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Teaching technical knowledge in architectural education: a framework for designing and reflecting on teaching activities

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Contemporary architectural education requires students to apply technical knowledge from a wide variety of sub-disciplines, from drawing to the performative aspects of design, such as structures, acoustics, and thermal comfort. While certain technical aspects of architectural projects are readily incorporated into the design studio, other forms of specialised knowledge are often taught in seminar-based formats, and there is rarely a cohesive approach to current practice in architectural education, particularly across different technical disciplines. This inconsistency extends to how teaching activities are typically documented, making them difficult to replicate or compare, particularly when contextual constraints are not clearly articulated. Drawing on instructional design, cognitive load theory, and exemplar teaching activities, this paper develops a framework for mapping and analysing teaching activities that complements existing instructional design models and pedagogical strategies, while remaining adaptable across different topics, tools, techniques, delivery modes, and activity durations. We demonstrate the framework by applying it reflectively to our own teaching and to analyse selected examples from the literature. Its application revealed how different technical disciplines' structure and sequence knowledge, manage cognitive load, and integrate problem-solving activities, while also supporting reflective practice and comparative analysis across teaching contexts. The application of the framework illustrates how technical knowledge can be defined, sequenced, and integrated into problem-solving activities in architectural design in ways that support comparison, analysis, and replication in other contexts. In doing so, the framework provides a more systematic approach to mapping and analysing the structure of teaching activities, while also supporting the integration of technical knowledge into architectural design education.

KEYWORDS
architectural design education, cognitive load theory, comparative pedagogy, design studio pedagogy, reflective teaching practice, teaching framework, technical knowledge

1 Introduction

David Brain defines architectural design as a discipline in which "its principles and practical conventions constitute a way of locating and giving conceptual definition to problems that are then susceptible to practical solution. Design involves a translation of the client-presented problem into terms provided and authorised by a body of practice to which the solution refers" (Brain, 1989, 816.). As a reflection of this practice, architectural education has long prioritised design and drawing as core training activities that simulate the dynamics of professional practice (Noffsinger, 1955). In contemporary models of architectural education, these core activities are supported by *technical knowledge* taught, depending on the school and approach, as both a means of developing ideas and/or translating concepts into practical solutions.

Researchers in architectural design and education have discussed technical knowledge in various ways. Donald Schön uses the term *technical rationality* (Schön, 1983, 21) to define the body of professional knowledge of a discipline that is applied to practice through problem-solving. His interest is in tracing a history that highlights the limits of this so-called technical rationality and, in turn, evolves into a more reflective design process. Lawson (2005) focuses instead on design workflows, discussing the interaction between design thinking and the pragmatic aspects of project development. Oxman (2004) distinguishes between technical and conceptual knowledge in digital design thinking, highlighting a paradigm shift from traditional to computational knowledge in architectural practice.

By analysing the literature on technical knowledge in architectural design, we have identified three core components that both define and shape technical knowledge. These are: (1) techniques and tools used by architects to design and communicate their work; (2) skills, intended as personal abilities, tacit knowledge, and competencies for using/mastering/gaining expertise techniques and technology, such as being able to use specific software, but also cognitive aspects of design, such as critical thinking and interpersonal skills; and (3) technology and technological development, as it affects processes and workflows in professional practice.

Concerning techniques and tools, Gabetti (1990) emphasises that all art forms, including architecture, contain a banausic component: namely, the necessity of using techniques to translate ideas into creative works. However, to become skills, Ong (1982) argues that techniques and tools must be internalised to become meaningfully and conceptually integrated, thereby attaining effective agency within the design process (Norman, 2013).

Regarding technology and technological development, we adopt a broad understanding of the concept inspired by Eco (1989) and Ong (1982) and later summarised by Pugnale (2010), as an organised system of tools and strategies used to perform activities. This interpretation encompasses all well-established, and therefore internalised, technologies commonly used by architects, such as drawing and applying geometry to visualise ideas. These technologies shape human thought, even though designers may no longer be consciously aware of them; for example, writing and drawing have become invisible to us and function as extensions of both body and mind (Norman, 1993, 1998).

