysis*. More information on the employed methods and the specific studies is provided in Chapter 3.

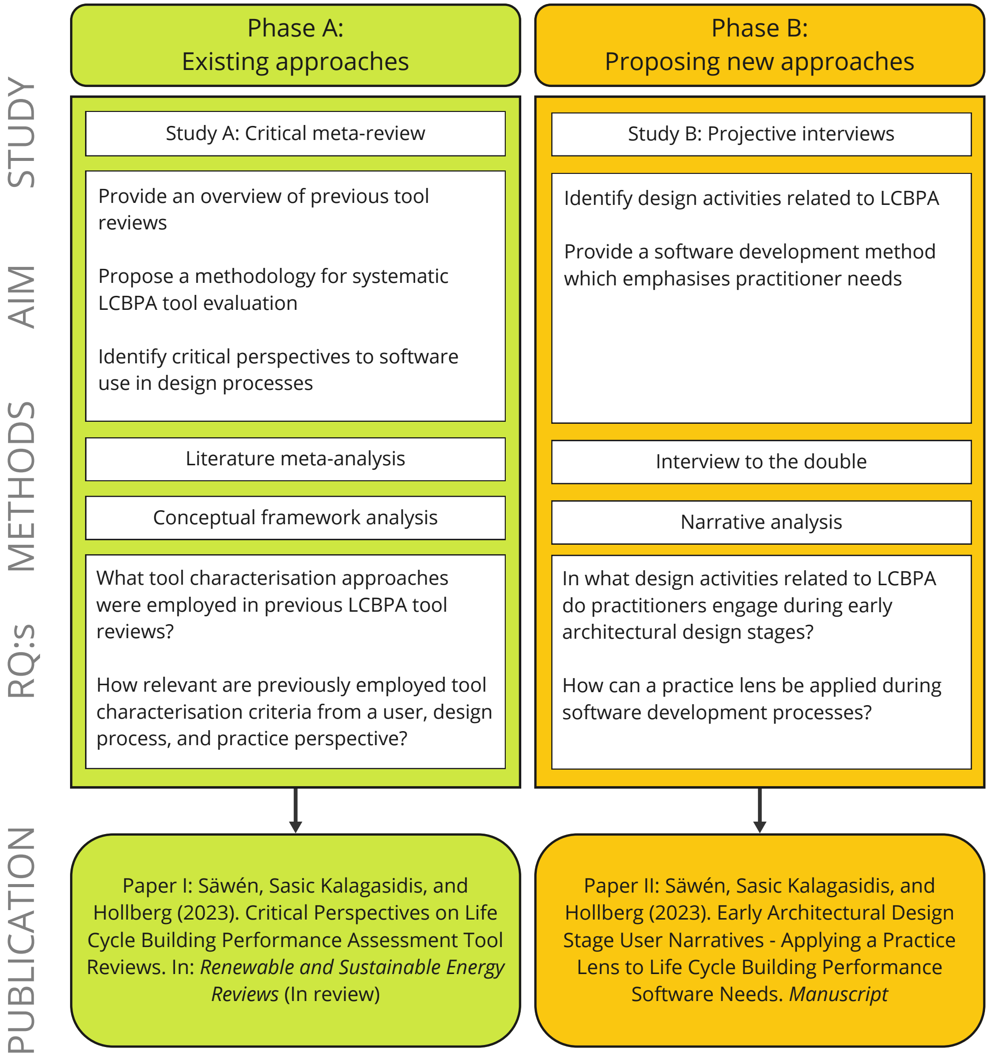

Figure 1.3: Research design.

This methodology is composed of qualitative, exploratory approaches. The research approach can be considered inductive as methods and theories emerge as knowledge gaps are identified (Woo, O'Boyle and Spector, 2017). This may be regarded as atypical for the field of life cycle building performance, which can be considered dominated by a techno-economic systems engineering research paradigm rooted in the quantitative observation of physical phenomena related to buildings (de Wilde, 2019; Janser, Hubbuch and Windlinger, 2020). However, design processes are social processes which involve numerous transactions between human stakeholders (Kimbell, 2012). Further, as Orlikowski (2007) argues, all practices are sociomaterial and their organisation shaped by their materiality, including technology. To meet the aims of this thesis, a research paradigm is needed which is able to investigate the sociomaterial assemblage of technology embedded in social organisations, to understand why a specific software development approach is working or not. This research paradigm is interdisciplinary in calling on methods from qualitative social research, observing analysis methods developed in building technology fields, as implemented through software engineering, and as applied in architectural design (Alvargonzález, 2011).

This thesis describes design processes, and the use of technology during their course, as a matter of social organisation which can be observed. This is guided by a critical realist view, which treats the social (design work) and the material (analysis tools) as separate entities which become entangled (sociomaterial) through human activity occuring over time (Leonardi, 2013). In treating (architectural design) practice as "able to speak for itself" (Nicolini, 2009), the research presented belongs to a constructivist interpretive paradigm which attempts to understand and reconstruct the practice of developing and using LCBPA tools in early architectural design stages by giving voice to the participants in that practice (Lincoln and Guba, 2005).

1.5 Structure of thesis

This thesis is divided into two parts.

Part I is a summary of the performed studies including background, methodology, and findings. Chapter 1 introduces the research background and motivation, the problem statement and aim, the research context and scope, and the research approach. Chapter 2 expands on the background of the research. Chapter 3 describes the employed methods. Chapter 4 presents and reflects on the key findings. Chapter 5 discusses limitations of the methodology and suggests a future research direction. Finally, Chapter 6 indicates the main contribution of the work.

Part II contains appended two appended papers detailing the performed studies.

Chapter 2

Extended background

2.1 Life cycle building performance assessment

This thesis introduces *life cycle building performance assessment* (LCBPA) as a combination of the Life Cycle Assessment (LCA) and Building Performance Analysis (BPA) methodologies.

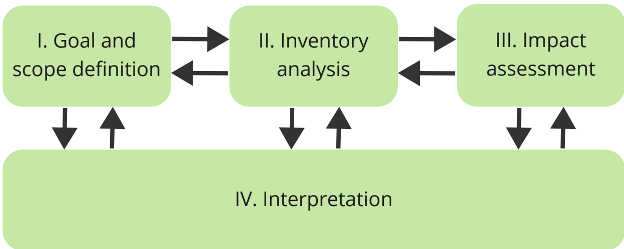

Figure 2.1: Steps in an LCA. Adapted from 14040:2006 (ISO, 2006a) via Hollberg (2016).

Life Cycle Assessment (LCA) - is a method of quantifying the environmental impact of a product such as a building (Tillman, Ekvall, Baumann et al., 1994). It has been internationally standardised in the ISO standard 14040:2006 (ISO, 2006a), with specific standards for buildings in the ISO standard 14044:2006 (ISO, 2006b) and EN15978:2011 (SIS, 2011). As shown in Figure 2.1, the methodology prescribes four steps: I) goal and scope definition, II) inventory analysis, III) impact assessment, and IV) interpretation. For buildings, conducting an LCA includes studying embodied and operational impacts over the full life cycle of the building, divided into a number of modules as shown in Figure 2.2. The specific modules to be included in each given assessment are defined during the goal and scope definition. In this step, a functional unit is defined, for instance an area in square metres, or a whole building unit. In the inventory analysis, the amounts of material used in the product is collected

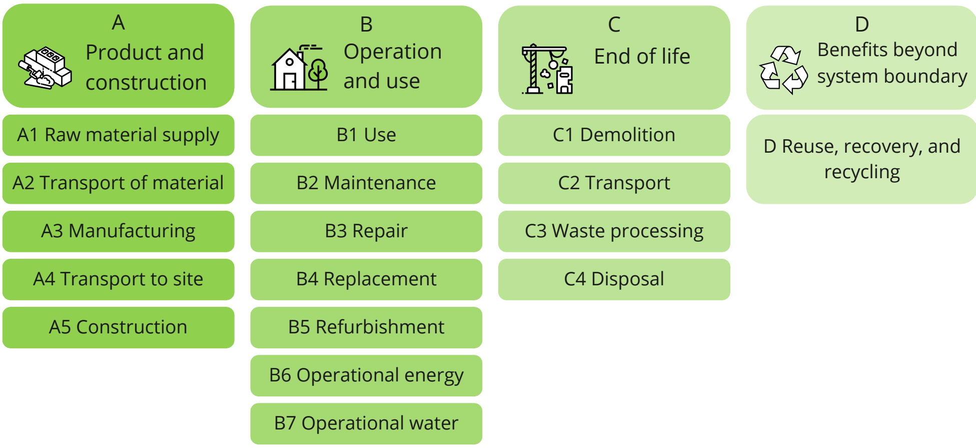

Figure 2.2: Modules included in LCA for buildings. Adapted from EN15978:2011 (SIS, 2011) via Hollberg (2016).

in a bill of quantities for calculation of the embodied impact, whereas the operational impact is determined by calculating the resource use needed to uphold the function of the building, usually dominated by the supply of energy for heating and cooling. In the impact assessment step, these collected values are multiplied by an array of environmental impact factors which have been previously collected for the given resource or are retrieved from one of several available databases (Hollberg, 2016).

The great amounts of data involved and the sensitivity of the outcome to the system boundaries have meant that the assessment is normally carried out by experts in late design stages within the architectural context (Hollberg, 2016). However, several researchers point to the usefulness of applying LCA in earlier design stages and have developed approaches of doing so (Basbagill, Flager, Lepech et al., 2013; Meex, Hollberg, Knapen et al., 2018). It should be noted that there is a number of alternative approaches to accounting for the environmental footprint of products, such as Material Flow Analysis (MFA) and Product Environmental Footprint (PEF), but LCA is more commonly applied in building contexts due to covering the full life cycle, being internationally standardised, and having good data availability (Hollberg, 2016).

To transpose a purely geometrical architectural model into an LCA model, the geometry of each building component needs to be modelled in three dimensions, and information about the materials used for each building component and their impact per volume unit needs to be added. Alternatively, building components can be represented in two dimensions, and their impact value included per area unit. Further, an energy model is required to quantify the operational energy use (Hollberg, 2016).

Building Performance Analysis (BPA) - is an umbrella term for a number of methods which quantitatively analyse the functional performance of a building (de Wilde, 2019). Computational tools were first developed for the simulation

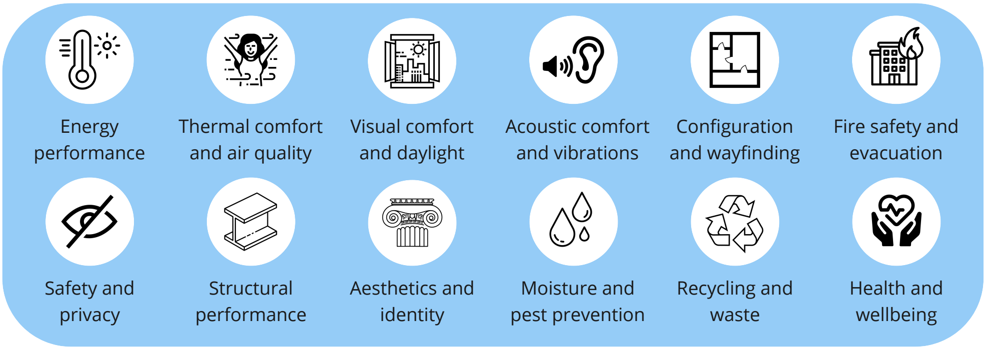

Figure 2.3: Overview of analysis modes considered part of BPA (de Wilde, 2019).

of energy performance after the introduction of energy requirements following the oil crisis in the 1970s. Subsequently, as shown in Figure 2.3, factors like thermal, visual and acoustic comfort, daylight, among other criteria were added to the analysis toolbox (Clarke and Hensen, 2015). As a collection of methodologies, no standardisation of BPA as a framework exists for various reasons discussed by de Wilde (2019). However, internationally recognised standards exist for several performance criteria, including energy performance in ISO 52000-1:2017 (ISO, 2017), daylight in EN 17037:2021 (SIS, 2021), and thermal comfort in ISO 7730:2005 (ISO, 2005). BPA has also seen a number of developments in recent years to allow integration of the analysis methods in early architectural design stages (Attia, Gratia, De Herde et al., 2013).