These three components, techniques and tools, skills, and technology, determine the boundaries of our definition of technical knowledge in architectural design. Nowadays, these components include performative aspects of design, such as structural, acoustic, thermal, and environmental performance, alongside more established areas like drawing, which Olmo (1990) describes as having evolved in polytechnic schools from an *interpretative* to a *technical* tool through the systematisation of descriptive geometry. This shift reflects a formalisation of technical knowledge in education.

In contemporary architectural education, pedagogical models that separate technical knowledge from architectural design are evident. Interestingly, this shift occurs at a time when technological literacy is increasingly central to architectural design, as graduates are expected to engage with pressing concerns such as environmental sustainability, occupant well-being, justice and equity challenges, and project cost and time effectiveness. Peggy Deamer alludes to this divide between the realms of technology and design, arguing that "the typical architectural studio is both outmoded and irresponsible..it is outmoded because it typically is organised around a nineteenth-century model of design virtuosity, and it is irresponsible because it ignores pressing and current spatial justice problems" (Deamer, 2020, 1). Within academia, there is a historical perception that technology-related education is situated in the context of didactic lectures and separate from the design studio (Oakley and Smith, 2007). Edward Allen highlights this dynamic, characterising the relationship as suffering from "the gap, that huge, bottomless gulf that exists in the schools between the design studios and the technical courses" (Allen, 2006, 1). As such, although technical knowledge is understood as a necessary component of architectural education, its integration into design curricula varies widely in method, extent, and depth.

This divide is reflected not only in the organisation of curricula, but also in the lack of homogeneity in how teaching is disseminated, and how we, as readers, can assess and compare the success of teaching activities. Instructional models like Constructive Alignment or ADDIE are often cited by instructors to develop teaching activities, but as Stefaniak and Xu (2020) assert, their broad principles rarely support the specificity needed to bridge theory and application in architectural education. Conversely, some instructors emphasise a novel inclusion or application of an activity, technique, or tool, without providing contextual details or specificity around the project briefs, institutional settings, or students' prior knowledge. As such, it is not always clear what the explicit contribution to architectural pedagogy is, nor how the work addresses broader curriculum development or pedagogical problems.

Many educators in architectural schools conduct research outside education and pedagogy, often lacking the time, training, or support to critically analyse or document their teaching. As a result, approaches to teaching technical knowledge are shared inconsistently, typically through minor venues, resulting in a fragmented view of current practice. Furthermore, when comparing published teaching activities involving technical knowledge, we found inconsistent or non-cohesive approaches to the design, delivery, and dissemination of such knowledge. Instructional design approaches often lack specificity or nuance, while novel activities are rarely documented in ways that facilitate replication and adaptation.

Each of these limitations indicates a lack of systematic approaches for documenting and comparing how technical knowledge is taught in architectural design education. As discussed in Section 2, there is limited work that translates the breadth of teaching activities and practices into forms that support structured mapping, analysis, and cross-context comparison. This gap motivates the study's aim: to develop and apply a structured framework for analysing how technical knowledge is embedded in architectural design education. In doing so, this research seeks to clarify how such knowledge can be documented to support systematic comparison across different technical disciplines, as well as facilitate reflective teaching practices.

We aim to answer the following questions to address this gap in the existing scholarship:

1. How can we design, analyse, compare, and reflect on teaching and learning activities that support the development of applied technical knowledge in architectural design studios?
2. How can we map such activities in a way that remains agnostic to studio topics, types of technical knowledge, delivery modes, intended outcomes, and duration, allowing us to analyse and learn from the structure and design of the activity itself?