Developing a BPA model based on a geometrical architectural model involves defining three-dimensional rooms describing how air moves through the building, and representing the boundaries of these rooms as two-dimensional surfaces with added energy and daylight properties (Hensen and Lamberts, 2011). Finally, apertures in the building envelope and the building context need to be modelled in three dimensions to account for the entry of solar radiation and daylight (Ochoa, Aries and Hensen, 2012). Information about the outdoor climate, based on the location, and the indoor climate, based on the intended use, is supplied (Hensen and Lamberts, 2011).

Although LCA and BPA have been developed by and traditionally belonged to different professional roles in design processes (Hollberg, 2016), there is a major overlap of modelling efforts, as shown in Figure 2.4: first, a quasi-three-dimensional representation of the building based on the geometrical architectural model is needed, and second, material data needs to be added to each building component. This motivates the combination of the two analysis methodologies into one holistic framework to make modelling more efficient and allow trade-offs during design processes to be investigated and managed (Østergård, Jensen and Maagaard, 2016). The added life cycle perspective to building performance shifts attention from the functional performance of the building at the moment of completion to the possible performance under multiple uses and changing contexts over the life cycle.

Although promising, such holistic approaches have been proposed in only

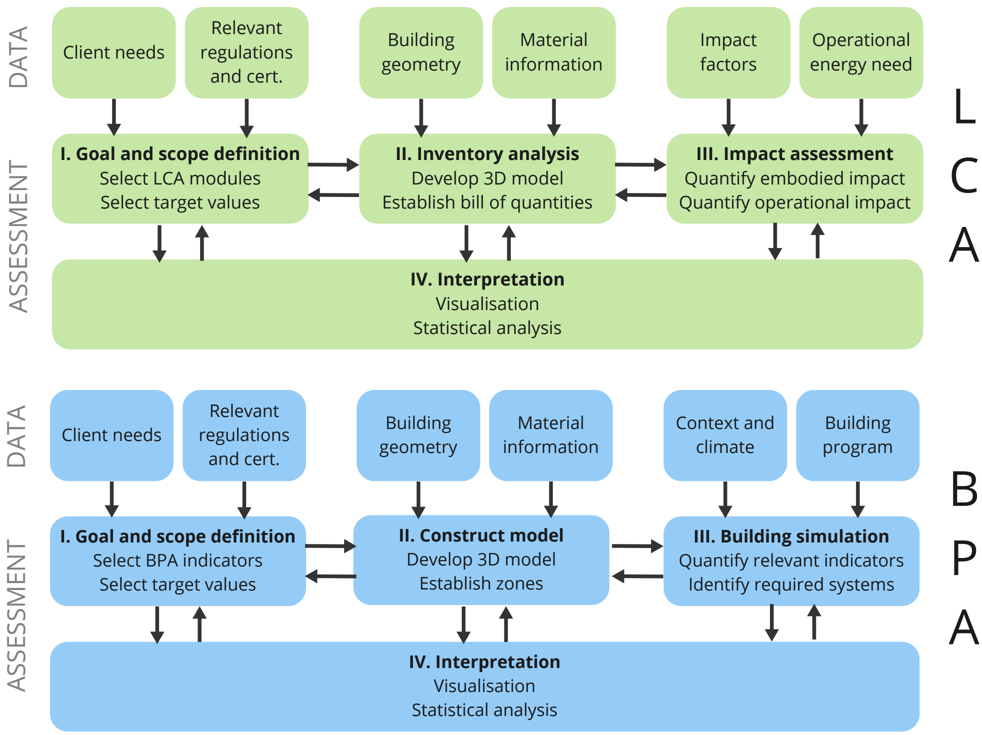

Figure 2.4: Overlaps of the steps taken when performing building LCA (Hollberg, 2016), and BPA (Østergård, Jensen and Maagaard, 2016; de Wilde, 2019).

a handful of previous studies beyond the consideration of operational energy in LCA (Magnusson, 2022). Østergård, Jensen and Maagaard (2016) propose that while difficult, the correlation of design objectives requires designers to consider them in conjunction as changes to improve the design with regards to one objective will affect other ones. They propose the integration of weighting systems which require the design team to think holistically and make prioritisations among objectives (Hopfe, Augenbroe and Hensen, 2013). Almeida and Ferreira (2017) propose in investigating renovation scenarios that the combined assessment of life cycle impacts, costs, and energy performance, allows the detection of synergies pertinent to a range of performance criteria like thermal comfort and daylight. Magnusson (2022) developed a tool combining simplified LCA and BPA methods, and found in user testing that the tool was both beneficial to design outcomes, and that architectural practitioners with limited technical knowledge were able to apply the tool independently. Beyond this, little research is available on opportunities and limitations in combining LCA and BPA into holistic workflows which require a single model instance.

This knowledge gap regarding the potential for combining LCA and BPA in early architectural design stages is treated in this thesis through analysing previous proposals for how to integrate analysis tools in design, identifying approaches to evaluating such combined workflows when applied in practice.

2.2 LCBPA tools

The usage of *tools* pervades the early stage architectural design practice (Dalsgaard, 2017). To be more specific than the figurative meaning of the term ("a tool to achieve a given purpose"), in this thesis the emphasis is on software tools for LCBPA. As shown in Figure 2.5, in a simplified sense these tools are composed of the front-end: the interface with which the user interacts; and the back-end: the services (analysis engines), and databases which operate on the information supplied by the user (Northwood, 2018). The tools may or may not be integrated in other design software (Østergård, Jensen and Maagaard, 2016).

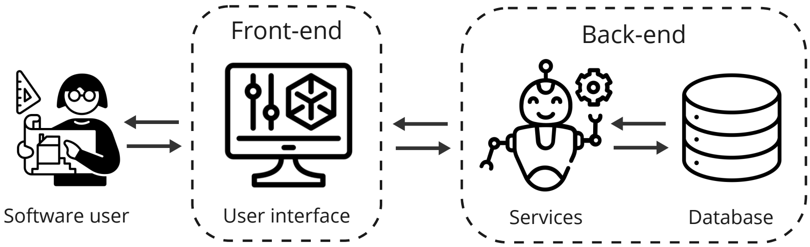

Figure 2.5: Simplified model of a software tool (Northwood, 2018). The arrows represent information and data flows.

This excludes several other kinds of tools used in the architectural practice, for instance physical design tools like the pen and sketching pad or the hardware and paraphernalia of the computer (Bueno and Turkienicz, 2014); or analogue design tools like templates and workshop implements (Peters, Loke and Ahmadpour, 2021). It also excludes the tools that are used by other stakeholders in design processes to influence life cycle building performance outcomes, like certification systems introduced by environmental agencies (Wallhagen, Glaumann, Eriksson et al., 2013), or regulations put in place by authorities (Sadri, Pourbagheri and Yitmen, 2022). It finally does not refer to the analysis methods discussed themselves, but rather their implementation and integration in software products.

Dalsgaard (2017) proposes an understanding of tools as *instruments of inquiry* in design processes, arguing that the use of tools allows for new ways of experiencing phenomena like those studied using LCBPA, allow experimentation with these phenomena, and can guide the designer toward improved solutions. He proposes that part of designer competence is selecting the correct tools for any given design activity. Purup and Petersen (2020a) investigated these design activities, and found in an interview study that design processes can be described as a sequence of such design activities between which architectural practitioners navigate. Their conclusion is that while design processes are hard to generalise, it is possible for the activities performed during their progress, and thus tool requirements can be stated in a way that allows the development of tools which support one specific, or a specific sequence of, design activities. Then, a modular workflow combining tools could be set up based on the needs in each specific process. Similarly, Østergård, Jensen and Maagaard (2016) propose that instead of developing a single tool which covers the entire workflow, a combination of existing tools would better fit designer needs. They developed a hypothetical simulation framework with six stages: 0) a knowledge database, 1) a baseline model, 2) sampling, 3) simulations, 4) statistical analysis, and 5) visualisation. The components of this framework would then be decided on a project-by-project basis.

These software tools would not exist without the *software developers* described as the beneficiaries of the research presented of this thesis. Their definition is a wide one, referring to various professional roles taking part in the software design and development process in a variety of software development practices.

In larger organisations dedicated to software development it may refer to the decision-makers and strategists investigating potential markets for product development (Regnell and Brinkkemper, 2005). It may refer to software architects and designers who are setting overarching software requirements and deciding on the system boundaries for any given software implementation (Vliet and Tang, 2016). Finally it may refer to the programmers interpreting the tool requirements and transposing them into software implementations, or the testers who ensure that the requirements are met (Franch, Palomares, Quer et al., 2023). Under this development paradigm, as shown on the left side of Figure 2.6, the software need is identified in an organisation, and the development then conducted by an external software consultant (DeBellis and Haapala, 1995). According to Comino, Manenti and Parisi (2007), software success in such situations is often measured in terms of the number of software units sold.

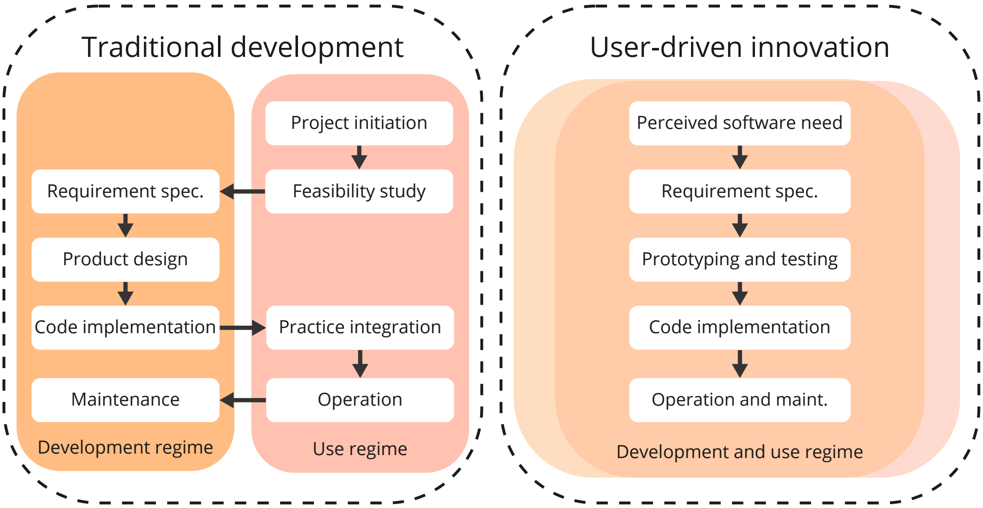

Figure 2.6: Steps of a traditional software development process (DeBellis and Haapala, 1995) and user-driven innovation (Comino, Manenti and Parisi, 2007).

However, much of development of LCBPA tools is performed not in traditional software companies but by architectural practitioners who have identified software gaps in their practices (Säwén, Magnusson, Sasic Kalagasidis et al., 2022a), a case of user-centric innovation (Comino, Manenti and Parisi, 2007). While not software developers by trade, these architectural practitioners have honed the skills to create simple yet functional software to perform specific tasks. They often rely on non-traditional development environments like spreadsheet tools (Excel, Sheets), or visual programming interfaces (Grasshopper, Dynamo) (Säwén, Magnusson, Sasic Kalagasidis et al., 2022a). They may take up any of the roles previously described from traditional software development organisations, and by merit of being embedded in architectural design practice, have even better means of applying the practice-centric development methodologies proposed in this thesis (Comino, Manenti and Parisi, 2007). As shown on the right side of Figure 2.6, in this development paradigm the process is initiated by practitioners who perceive a software need and develop open-source tools to meet that need (Comino, Manenti and Parisi, 2007). Success in this case is measured in terms of whether the tool codebase reaches a stable release.

While little research exists on the competences of the people and organisations responsible for the development of LCBPA tools, several studies have problematised the perspectives previously applied during software development processes. Coming from the perspective of architects wanting to integrate analysis in design processes, Bleil de Souza (2012) explains the low uptake of BPA tools through a mismatch between design thinking paradigms of the engineers who develop thermal analysis tools, and the designers who need to use the outputs of these tools to make design decisions. She proposes that the tool developers need to gain an understanding of the epistemology of designers, and conversely, that designers need to improve their intuitive understanding of physical phenomena so that they can gauge what performance criteria are relevant to any given design decision, and request the applicable tools. From the perspective of building performance engineers aiming for better tool uptake, Attia, Hensen, Beltrán et al. (2012) surveyed architects and engineers to analyse their tool requirements, and found that while architects emphasise the integration in tools of knowledge which could support decisions, engineers prioritise accuracy and the ability to create complex models. They propose that uniform definitions of tool specification criteria which relate to these needs would improve tool uptake.

As shown in Paper A appended to this thesis (Säwén, Sasic Kalagasidis and Hollberg, 2023a), a number of studies which more or less systematically evaluate LCBPA tools has emerged. While some of these actually employ the criteria proposed by Attia, Hensen, Beltrán et al. (2012) e.g. Bazafkan (2017), most unfortunately fail to support the selection of specific criteria with references, and using the terms of Bleil de Souza (2012), are "based on interpretations of what the [LCBPA experts] assume the building designer needs" (Donn, 2004). An example is a suite of reviews of "architect-friendly" tools (Attia, Beltrán, Herde et al., 2009; Weytjens, Attia, Verbeeck et al., 2011), which mostly fail to investigate research about design processes and how tools are used as instruments of inquiry (Dalsgaard, 2017). Further, all identified tool reviews are carried out based using idealised experimental setups with hypothetical design cases. There appear to be no reviews which investigate tools as used in real design processes (Säwén, Sasic Kalagasidis and Hollberg, 2023a), which would allow going beyond making assumptions, to truly understanding, architectural practitioner needs (Bleil de Souza, 2012).

This knowledge gap regarding how tools can be evaluated through a practice lens is bridged in this thesis through the development of a tool characterisation framework based on previous approaches, which is intended to allow consistent evaluation of tools and the specification of software requirements which take architectural practitioner needs into account.

2.3 Early stage architectural design practice

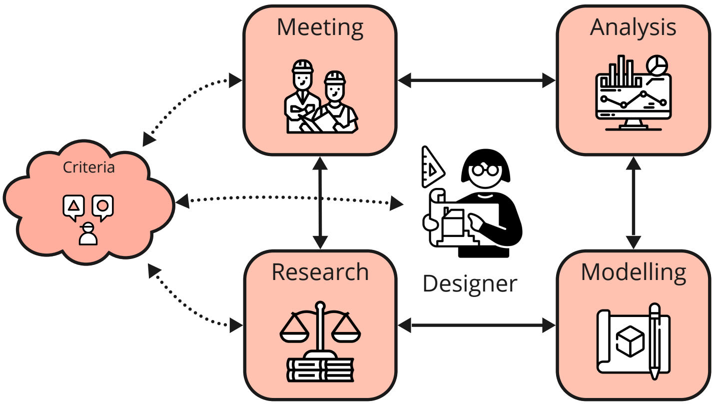

Figure 2.7: Model of the design process and the role of the architectural practitioner. Adapted from Purup and Petersen (2020a).

The term *architectural practitioner* is defined in this thesis as a person involved in design processes through 1) research activities, retrieving supporting information; 2) modelling activities, creating analogue or digital models representing the developing design options; 3) analysis activities, analysing these models quantitatively or qualitatively; and 4) meeting activities, providing arguments for why a design option should be selected or receiving feedback supporting design changes (Purup and Petersen, 2020a). As shown in Figure 2.7, the design process is open-ended, and the architectural practitioner constantly navigates between activities as needed to solve the design task by comparing the design outcomes against a number of evolving criteria (Cross, 1982). This definition of the architectural practitioner covers a number of stakeholders in design processes who may have a range of formal educations, and belong to a range of professions: architects, urban designers, engineers, sustainability experts, and so on. However, it leaves other stakeholders out, for instance: real estate developers as clients of the design project, land owners, end users, and politicians. These groups are referred to by Mavrigiannaki, Pignatta, Assimakopoulos et al. (2021) as *internal* and *external* stakeholders, respectively, in the sense that the internal stakeholders develop the design project, and the external stakeholders either set the boundaries and make decisions regarding its development, or benefit from it as end users.

While it is clear that the relationships between stakeholders are crucial for making tool integration in design processes possible, little appears to be known about what tools are actually used by these various stakeholders during design processes. Mahmoud, Kamara and Burford (2020) found in a survey with architects that the client interest in the output of tools is crucial, arguing that if the knowledge among architectural practitioners about the potential of tool integration is increased, clients' awareness would also improve. Jusselme, Rey and Andersen (2020) also surveyed architectural practitioners, and noted that a major barrier toward tool uptake is a lack of clients' incentives to integrate LCBPA outputs in their decision making. They call for regulatory requirements that would increase the willingness of real estate developers to include performance requirements in design brief, motivating its use in early design stages. Such developments are happening, but as discussed by Sadri, Pourbagheri and Yitmen (2022), the implications in industry are yet unclear. Further, such proposals raise a question which remains unanswered about what kind of tools regulatory bodies and real estate developers need to use to be able to set reasonable, progressive limit values for performance criteria.

The term *early design stages* has a wide meaning for different stakeholders. In this thesis, they are defined in accordance with the Royal Institute of British Architects (RIBA), as shown in Figure 2.8 (RIBA, 2020). This firstly includes the preparation and briefing stage, when an architectural brief is developed and the design team is defined. Secondly it includes the concept design stage, which serves to develop one or more design concepts which can be developed in later stages. Preceding the early design stages is the strategic definition stage, when the feasibility of the project is investigated and the decision to start the design is made. Following the early design stages are the spatial coordination and technical design stages in which detailed drawings are produced, and finally the manufacturing and construction, handover, and use stages. In Sweden, the design process is similarly organised according to the delivery of a sequence of drawing packages, also shown in Figure 2.8. As shown in the figure, architects have a larger influence in decision making in earlier stages, and engineers gain more influence as the design crystallises (Morbitzer, 2003). Further, the previously discussed process first described by Paulson (1976), where design changes are both more expensive, and have less impact on the final outcome, is schematically represented.

While several studies (Schlueter and Thesseling, 2009; Østergård, Jensen and Maagaard, 2016; Meex, Hollberg, Knapen et al., 2018) emphasise the usefulness of integrating LCBPA in early stage design, little is known, especially in relation to the Swedish context, about what tools are used, in what context, by what stakeholders, in actual design processes (Schade, Wallström, Olofsson et al., 2013). Such information would be highly beneficial to guide the community developing tools. However, it requires researchers to venture into the field

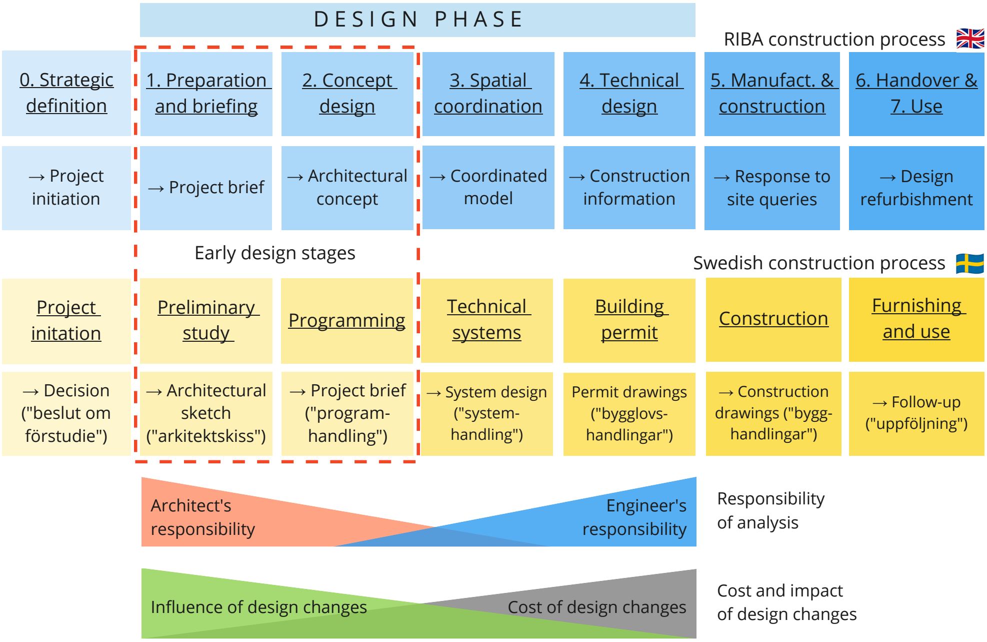

Figure 2.8: Architectural design stages as defined in the UK by RIBA (RIBA, 2020), and in Sweden (Hansson, Olander, Landin et al., 2015), and the deliverables excpected of architectural practitioners in each design stage. Further schematically shows the degree of involvement of architects and engineers as the design progresses (Morbitzer, 2003), and the cost versus effect of design changes on outcomes (Paulson, 1976).

and observe what is going on in practice.

This knowledge gap regarding the use of life cycle building performance assessment tools in early architectural design practice in Sweden and elsewhere is bridged in this thesis through the proposing a method of observing practice, by exploring the usefulness of ethnographic interviews as a way of making sense of practice during software development processes.

Chapter 3

Methodology

The research in this thesis employs qualitative methods which are aimed to understand phenomena in terms of their meanings ascribed by people (Denzin (ed) and Lincoln, 2018). In any qualitative study, interpretation is needed of the collected evidence to elicit understanding (Corbin and Strauss, 2008). In the research presented this is done, firstly by interpreting the available literature to find out how researchers and software developers conceptualise LCBPA tools, and secondly by interpreting the accounts of architectural practitioners to find out how they conceptualise their activities in design processes. As illustrated in Figure 3.1, insight into questions guiding the work of these practitioners could be gained through such conceptual thinking. The analysis of qualitative data is a powerful strategy for discovery and exploration (Miles, Huberman and Saldaña, 2020). In approaching the sociomaterial problem of software integration in design processes in the research presented in this thesis, qualitative methods offer tools to consider software and the processes in which they are embedded as social phenomena which can be understood through inquiry among the actors which interact with them.

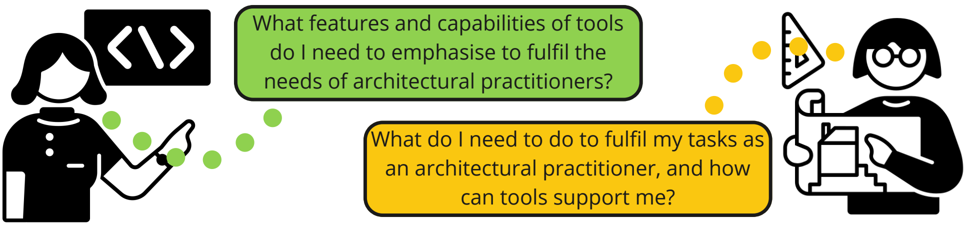

Figure 3.1: To solve the problems of software developers (left) and architectural practitioners (right), qualitative methods can help understand how they conceptualise tools, and the work supported by those tools.

In the following, the methods applied in the study are presented in more general terms, followed their specific implementation in the performed studies, as summarised in Figure 3.2.