Our study adopts a qualitative action research approach, grounded in reflective teaching practice (Leitch and Day, 2000). We understand this approach as integrating inquiry with practice-based reflection to support the ongoing development of teaching. In this context, our proposed framework is developed and applied as an analytical method to examine how technical knowledge is embedded within teaching activities, which we apply to our own teaching as well as to exemplars from the literature. The findings demonstrate how the framework enables the systematic documentation and comparison of teaching practices across different technical domains, supporting analysis and replication in other architectural education contexts.

2 Approaches and methodological problems

There are numerous publications on teaching activities in architectural design education, ranging from design studios that have undergone multiple iterations of development and refinement to intensive courses that explore innovative techniques. Yet, comparing activities remains difficult due to inconsistent documentation practices and methodological differences. This fragmentation likely reflects teaching not being traditionally considered a research output, creating non-ideal situations for researchers to publish their teaching activities from an educational perspective. It is also plausible that researchers publishing novel activities may treat the activity itself as the original contribution, and therefore, not value further reflection on its design. Although these dynamics suggest that the literature cannot provide a comprehensive picture of experimentation and innovation, it is worthwhile to review current approaches with respect to technical knowledge in architectural education.

2.1 How educators document their teaching

For our survey, we identified articles about technical knowledge in architectural education by combining search terms about education, pedagogical design and frameworks, instructional design, and curriculum design with those about architectural design education, architectural technology, performance-based design, and technical knowledge in architecture. We observed three predominant approaches to documenting teaching activities used by researchers. It should be noted that this survey is not intended as an exhaustive or systematic review; rather, it selects articles to broadly illustrate problems of cohesion in the architectural education literature.

2.1.1 Using existing instructional design models

The first approach involves using instructional design models developed within education and learning psychology as structured guides. One commonly cited model is Constructive Alignment, which aligns Intended Learning Outcomes (ILOs) with teaching activities and assessment (Biggs and Tang, 2011).

While some studies apply Constuctive Alignment rigorously, using ILOs to directly inform task development (Pugnale and Parigi, 2012), many others reference the model without explicitly articulating learning outcomes at the activity level, or are described instead at the course level (Camiz, 2021; Mendoza et al., 2018; Rodriguez Bernal, 2017). Blooms Taxonomy is also frequently used to categorise levels of learning new skills (Doyle and Senske, 2017; Goli and Dastmalchi, 2024), or even for curriculum mapping (Hamza and Horne, 2007). Similarly, the ADDIE model is used in architectural education but exhibits varying levels of adherence (Castronovo et al., 2019; Rodríguez and Zapata, 2024).

Merrill (1994) suggests that, while these instructional design models are often presented as a series of easy-to-follow flowcharts or procedural diagrams, the theory behind them is often misunderstood. As a result, researchers outside the education field tend to utilise the models in ways that lack clarity and utility in their applications (Allen and Sites, 2012).

2.1.2 Designing new frameworks

The second approach involves developing a new framework that acts as a mapping tool for knowledge, pedagogical strategies, or tasks. Some studies adapt existing frameworks, such as Đorđević et al. (2022), who correlated design actions, approaches, and tools with the Royal Institute of British Architects (RIBA) criteria to identify curricula gaps across course types and scales. This approach is useful for curricula mapping, but less useful for analysing teaching activities. Other studies focus on integrating pedagogical strategies within design studios, such as aligning Problem-Based Learning and Game-based learning with class activities (Shareef and Farivarsadri 2020). Other educators propose bespoke frameworks, such as aligning skills and knowledge with specific tasks and deliverables (Soliman 2017), or analysing how students use declarative and procedural design knowledge to communicate design knowledge, and designing courses to target weak areas (Uluogˇlu, 2000).

In most cases, design choices for the new framework are made to address a specific curricular or pedagogical problem, meaning that while the overall methodology can be adapted, the framework has limited direct applicability. Alternatively, they are too broad, or only apply to certain delivery modes, such as a design studio, or make assumptions about the pedagogical strategy, such as using PBL, which similarly limit its applicability.

2.1.3 Focusing on the novel pedagogical technique

The third, and most prevalent approach, is to highlight a novel technique, tool, or pedagogical strategy used within a teaching activity. To give a few examples: educators found ways to incorporate virtual reality to visualise or experience performance criteria (Horne and Hamza, 2006; Zuo et al., 2010); other studies focused on trying to understand how architectural students might use and embed building simulation in design scenarios (Charles and Thomas, 2009; Fernández Antolín et al., 2020; Reinhardt et al., 2012); and investigate pedagogical strategies using model making or physical analogies continues to be explored in communicating structural design principles (Guerguis and Pitts, 2021; Soto Rubio, 2017; Wang, 2023).

These studies often exhibit significant variation in their descriptions, showing little similarity in the approaches used to detail activities and content. They can be useful for inspiring the design of new exercises or tasks. However, in almost all cases, they are tied to contextual constraints and a lack of detail around student knowledge, delivery modes, activity lengths, and specificity on the content being taught. Focus is placed on the methodology or technique, and those activities are not always documented in a way that the teaching activity and its delivery is placed under scrutiny. In particular, student works are often showcased, but are usually only selected to illustrate examples of novel approaches, rather than as an assessment of the success of the teaching activity. All these factors impede the ability to adapt or replicate the activity in other circumstances.

2.1.4 Comparing pedagogies

Beyond the three methods used to document activities, it is also worth acknowledging how pedagogical comparison takes place in architectural educational research. However, a similar trend of inconsistent comparison styles also emerges. For example, studies compared pedagogical models, such as problem-based learning and direct instruction (lectures), to demonstrate the strengths of different approaches in design studio environments (Al-Ayash, 2025; Dabbagh and Dass, 2013; Srikanth et al., 2019), contextualising existing research into those models in architectural education. While other studies compared various design studio structures to international standards and professional competencies (Álvarez et al., 2016; Milovanović et al., 2026), similar to the examples in Section 2.1.2. One study compared the curricula of institutions in terms of the skills they taught in their coursework (Asgari et al., 2020), using skill designations such as drawing, presentation, and design. Similarly, Soliman (2017) surveyed educators on the types of exercises they would use for certain skills, such as using diagramming to teach design theory and thinking skills. In both cases, while their conclusions suggest the best approaches for designing studio exercises, the skill designations are far too broad, making them less useful for nuanced comparison across specific subject areas.

Taken together, the limitation is not the absence of comparative studies, but the lack of a consistent structure for comparison. Furthermore, none of these approaches focuses on the underlying organisation of topics, problems, and learning sequences—a problem that is particularly significant for understanding how the complex information is decomposed to support learning.

2.2 Analysing a pedagogical exemplar

The study by Vrontissi et al. (2018) is a comprehensive example that provides a clear overview of the topics taught, a sequential breakdown of content delivery and exercises, and an analysis of student outcomes with respect to the content. This level of detail allows the structure of the learning process to be examined more closely, helping to address some of the issues identified in the previous sections

Vrontissi et al. (2018) adopt a pedagogical approach that emphasises conceptual structural design thinking in architectural education. They state, “the objective is to eventually shift the focus from the actual formal composition of the material construct to the conceptual relational disposition of the inherent structural concept; hence, to transform the structural organisation to a spatial one” (Vrontissi et al., 2018, 9). They achieve this goal by structuring their teaching activity in three distinct steps, which can be summarised as: (1) exploring structural principles, (2) translating the structural principles into an architectural idea, and (3) materialising the architectural idea. This sequence is common in structural design education: beginning with principles and concepts, translating them into spatial schemes, and then into architectural projects with real materials and dimensional calculations.

Nonetheless, the three-step approach by Vrontissi et al. (2018) is valuable because it provides a framework for understanding each stage of the teaching process as a distinct activity with its own content, tasks, and objectives. We propose that a similar approach can also be adapted to teach, design, and evaluate technical knowledge more generally in architectural design education. However, there are two limitations to directly translating these steps.