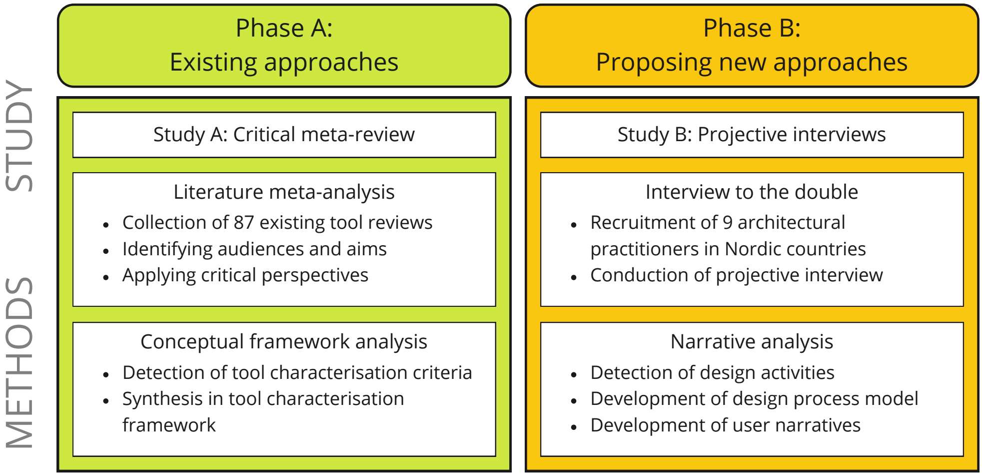

Figure 3.2: Overview of methods employed in each study.

Literature meta-review - is applied to integrate the findings of a large collection of studies and compare methodologies (Glass, 1976), gaining an understanding from a variety of perspectives on a phenomenon (Post, Sarala, Gatrell et al., 2020), in the present case, on how researchers and software developers conceptualise LCBPA tools in terms of evaluation criteria. Meta-reviews can be applied for a variety of reasons, including to analyse the assumptions dominating a research area, to clarify the constructs present in the literature, and to define a research agenda based on different assumptions or a more holistic understanding of the involved constructs (Post, Sarala, Gatrell et al., 2020). The meta-review is a kind of document analysis, a powerful way of producing rich descriptions of single phenomena Bowen (2009). However, Coffey (2014) warns researchers against trying to "learn from records alone how an organization actually operates day by day". Nevertheless, documents can be used to track developments and changes within a research field, identify unanswered questions related to that field, and be the foundations of a knowledge base within a research project (Bowen, 2009).

Conceptual framework analysis - is a way of creating a structure for the ways that people make sense of a phenomenon such as LCBPA tools. Jabareen (2009) describes a conceptual framework as a "network of interlinked concepts that together provide a comprehensive understanding of a phenomenon". He argues that these frameworks are useful in multidisciplinary research observing social phenomena which are complex and linked to different disciplines, and proposes that conceptual frameworks be composed entirely of concepts - if they include variables and factors, they should be referred to as models. They conceptual framework is an example of a grounded theory in that concepts emerge and theory is "discovered" during the data analysis process (Glaser and Strauss, 2017). Orlikowski (1993) argues that grounded theory is useful in studying technology in organisations as "it allows a focus on contextual and processual element as well as the action of key players associated with organizational change". Jabareen (2009) describes seven steps to the conceptual framework analysis: 1) mapping of the data sources, 2) extensive reading and categorisation of the data, 3) identification and naming of concepts, 4) deconstruction and categorisation of concepts, 5) integration of concepts, 6) synthesis and sense-making, and 7) validation. This process always occurs in constant movement between concept and data (Glaser and Strauss, 2017).

Interview to the double - is a projective, ethnographic interview method first employed by Marxist occupational psychologists Oddone, Re and Briante (1977, cited by Nicolini [2009]), and formalised and presented by Nicolini (2009). The respondents are asked to imagine that the interviewer is a body double who is supposed to take over their tasks the next workday. Then they are prompted to describe the workday, including tasks, social interactions, and so on, in so much detail that the body double would not be discovered. Ideally, the researcher does not interject, but they may ask for clarifications or delving into more detail as necessary. Nicolini (2009) suggests that, although initially conceived to be able to articulate practice to those unfamiliar with it, its use as a standalone technique is problematic for several reasons: because it means trying to understand cultural phenomena through etic (outsider) as opposed to emic (insider) perspectives (Denzin (ed) and Lincoln, 2018); because the method requires a certain level of trust between participants which can be built up only through spending time in the research environment (Branthwaite and Lunn, 1985, cited by Nicolini [2009]); and because of low "ecological validity" - a risk for differences in interpretations of concepts and terms between practitioners and researchers if not backed up by other ethnographic methods (Cicourel, 1982). Nicolini (2009) describes methodological decisions to be made by the researcher, such as whether to prompt the interview with a short example or not, and whether to offer categories to structure the responses or to leave the organisation of the narrative entirely to the respondent. Finally, he prescribes recording and verbatim transcription to capture the linguistic repertoire in the practice.

Narrative analysis - is a way of understanding how participants in a qualitative study construct stories and narratives from their personal experiences (Reissman, 2011), or a way of mapping what elements of practices have been investigated during an ethnographic study, and what assertions or hypotheses currently lack evidence (Kemmis, McTaggart and Nixon, 2013). The key difference to other qualitative analysis methods such as thematic analysis is a reliance on larger blocks of text, narratives, rather than developing themes from extracted quotes (Denzin (ed) and Lincoln, 2018). The narrative analysis is inductive: the focus of the analysis emerges as the narratives produced by respondents are read (Reissman, 2011). A key element is that the narrative production has two steps of interpretation - first the respondent interprets their lived experience as a narrative, and second the researcher interprets their account. To be useful to the researcher, the rich accounts produced by respondents need to be interpreted to create condensed narratives. Several strategies for data reduction are proposed by Reissman (2011): through core narratives, understanding narratives as constructed from a common set of elements - abstraction, orientation, complication, evaluation, and resolution (Bell, 1994, cited by Reissman [2011]); or through poetic structures - framing, affect and conflict, and enduring role strains (Reissman, 2011). The former approach allows comparing different narratives through adapting them to the same structure, while the latter allows observing the way that respondents choose to organise the narrative; "why does the informant tell her tale *this* way in conversation to *this* listener?" (Reissman, 2011).

3.1 Study A: critical meta-review

During a previous study, reviewing LCBPA tools (Säwén, Magnusson, Sasic Kalagasidis et al., 2022a; Säwén, Magnusson, Sasic Kalagasidis et al., 2022b), it was identified that there was a lack in the literature of a consistent methodology for evaluating tools in the context of life cycle building performance. To bridge this gap, the goal of Study A, previously detailed in Säwén, Sasic Kalagasidis and Hollberg (2023a), is to propose such a methodology through a more comprehensive analysis of the previous research in a meta-review.

The scope for the meta-review is reviews of tools relevant to the field of life cycle building performance, with an emphasis on reviews of LCA and BPA tools, but also including tools for e.g. architectural design in general, sustainability evaluation in a wider sense, structural analysis, and energy systems. The understanding of tools is also rather broad, including both digital and analogue analysis tools. Through a systematic, snowballing literature search (Wohlin, 2014), 87 relevant reviews were identified. These reviews were then subjected to a three-stage reviewing process, shown in Figure 3.3.

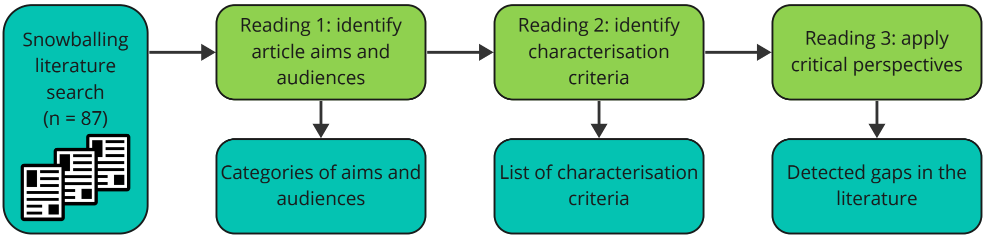

Figure 3.3: Steps in the three-stage critical meta-review

In the first reading, the aims and intended audiences of each article were identified to understand the context in which the research was carried out (Bowen, 2009). This allowed reflection on the usefulness of tool reviews in different situations such as tool development, selection, and integration in design processes. In the second reading, a conceptual framework was constructed which collected and categorised the criteria using which researchers had interpreted and evaluated tools in the previous studies (Jabareen, 2009). The framework represents a kind of grounded theory which describes how the research and development community understands tools, and allowed a reflection on the perspectives applied to understanding how tools function in design processes (Glaser and Strauss, 2017). In the third reading, perspectives which were found to be missing in the literature were applied to the conceptual framework. This was done to identify if and when the previous authors had acknowledged aspects which determine the feasibility of software integration in practice (Orlikowski, 2007). This allowed listing a number of questions which remain unanswered in the existing literature evaluating tools, and proposing a method of organising software requirements which serves to answer these questions.

3.2 Study B: interview to the double

An investigation into approaches to applying the critical perspectives identified in Study A was initiated in Study B. The first identified approach s the paradigm of user-centric software development (DeBellis and Haapala, 1995). The second approach is a more wide set of methods within the framework of action research, an approach which acknowledges the ability of people in a specific practice to be active participants in research about that practice, and where the research is oriented specifically to allowing practitioners to propose changes to the practice, and to evaluating those changes (Kemmis, McTaggart and Nixon, 2013). Purup and Petersen (2020b) propose that this approach allows identifying and solving problems in the practice such as a lack of tool uptake. While the work presented in this thesis does not strictly conform to the action research approach as introduced by Lewin (1946, cited by Kemmis, McTaggart and Nixon [2013]), the ethnographic, practice-centric methods applied are retrieved from the methodological toolbox applied in action research.

The Interview to the Double (IttD) method proposed by Nicolini (2009) was identified as interesting because it both serves to apply a practice lens and give voice to practitioners, and provides an effective and succinct way of representing the findings convincingly. In this method, the respondents are asked to imagine that the interviewer is a body double who is to take over their tasks on the upcoming workday, and needs clear instructions in order to accomplish them, as artfully shown in Figure 3.4. This, according to Nicolini (2009), mimics the familiar relationship between the instructor and the novice in the practice. It further acknowledges the expertise of the practitioner and attempts to extract that knowledge to represent what is done in the practice and why. This appears promising in terms of giving software developers a method to better understand practice needs.

Nine architectural practitioners were recruited and interviewed. The interviews lasted between 20-60 minutes. Most respondents quickly caught on to the concept of the interview method, and described their tasks without inhibition. The following is an example of a response to the prompt: "tell me what I would have to do to accomplish your task the next workday":

Figure 3.4: "Tell me about your day. I'd like very much to hear about it." Artist's rendition of the interview method. ©Magdalena Lundberg, used with permission.

> *"On Monday I will [...] calculate a Green Area Factor. I'll create drawings where I draw all the areas and note their properties, and then I will enter their areas in a spreadsheet provided by [the municipality], and that will help calculating if it works fine, if the Green Area Factor is OK."*

As can be seen, the response is on a quite high level, noting the sequence of activities, and also mentions the purpose of that activity. While most of the conversation was driven by the respondents detailing their activities during the day, interjections were made and questions posed as needed to ask for more details or clarifications of the steps taken to accomplish each task.

Once the interviews were conducted, they were transcribed verbatim and analysed as shown in Figure 3.5. The initial idea for analysis of the interview responses after transcription was to cross-check the tool characterisation framework developed in Study A. However, in the first round of coding the responses, it was quickly realised that the respondents did not go into much detail about software usage without very specific prompting. Too much interpretation was needed to fit the responses into that conceptual framework. Instead, the next step of the analysis was driven by the realisation that the information in the responses contained a higher level understanding of the design process, de-

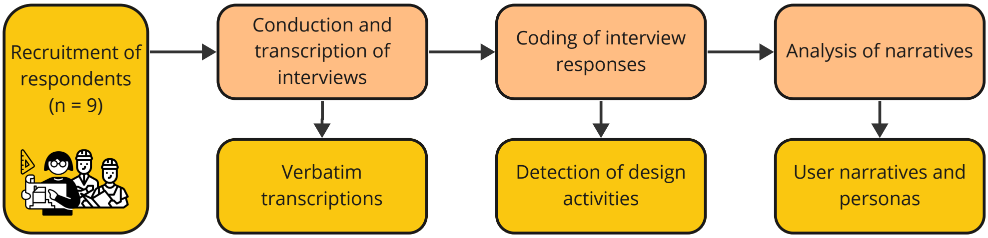

Figure 3.5: Steps in the interview study.

scribing the activities and the purposes of these activities. This allowed an investigation into design activities in the second round of coding (Reissman, 2011), building upon the framework by Purup and Petersen (2020a). In their interview study, 31 design activities in four categories were detected: research, modelling, analysis, and meeting. The present study builds upon their proposed framework through the identification of further design activities mentioned by the respondents.

To be able to present the narratives presented by the various respondents in a more useful way, core narratives were identified (Reissman, 2011), and presented in the form of two narrative accounts of personas representing architectural practitioners (Kemmis, McTaggart and Nixon, 2013). In doing this, the overlap was noted between these textual outputs inspired by Nicolini (2009): short narrative accounts describing the workday; and user story methods as applied in agile, user-centric software development (Lucassen, Dalpiaz, Werf et al., 2016). The developed narrative accounts could now be put to the test in participatory software development - actual action research.

Chapter 4

Findings and reflections

This chapter presents and reflects on the findings in the two performed studies, as summarised in Table 4.1. In Study A it was found that most previous tool research emphasised technological advances and paid little mind to practice, user and design process perspectives. In Study B a methodology is proposed for applying such a perspective, using which it was possible to identify a number of important design activities as well as a model for the early stage architectural design process which enables understanding of how LCBPA software can support it.

Table 4.1: Overview of findings in Study A and Study B.

Article	Key findings

Study A: T. Säwén, A. Sasic Kalagasidis and A. Hollberg (2023a). "Critical Perspectives on Life Cycle Building Performance Assessment Tool Reviews". In: *Renewable and Sustainable Energy Reviews* - in revision.	• Previous reviews emphasise *what tools do*, not *what can be done using them*
	  – There is a lack of systematic tool characterisation frameworks
	  – There is a missing emphasis on practice integration
	• A framework for how software developers can conceptualise LCBPA tools
	• A proposed method for software requirement specification emphasising tool use in practice

Study B: T. Säwén, A. Sasic Kalagasidis and A. Hollberg (2023b). "Early Architectural Design Stage User Narratives - Applying a Practice Lens to Life Cycle Building Performance Software Needs". In: *Automation in Construction* - manuscript for submission	• Identified design activities
	  – Develop argumentative material
	  – Understand regulations/client needs
	  – Sustainability analysis
	• The practice lens
	  – Useful method of identifying design activities and software needs
	  – User narratives as a way of enabling participatory software development

4.1 Study A: critical meta-review

Study A (Säwén, Sasic Kalagasidis and Hollberg, 2023a) applies critical perspectives to tool reviews in the field of life cycle building performance by conducting a meta-review (Bowen, 2009) and applying conceptual framework analysis (Jabareen, 2009). The main findings are, firstly, a *tool characterisation framework*, and secondly, an *analysis of applied perspectives* in previous tool reviews. The main conclusion of the study is that most previously performed studies on tools emphasise *what tools do* (a technological perspective) and not *what tools allow architectural practitioners to do* (a sociomaterial perspective).

4.1.1 Characterisation framework

In the collection of previous tool reviews, 87 studies were identified. The initial reading of the literature revealed that the methodologies applied in evaluating and characterising LCBPA tools were inconsistent and often poorly supported in terms of why the specific methodology was chosen. The next step was thus to get an overview of the applied approaches and collect the most useful ones into a robust characterisation framework supported by previous research.

Through analysis of the literature, a picture of the understanding among researchers about LCBPA tools was created by investigating what criteria had been employed in previous tool reviews to evaluate and characterise tools, and organising these criteria into a conceptual framework, referred to as a *tool characterisation framework*. This framework firstly constitutes a practical tool for software developers to organise tool requirements, but more importantly, reveals a grounded theory about how researchers conceptualise tools and describe them, allowing the perspectives applied to be critiqued.

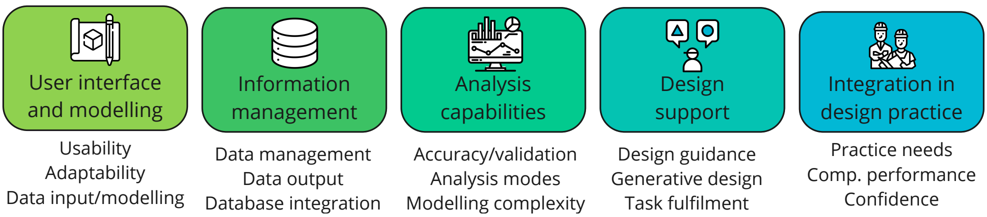

Figure 4.1: Categories and subcategories developed through the conceptual framework analysis.

The five main categories, and fifteen subcategories, in the tool characterisation framework are shown in Figure 4.1. Each category of criteria requires investigation through different methods to understand how tool requirements can be specified that lead to tools which better support design processes.

For example, questions of *user interface and modelling* such as usability could be answered through testing in different design scenarios and deciding how easily beginners pick up the tool and start making simple models, or how much time is required for expert users to achieve their goals. It is then important that such tests are carried out in real design processes and not on streamlined, hypothetical models, to correctly capture the complexities of software usage in practice.

Another example is the investigation of *integration in design practice* which may be investigated through surveys or interviews among those in charge of deciding on tool usage within practices. Possible questions include: "what are acceptable costs?", "what are the existing approaches for educating staff on new tools?", and "what do existing workflows look like in practice, can new tools be integrated?".

In essence, the tool characterisation framework is proposed to allow software developers to apply a variety of methods to investigate the specific needs in each practice as structured by the framework, to develop tool requirements emphasising the categories deemed important, and to then present the developed requirements to practitioners in a participatory development setting to find out if their needs are met.

4.1.2 Critical perspectives

Beyond the practical implementation in participatory software development processes, the tool characterisation framework also allows investigating the perspectives previously applied when conceptualising tool requirements, and identifying missing perspectives. It was found that most of the reviews have the aim of supporting architectural practitioners in selecting the best tools among those on the market, or helping software developers identify missing capabilities to fill gaps on the market. However, very few studies investigate how tools perform when entering the design practice and being integrated by architectural practitioners in design processes. Thus, three critical perspectives were applied to the identified characterisation criteria: those of the tool user, the design process, and the design practice. This was done to investigate the usefulness of each criterion in understanding how tools perform when out of the hands of the developer and in the hands of the practitioner. An overview of the findings is shown in Figure 4.2.

From the *user perspective*, it was found that a lot of reviews emphasise user-friendliness, and the efficiency of tool learning processes. However, this is mostly done without defining that user, their background knowledge, and what tasks they need to perform. Future tool reviews need to clearly define the user from the perspective of which tool reviews are carried out. It was also found that a reduction of calculation times is highly valued in the reviews, whereas the time spent creating the analysis model has received little attention although it takes up a large portion of the time spent performing LCBPA. Further, many reviews applaud tools with high flexibility, but do not investigate how that flexibility was actually utilised in practice. Future tool reviews should carefully observe tool usage in design processes and note where the time consumption lies, and how (or if) this flexibility is leveraged by actual users.

On a similar note, from the *design process perspective*, it was found that examples are missing of how the tools contributed to actual improved design outcomes. This makes it difficult for potential users to envisage the benefit

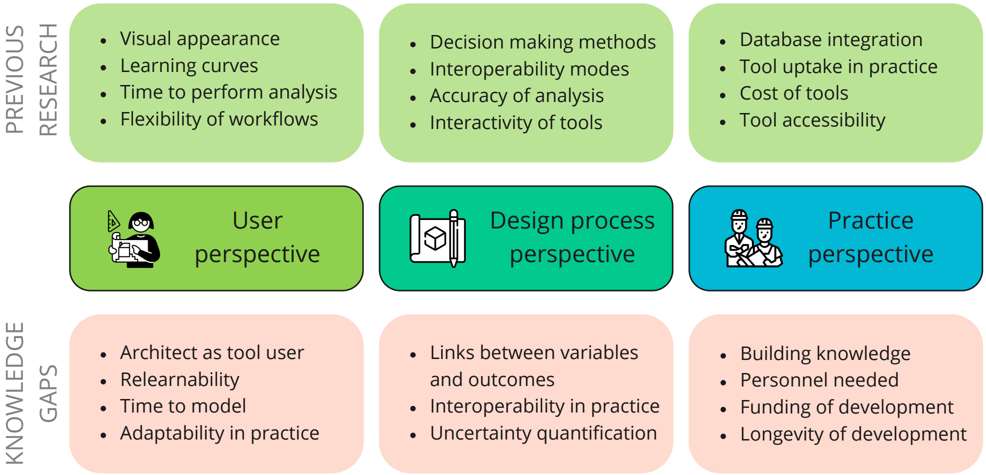

Figure 4.2: Previous trends and present gaps as identified through application of critical perspectives.

of integrating the tool, and to map the proposed usage of the tool to actual processes which occur in the practice. Examples of usage in actual design processes should be presented when evaluating tools to allow practitioners to react and improve the understanding of the developer. Further, few tool reviews acknowledge the multidisciplinary nature of the design process which requires the input from practitioners with varied expertise to meet the needs of several stakeholders in one final design proposal. Firstly, a high degree of interoperability is requested in several reviews, but no accounts are provided of how networks of tools accomplish complex tasks in practice. Secondly, collaboration beyond interoperability is little discussed, that is, examples of how tools are used to support communication between stakeholders are missing. Observation of these collaborative modes of tool usage should be carried out to see where and how conflicts arise and are resolved through the use of tools.

From the *practice perspective*, it was found that the process of actual tool adoption is little discussed. Questions of cost, training of personnel, and the possible organisational structures that enable tool integration, were not raised. The current use of tools in practice, and how these tools came to be integrated in existing workflows, should be investigated. Another question is how tools integrate and build upon the data already generated in design practices. Few reviews discuss how knowledge databases could be developed within a practice by collecting previous projects and references, and building a collection of good design solutions within each practice and the wider field. The ways that companies manage such data should be observed to learn best practices and propose better methods of leveraging the great amounts of data being generated during design processes.

4.1.3 Reflection on meta-review

The critical literature meta-review reveals that tool user, design process, and practice perspectives have been generally neglected in the previous literature evaluating tools. To a large extent, these tool reviews have been carried out with the explicit aim of either helping architectural practitioners select tools from the market (Attia, Hensen, Beltrán et al., 2012; Hildebrand and Bach, 2018), or helping software developers identify best practices and gaps among tools in the market (Weytjens, Attia, Verbeeck et al., 2011; Wastiels and Decuypere, 2019). This narrow perspective is problematic for several reasons. First of all, it is questionable whether either of these kinds of publications are useful to or even reach their intended audience. Further, very few of the investigated tool reviews answer to the call of Attia, Hensen, Beltrán et al. (2012) in establishing and applying consistent conceptual frameworks which allow the identification of "useful tools". Instead, bespoke characterisation criteria are developed as part of every tool reviewing effort, and only superficial motivations for the criteria applied are provided - the view of Donn (2004) and Bleil de Souza (2012) that much of LCBPA tool research occurs under assumptions about "what designers want" is asserted by the review findings. Another identified issue is that defining tool requirements solely based on incrementing what already exists in the market without critically inquiring into what assumptions about user needs were made during the development of those previous tools, risks digging software developers into an echo chamber developing tools with little relevance for practitioners.

That is not to say that the tool review as a genre is useless. Rather, as shown through the application of critical perspectives, it has the opportunity to reveal good practices and open up a conversation between researchers and practitioners about what is needed from "useful tools". For this to happen, the research community should focus efforts into understanding the practice of developing tools for LCBPA, and how these tools perform when applied in practice, rather than emphasising technological leaps, whether in user interfaces or analysis engines, as potential pathways involving innovative technologies are already thoroughly mapped (Østergård, Jensen and Maagaard, 2016). Such a shifted focus to practical elements could be applied by initiating participatory, user-centric software development processes and investigating them as research subjects, allowing the epistemological differences between analysts, architects, and software developers to be identified and overcome (Bleil de Souza, 2012). Even better, the high ambitions in terms of improving LCBPA outcomes among architectural practitioners (Jusselme, Rey and Andersen, 2020; Mahmoud, Kamara and Burford, 2020) should be leveraged by observing the ways in which innovation is already occurring within the practice to meet rapidly increasing demands from clients and regulations (Sadri, Pourbagheri and Yitmen, 2022). No recent research in the tool development community appears to investigate the strategies invented in practice to integrate LCBPA in design processes. Action research methodologies are promising as a way of changing this, by emphasising identifying and solving practice needs through research, instead of developing technologies based on previous knowledge and then attempting to fit these technologies into practice (Purup and Petersen, 2020b). This could lead to an acceleration of user-driven innovation, where software success is measured not in terms of product licenses sold, but in terms of how well the software supports the needs of the developer-practitioner (Comino, Manenti and Parisi, 2007).

The key omitted perspectives in previous tool reviews are those of the tool user, the actors in the design process, and the design practice as an organisation. When these perspectives have been applied, the analysis has been superficial: usability is often arbitrarily graded on a scale from "user-friendly" to "complex" (Attia, Beltrán, Herde et al., 2009), without defining the competence and background of the user (Shackel, 2009); what actually happens in design processes is normally completely omitted, discussing ways of enabling decision-making (Nielsen, Jensen, Larsen et al., 2016) without providing examples of how decisions are actually made (Yu, Gu and Ostwald, 2022); and the perspective of the practice as a whole is usually limited to the cost of the software product (Kanters, Horvat and Dubois, 2014), disregarding the building up of infrastructure which supports tool apprehension by practitioners and integration into the existing workflows of the practice (Mahmoud, Kamara and Burford, 2020). The proposed characterisation framework allows a more fine-grained understanding of these perspectives, and by applying it, several knowledge gaps which deserve further attention in future tool reviews have already been identified, as presented in Paper I.

As a final note on the outcomes of the critical meta-review, it is worth considering at what level of decision making about the built environment that software developers and the research community investigating tools should focus their attention. The tool reviews identified focus to a large extent on architectural practitioners as the tool operators. An investigation is needed into what tools are used among and what tools would be beneficial for other stakeholders in or preceding early architectural design stages, such as authorities and policymakers (González Caceres, Rabani and Wegertseder, 2019), real estate developers (Haapio and Viitaniemi, 2008), or homeowners (Buda, Gori, Hansen et al., 2022). Untapped research directions quickly emerge: for instance, investigations of how LCBPA tools could be applied by governments to define national carbon budgets (Sadri, Pourbagheri and Yitmen, 2022), in building asset management to ensure sustainable investments (Cherrington, Lu, Xu et al., 2020), or in evaluating entries in architectural competitions (Eicker, Monien, Duminil et al., 2015). Again, researchers into LCBPA tools need to delve into these practices in a systematic way to be able to identify current and future potential software uses.

> *Research Question I: how can critical perspectives that identify practitioner needs be applied by software developers to allow them to define software requirements which meet these needs?*

In exploring the above research question, the presented study has firstly discovered that these critical perspectives have, consistently, not been applied in the previous literature reviewing tools. It has secondly been useful in proposing a methodological toolbox which now requires testing through practical application to confidently answer the research question.

4.1.4 Summary of findings in critical meta-review

In summary, it is proposed as shown in Figure 4.3 that future reviews should investigate tools as applied by real users, in real design processes, in real practice. When presenting the studies, the assumptions about user competences and tasks, and about the relevant design processes and practices, should be explicit. The data collected during such observation should be organised systematically. It is proposed that by reviewing tools or defining tool requirements this way, a participatory tool development process can be initiated by allowing practitioners to react to the requirement definition and propose new perspectives which better represent their real needs.

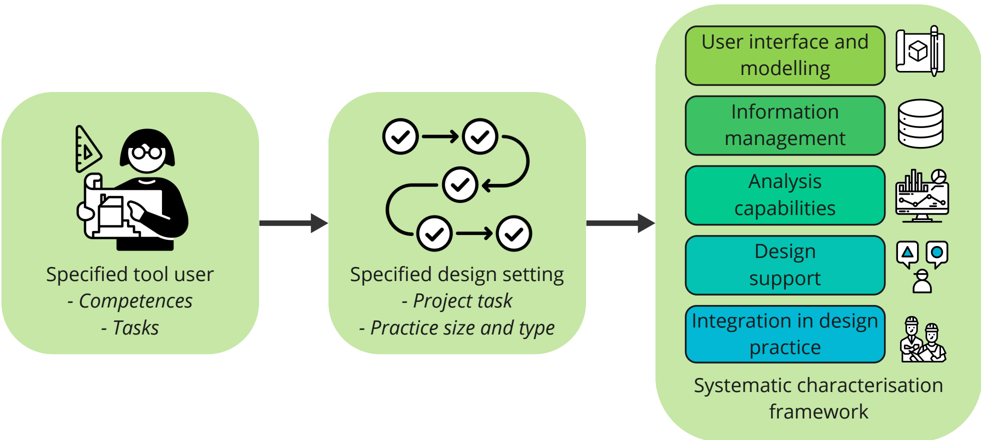

Figure 4.3: Proposed tool review framework, clearly defining the user, observing tools as used in real design processes, and organising the findings according to a systematic framework.

4.2 Study B: interview to the double

Study B (Säwén, Sasic Kalagasidis and Hollberg, 2023b) investigates the application of a practice lens to architectural practitioners' use of LCBPA tools, through application of the Interview to the Double (IttD) (Nicolini, 2009) and narrative analysis (Reissman, 2011). The main findings are, firstly, an incremented *model of the design process* in terms of design activities, as first proposed by Purup and Petersen (2020a), and secondly, a proposed method of applying a practice lens during software development processes by synthesising interview responses into *user narratives* (Kemmis, McTaggart and Nixon, 2013). The main conclusion of the study is that qualitative methods which apply a practice lens show promise in terms of supporting software developers' understanding of practice, and allow the identification of design activities and ways for tools to support these activities.

4.2.1 Design activities

Using the Interview to the Double (IttD) method, and building upon the framework of 31 design activities defined by Purup and Petersen (2020a), 11 previously described activities were identified in addition to 17 new ones, as shown in Figure 4.4.

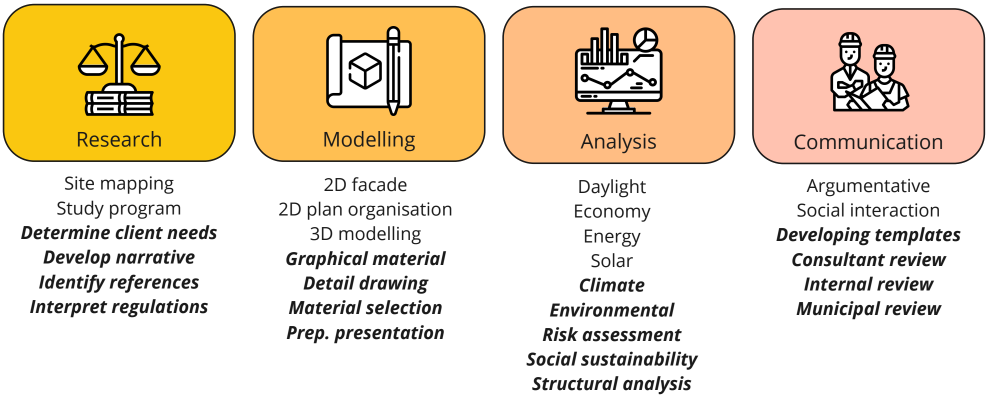

Figure 4.4: Design activities detected in interview responses. Highlighted text represents an activity not identified by Purup and Petersen (2020a).

Several of the identified design activities relate to understanding the context for the design in terms of the client needs and the relevant regulations and certification systems. Tools could provide ways of documenting these requirements, and further include a comparison with relevant regulatory systems as part of the analysis workflow.

Another set of design activities largely related to the role of the architect in presenting the outcome of the design process in communication with stakeholders with decision making power. These activities include developing narratives, and preparing graphical material and presentations. As a lot of the information supporting decision is based in text, it is worth considering if tools can support the generation not only of data for further analysis, but of text which explains the analysis results. Conversely, tools could be developed to determine what kind of analyses are required to quantitatively evaluate the narratives which are presented to support a design proposal.

Finally, the respondents mentioned performing several analysis activities related to sustainability, including environmental analyses, social sustainability, and climate risk. It appears that architectural practitioners are increasingly assuming the responsibility for this kind of analyses, and need a wide array of tools to be able to integrate them in design processes.

The IttD method not only allows detecting design activities carried out by architectural practitioners, but also allows observing what activities are linked to each other, and investigating what is the driving force for each activity. Acquiring this information would help software developers gain a deeper understanding of how software could support specific sequences of activities.

4.2.2 User narratives

In order to make the interview responses useful in software development processes, inspiration was gained both from the textual representation of IttD responses proposed by Nicolini (2009), and the user stories employed in agile, user-centric software development (Johansson and Messeter, 2005). Statements representing a sequence of design activities were collected from the various responses, and reorganised to represent a convincing account of a workday, referred to as a *user narrative*. Two such user narrative were developed, each understood to hypothetical architectural practitioners with different roles in design processes. Firstly, the "educator-strategist", communicating about design proposals to stakeholders and investigating overall design strategies. Secondly, the "modeller-analyst", whose tasks are developing the model representation of the design proposal and performing quantitative and qualitative analyses using it. The following is an excerpt of the user narrative representing that role in the design process.

> *Imagine you had to take the place of a modeller-analyst at architectural design firm A. This is what you'd have to do:*
>
> [...]
>
> Hopefully you can finish the drawings by lunch, in that case you can get started on some analysis tasks after a quick bite (hot lunch, not just a sandwich!) on the office balcony. Since it is a detail plan project, you need to do some solar analyses of the lighting conditions in the courtyard. Your colleagues have modelled the entire project in Archicad for rendering purposes, but you prefer using Rhino/Grasshopper for the solar simulations and it saves time to remodel the geometry rather than trying to import everything and remove the detail so that the solar simulation runs efficiently. At this stage it's just a shadowing study, but you make sure that the model can be used for more detailed daylight simulations in the future...

This user narrative firstly situates the description of the activities in a context which the practitioners can relate to. Secondly, if presented to an actual architectural practitioner, it would allow them to react to the narrative and provide a more nuanced description of the activities. Thirdly, it triggers the imagination and reveals several potentials for tool integration: for instance, a workflow for transferring models from a Building Information Modelling (BIM) environment to a parametric analysis environment like Grasshopper;

a modelling environment for shadowing and daylight studies; or a way to integrate the municipal requirements from the detail plan into the analysis.

In convincingly describing the activities of architectural practitioners, these accounts, the *user narratives*, could be used in participatory software development processes as a starting point for discussions about *what the practititioners do*, and *how software could support these doings*.

4.2.3 Reflection on interview study

Purup and Petersen (2020a) propose that each design process can be understood as a unique sequence of design activities, and further argue that, to conform to design practice, software developers should emphasise identifying and supporting specific specific design activities during the development of tools. They provide a framework of 31 design activities detected in interviews with Danish architectural practitioners. In applying the Interview to the Double (IttD) method in Study B, several additional activities were found among architectural practitioners in Sweden, Norway, and France. The discrepancies in terms of results could be explained by the limited sample sizes in the studies - Purup and Petersen (2020a) make an argument about data saturation, but it could be conceived that a wider set of respondents representing further roles within architectural practice would yield far more activities in which practitioners engage. Another explanation could be methodological - the cited study employs a semi-structured interview approach in which the questions are on a general level: "how do you usally work?", and "how would you describe your methods?", whereas the present study uses a projective method requiring the user to describe their process more step-by-step. This is not to say that either method is more suited to investigating design activities - they simply focus on different levels of organising work in the architectural practice.

The model of the design process developed by Purup and Petersen (2020a) as iterative and open-ended is supported by previous studies (Lloyd-Jones and Erickson, 2001, cited by Somanath [2022]). However, while Purup and Petersen (2020a) consider criteria in design processes (formal and informal goals which allow evaluation of a design proposal (Cross, 2007)) as an important framing for a design process, they do not treat the processes which lead to definition and redefinition of these criteria as actual design activities. In the interview study, many of the activities described by respondents involve interpreting regulatory requirements, and trying to establish what clients or other stakeholders with decision making power of the design project wanted to achieve. As Cross (1982) argues, the reformulation of design evaluation criteria is central to the way that designers make sense of the design problem and solution: "the designer has to learn to have the self-confidence to define, redefine and change the problem-as-given in the light of the solution that emerges from [their] mind and hand". Thus, the design activities which aim to define the "problem-as-given" should be considered central to the designer's activities.

A useful advantage in describing the model of the design process as a sequence of design activities is a reduced need to tailor tools to specific professional roles. As Schade, Wallström, Olofsson et al. (2013) note, the roles of architectural practitioners differ in different national contexts. As an example, in their study they note that German architects are involved to a greater extent in later design stages than their Swedish counterparts, a fact they use to explain that German architects more often have energy advising or passive house expertise (Schade, Wallström, Olofsson et al., 2013). By considering software tools as linked to specific sequences of design activities instead of whole design processes, they can be tailored to suit the responsibilities given to a specific practitioner in a specific practice.

The representation of practice in terms of user narratives builds both upon the tradition of narrative accounts in ethnographic studies (Nicolini, 2009; Kemmis, McTaggart and Nixon, 2013), and of representing user needs as stories in user-centric software development (Johansson and Messeter, 2005; Lucassen, Dalpiaz, Werf et al., 2016). This follows the conceptualisation by Kimbell (2012) of *design-as-practice*, which suggests that "descriptions of design thinking often rely on accounts of what designers do in their embodied, situated routines, and cannot be completed without reference to the artifacts they use, make and work with". In the method proposed in this thesis, software developers use the accounts of practitioners to extract core narratives while paying close attention to links between design activities and artifacts such as tools or the inputs or outputs of tools. This would allow them to gain the insight into design thinking sought after by Bleil de Souza (2012).

The defined user personas and narrative need to be applied in actual software development for their practical usefulness to be confirmed, but they are convincing in that they capture the situated nature of practice, and in using the familiar rhetorical devices of the "expert-novice" relationship (Nicolini, 2009). As Lucassen, Dalpiaz, Werf et al. (2016) note, user stories are not useful to improve technical quality or the efficiency of software development, but rather "enable developing the *right* software". They find that stakeholders in the software development process enjoy working with them, and that they allow building a shared understanding among stakeholders and developers about what the end-users expect. The user narratives presented in this study could either be used as an intermediate step toward defining traditional user stories in the format "As a <user> I want to <action> so that <benefit>" (Lucassen, Dalpiaz, Werf et al., 2016), or alternatively, be used to replace these stories in novel agile or participatory methodologies (Johansson and Messeter, 2005). This would help resolve some issues noted with prevalent user-centric approaches: it could help overcoming the ambiguities inherent in the bite sized user stories (Amna and Poels, 2022); and it would make the user persona representing the user more engaging for software developers by being constructed from ethnographic material, improving immersion when presented to potential users (Johansson and Messeter, 2005).

Research Question II: how can applying a practice lens during software development help identify opportunities for integration of life cycle building performance assessment software?

Through the exploration of this research question, it is clear that only a handful of interviews were enough to generate a specific yet rich view of design practice. It is proposed that the established method of defining software requirements as user stories could be incremented by instead developing user narratives as a condensation of practitioner perspectives. However, the usefulness of this approach in practice would need to be determined through application in actual software development processes.

4.2.4 Summary of findings in interview study

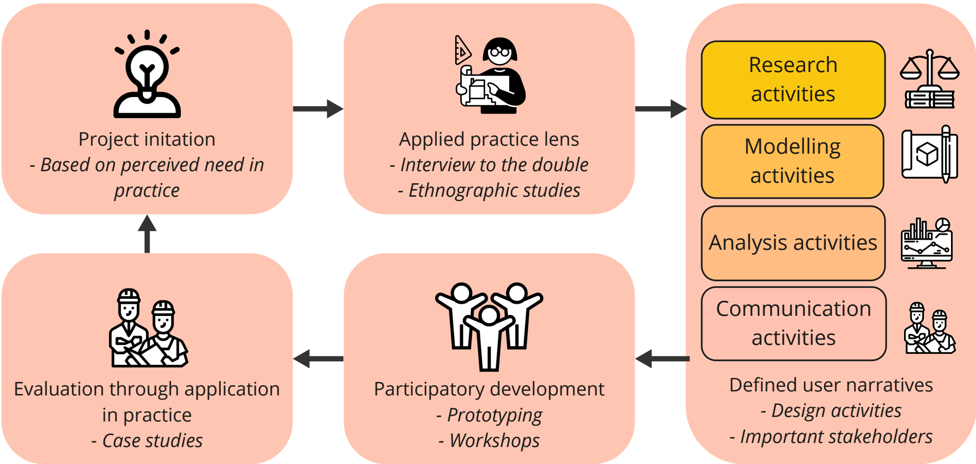

Figure 4.5: Proposed participatory software development method.

In summary, as shown in Figure 4.5, software developers could introduce qualitative methods like the IttD to apply a practice lens and learn about practitioner needs. This could be done both to detect important design activities or sequences of design activities in the specific practice, and to develop user narratives which can be presented as starting points for participatory software development processes.

4.3 Synthesis of findings

Based on these findings and the above reflection, software developers aiming to support architectural practitioners with useful LCBPA tools are urged to always, and again and again during development processes, explicitly pose the questions: "is this technological solution useful to someone in practice?", "who is that person and what do they know?", "why is it useful to them in the context of the wider practice?", and "how can this software solution be practically integrated by that person?". It is proposed to apply a systematic software development approach consisting of two methods, shown in Figure 4.6, to allow keeping track of these questions. Firstly, a characterisation framework

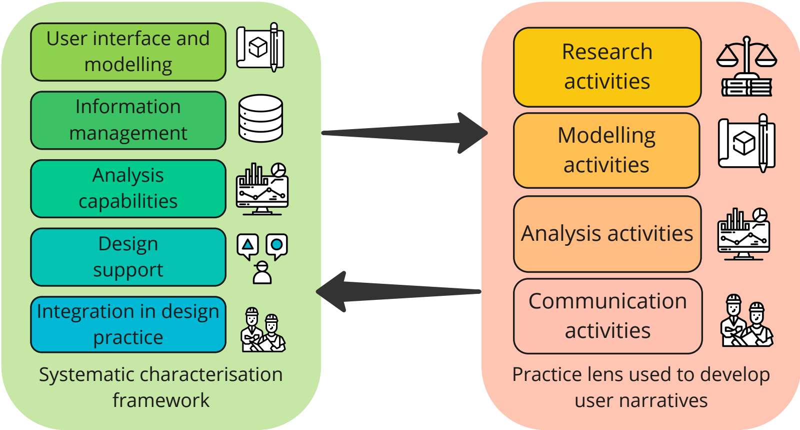

Figure 4.6: Proposed systematic software development approach, developing user narratives as sequences of design activities, and organising the findings according to a systematic characterisation framework.

which categorises and lists a number of criteria for investigating software performance from a user, design process, and practice perspective. Secondly, the user narrative method which transforms evidence about the architectural design practice collected through qualitative approaches into a digestible format which can be a starting point for participatory design processes. These methods need practical application in future studies to evaluate their effectiveness in terms of developing tools which can improve design outcomes related to LCBPA.

Chapter 5

Limitations and future work

5.1 Limitations and reflection on research design

The exploratory, inductive nature of the research presented means that the research design emerged as data was collected and analysed (Woo, O'Boyle and Spector, 2017). Although atypical for the life cycle building performance field, leaving few sources to build upon, such approaches may be needed to bridge the disciplinary gap (Jabareen, 2009) between discipline experts developing tools, rooted in science, and architectural practitioners intended to apply those tools, rooted in design traditions (Cross, 1982). This is in line with the argument of Purup and Petersen (2020b), who state that if the attention of researchers studying LCBPA tools is to shift from barriers preventing tool uptake to ways of overcoming those barriers, the methods traditionally employed in the field of life cycle building performance are not enough but need to be supplemented with tools from design research, social science, software development, and innovation research - often qualitative, inductive methodologies that aim to explain not only technological but also social phenomena (Orlikowski, 2007). Purup and Petersen (2020b) further propose that the action research approach offers such a solution-oriented perspective.

While the methodology applied in the present research is inspired by action research in aspiring to "change the ways things are done", the call by Kemmis, McTaggart and Nixon (2013) to consider "*actual* practice, not practices *in the abstract*" has only been partly adhered to in applying the interview to the double as a stand-alone method. This also goes against the recommendations of Nicolini (2009) in applying an etic method to make claims about practice. Thus, emphasis in building upon this work should be triangulation through ethnographic, emic methods, for researchers to be able to make more confident claims about what actually happens in design processes in Sweden and elsewhere, and about in what ways those processes could change toward more sustainable approaches. This would also allow use of the tools offered by narrative analysis to investigate the rhetorical and critical aspects uncovered through narrative approaches (Reissman, 2011).

Triangulation is also of relevance when considering the document analysis carried out in the critical meta-review (Bowen, 2009). The literature was observed through a narrow lens of research explicitly reviewing tools, as a way of making much broader statements about how tools can be conceptualised. It is also difficult to say whether the conceptual framework developed makes sense as a theoretical framework describing LCBPA tools in general without validation (Jabareen, 2009), for instance as applied in a tool review or to organise software requirements.

The proposed user narrative method also requires application to evaluate its usefulness, for instance adjacent to prototyping (Ince and Hekmatpour, 1987), or in participatory software development (Johansson and Messeter, 2005). This would ideally be done in a critical participatory action research context where the goal of the research is to directly improve the situation of the participants, improving their engagement in the research (Kemmis, McTaggart and Nixon, 2013). First, such an inquiry should evaluate whether the proposed method makes sense to software developers and stakeholders in the software development process. Second, an investigation is needed into if the tools developed through such a process actually improve life cycle building performance outcomes of the building as designed, and more importantly, the building as built.

One interesting aspect of the interview to the double as a method of applying a practice lens is that it mimics an ethnographic approach but adds one layer of interpretation - that of the respondent interpreting their workday as a narrative - beyond that of the researcher interpreting the collected data. The fact that design activities of different kinds from the similar study by Purup and Petersen (2020a) suggests that it represents a different kind of inquiry as compared to the semi-structured interview approach in that study. The discrepancy could of course also be explained in terms of differences in research framing, respondent sample, and the different researchers involved in the interpretation. Again, triangulation would strengthen the understanding of the kind of inquiry each specific method constitutes.

The sample used in the interviews, including mostly Swedish practitioners, with previous familiarity with the research team, needs to be considered before drawing extensive conclusions. The design activities detected should have relevance to understand design processes even outside the context of Swedish architectural practice. However, although useful responses were retrieved in the present study which suggests that the interview to the double is a promising method of applying a practice lens during software processes, the method might work differently in other contexts and when considering other relationships between the research team and the respondents. The method needs to be tested in other settings before its use can be widely recommended.

Another reflection is that the research is built upon a number of assumptions which deserve further attention, and can be considered alternative research paths which were not traced during the exploration of the topic of LCBPA tools integrated in early architectural design stages. For instance, the emergence of simplified, non-traditional methods of delivering software, such as visual programming (Aish and Hanna, 2017), mean that the computational designer has emerged as a professional role in architectural practice. The computational designer often has a background in architectural design but with an added proficiency in computational tools and programming. Investigations are needed of how their software development methodologies as embedded in architectural practice differs from that of traditional, or even modern and agile, software development approaches. Another underlying assumption of this work is that the combination of life cycle assessment and building performance analysis is a useful and beneficial one - that idea framed the research, but it was found during its course that it mostly remains unanswered.

Finally, while the theoretical and methodological frameworks offered by sociomateriality (Orlikowski, 2007; Leonardi, 2013) and constructivism (Nicolini, 2009; Reissman, 2011) have inspired the framing of the work and the selection of analysis methods, a much deeper analysis would be needed to investigate if the findings of the present research can be used to advance these frameworks. Such an in-depth analysis is a possible pathway for the next step of this research. The work of Dalsgaard (2017), defining tools as *instruments of inquiry* in design processes, is a promising starting point.

5.2 Future work

Among the findings of this research, several knowledge gaps have been identified which should be treated in the next stage of this doctoral research. Two studies are proposed to bridge these gaps. These studies are summarised in Figure 5.1.

The proposed Study C aims to bridge the lack of field testing of the methods proposed in this thesis by evaluating the proposed software development methodology through application in participatory development processes. This could be done either by observing other software developers as they apply the proposed methods in their practice, or by joining a design team and developing tools for them using the proposed methods. The goal is to evaluate the outcomes of applying the proposed methods, firstly for software developers in supporting their goals of producing software which is useful both to a specific and a generic user group, and secondly for architectural practitioners in helping them become aware of and communicate their software needs to support the development of tools which are relevant to their design work. Participatory observation is proposed as a method because of its shown applicability within the action research framework, and because it allows observation of actual practice as opposed to practice in the abstract, overcoming a major limitation of the present work (Kemmis, McTaggart and Nixon, 2013). Software prototyping is an established method of quickly delivering a limited yet functional product to potential users and is useful to establish early during a software development process that the "right" software is being developed (Tate, 1990). Other potential methods retrieved from innovation research (Purup and Petersen, 2020b) include co-creation and design games (Vaajakallio and Mattelmäki, 2014). The analysis of the outcomes could be theoretically grounded in sociomateriality (Orlikowski, 2007) or in burgeoning design research strands analysing designer tools as instruments of inquiry (Dalsgaard, 2017).

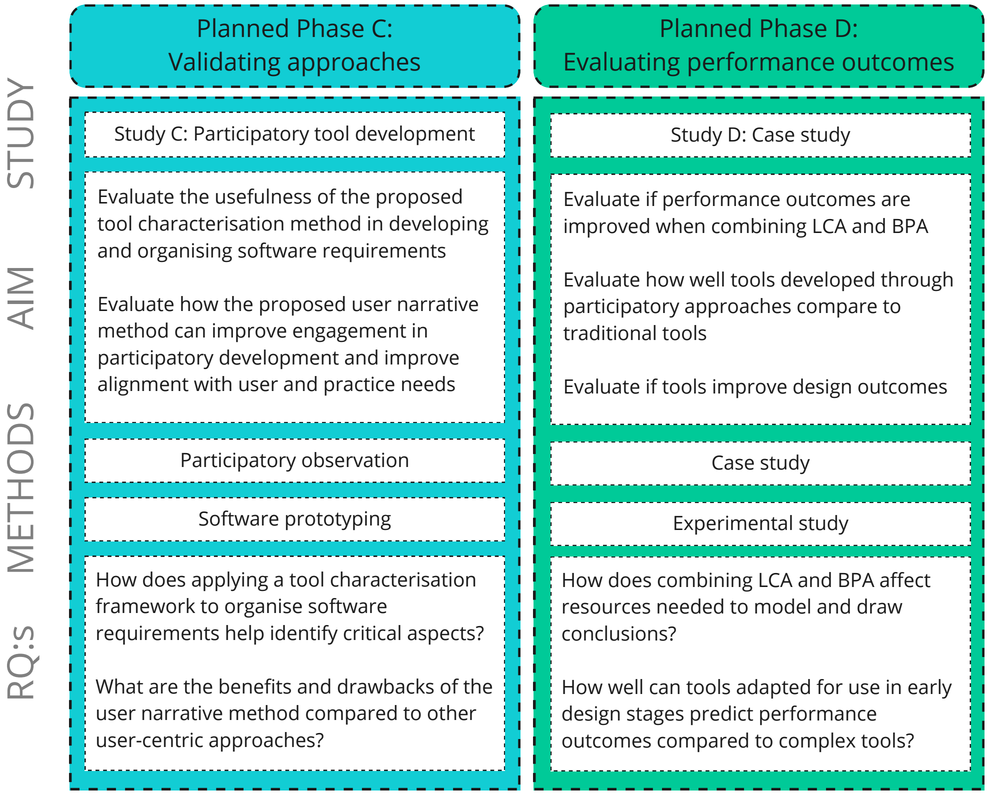

Figure 5.1: Aims, methods and research questions in the proposed future studies.

The proposed Study D applies a broader scope to the research topic in evaluating whether the integration of LCBPA tools in early architectural design stages actually improve the outcomes of the design process, both in terms of resources needed to develop a satisfactory design proposal (Cross, 1982), and in terms of improving the performance of the design and the final building (de Wilde, 2019). The first question investigated is if the combination of LCA and BPA into a holistic framework yields better performance outcomes both in terms of reducing time needed for modelling, and in terms of more effectively identifying tradeoffs and synergies between performance criteria. The second question is what kind of benefits in terms of usefulness when integrated in design processes can be detected for tools that were developed through participatory approaches to meet the needs in a specific practice, in comparison to integrating tools available on the market. Since the goal is both a quantitative and qualitative evaluation of the benefits of certain tool integration approaches, case studies are a fitting method (Purup and Petersen, 2020b), as they allow studying tacit knowledge among practitioners through reflective participation (Schön, 2017). Experimental studies including A/B testing have also been applied to quantitatively compare the outcomes of different tool integration approaches (Struck, Wilde, Hopfe et al., 2009;

Hollberg, Ebert, Schütz et al., 2016). The theoretical contribution of this study could be an advancement of the the discussion about design thinking paradigms initiated by Bleil de Souza (2012) and Attia, Hensen, Beltrán et al. (2012), by further considering the life cycle perspective in comparison to building performance and architectural design perspectives. It could also contribute to the advancement of participatory and co-design approaches in software development by considering the case of LCBPA in early stage architectural design (Johansson and Messeter, 2005; Peters, Loke and Ahmadpour, 2021).

Chapter 6

Conclusion

This thesis presents research into how developers of life cycle building performance tools for early architectural design practice can improve the usefulness of tools by applying a practice lens when defining software requirements. This was done firstly through a literature meta-review investigating previous approaches to evaluating tools, and secondly through an interview study investigating architectural practitioners' activities during design processes. The findings were synthesised into a proposed methodology for defining software requirements through the application of a practice lens and the systematic organisation of characterisation criteria. An overview of the research, including methods, key findings, and research questions of the performed studies, and an outlook for future studies, is shown in Figure 6.1.

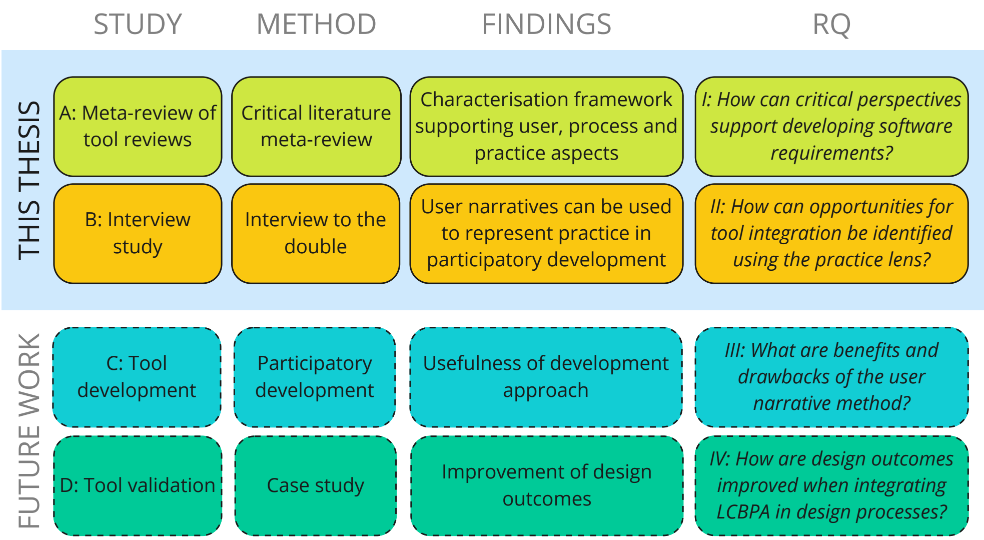

Figure 6.1: Overview of methods, findings, and research questions presented in this thesis and proposed in future work.

It was found in the meta-review of 87 previous tool reviews that an overwhelmingly technological perspective had previously been applied when evaluating tools in the field of life cycle building performance, and that the perspectives of tool users, design processes, and architectural practices, had been applied to a little extent. Knowledge gaps in the tool research community related to the missing perspectives were identified, such as a missing understanding of architectural practitioners as tool users, of what goes on in design processes, and of what key requirements are for practices to be able to integrate tools in their existing workflows. The previous review approaches were comprehensively analysed and the employed characterisation criteria were collected and organised into a conceptual framework. This framework is intended to capture the ways that previous researchers investigating tools have conceptualised and evaluated them, and includes five categories: user interface and modelling; information management; analysis capabilities; design and evaluation support; and integration in design practice. It is proposed that this framework can be used in software development processes to organise software requirements.

In the interview study with nine participants from Sweden, Norway, and France, several design activities related to designers gaining understanding about the design problem, as well as preparing material for argumentation, previously not discussed in activity-based design process models, were identified. Further, a method of applying a practice lens and condensing the rich accounts of designers about their practice into digestible user narratives is presented. This method includes the interview to the double, using which interview respondents are asked to imagine that the interviewer is a body double who is to take over their role in the workplace the next workday, and needs to be instructed in detail not to be uncovered. The narratives collected are proposed to be useful in a software development setting because they mimic the familiar "expert-novice" relationship which encourages the narrator to explain things in a way which allows outside observers of practice to get familiar with what should be done, and how those things are done. It is proposed that this method is evaluated as an alternative to user stories in participatory software development processes in representing the actual potential tool users, and in allowing them to react to and improve the software developers' understanding of practice.

The developed methods were combined to a proposed methodological framework which allows software developers to pose a range of questions pertinent to practitioners when developing tools useful to them: "who is the intended user?", "what do they need to accomplish in the design process?", and "how can the practice integrate the new tool effectively?". The intention is that software developers can pose these questions to potential users in a participatory development setting and organise the answers as software requirements using the tool characterisation framework. Then, as development progresses, they can reformulate the requirements as user narratives, and bring them back to practitioners to build a common understanding of what the tool is intended to achieve.

In future research, triangulation of the applied methods should be carried out, firstly to gain a better understanding of how tool developers work and conceptualise tools, and secondly to gain a better understanding of what design activities are carried out in design processes in Sweden and beyond. Then, the proposed methodological framework should be applied in participatory software development processes, and the application documented to validate its usefulness. Finally, the usefulness of software developed using this methodology in terms of improving life cycle building performance outcomes should be evaluated.

As a whole, this research aims toward a new, practice-oriented paradigm of software development for life cycle building performance tools, which would improve their potential for uptake in early architectural design stages, and accelerate their application to enable an elimination of negative social and environmental impacts of new construction in the built environment.

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