First, not all topics can be isolated and taught in sequence in the same way. Although task complexity increases with the addition of architectural constraints and materials, the fundamental principles of structural design, such as static equilibrium, remain unchanged. Second, not all topics in architecture benefit equally from adding architectural or other constraints to contextualise or test higher levels of learning or application. Architecture and structural design are intrinsically linked through the design of space. There are many other topics, such as material sustainability and thermal and acoustic comfort, that are fundamentally dependent on factors including the building envelope and material properties.

2.3 Linking architectural pedagogy with cognitive load

To dissect the study further, we analysed the Vrontissi et al. (2018) study through the lens of *Cognitive load theory* (CLT), developed by John Sweller in 1988. Sweller was a pioneer in studying how instructional design impacts cognitive load, which subsequently affects a student's ability to learn (Sweller, 1988). Cognitive load refers to a person's working memory resources, which refers to memory that can be stored, manipulated, and used to solve problems. Over the course of his work, Sweller defined three types of cognitive load (Sweller, 1988, 2010; Sweller and Chandler, 1994; Sweller et al., 1998). *Intrinsic Cognitive Load* refers to the inherent level of difficulty of a specific topic or task, which cannot be altered regardless of the instructor or type of instruction. *Germane Cognitive Load* refers to working memory that the learner needs to dedicate to manage the intrinsic load and is partially dependent on the learner's characteristics. *Extraneous Cognitive Load* refers to how information is presented to the learner.

Typically, CLT is incorporated into education research as a series of strategies for mediating these different forms of cognitive load at different stages of the instructional design process (de Jong, 2010; Sweller, 2010). For example, presenting complex information through both diagram and text reduces demand on germane load, while isolating key information benefits extraneous load. While there doesn't seem to be wide adoption of CLT within architectural design education, some researchers have highlighted these strategies to design teaching exercises (Becker, 2017; Darwish et al., 2023), or used principles of CLT to study how students manage their cognitive load during a design studio or other exercises (Mohamed-Ahmed et al., 2013; Wu et al., 2017).

It is worth acknowledging some limitations of CLT in pedagogical design strategies. Findings from neuroscience indicate that CLT's emphasis on the content of instruction does not necessarily align with human elements of learning, such as the emotional and meta-cognitive skills essential for long-term learning (Sortwell et al. 2026). Similarly, the application of CLT strategies to only three working memory types oversimplifies learning processes (Schnotz and Kürschner, 2007). Furthermore, a review of CLT studies found that cognitive load can both benefit and adversely affect creative problem-solving, depending on the nature of the task, cognitive processes and level of attention required, and individual factors such as motivation and feedback received (Hernandez Sibo et al. 2024). However, these limitations apply to how CLT is directly used to design learning activities and do not affect its usefulness in defining the cognitive processes related to problem-solving. In particular, CLT offers two principles that are useful for addressing the limitations of the Vrontissi et al. (2018) study:

2.3.1 Stages in instructional packages

In early experiments, Paul Chandler and Sweller investigated how instructional packages can be broken down into constituent components, and suggested that "in technical areas, complete instructional packages consist normally of three parts" (Chandler and Sweller, 1991, 331), which are: (1) an introductory explanation, (2) one or two worked examples, and (3) numerous problems or exercises. This recommendation suggests that learning can be broken down into smaller, lower-level segments and introduced progressively through worked and semi-worked problems until expertise is attained.

The intermediate stage is important because it eliminates the need for learners to use a means-end strategy, in which they must simultaneously consider the problem state, the goal state, and everything in between. Instead, worked or semi-worked examples, with complete or partially complete solutions, allow learners to focus on developing expertise in the problem-solving stage, before moving onto exercises.

In architectural education, this underscores the importance of not assuming that students can apply technical knowledge in design problems once they have learned the principles. Instead, it is necessary to define a complete method for students to do so.

2.3.2 Element interactivity

A concept central to linking these three types of cognitive load theory is *element interactivity*. As defined by Sweller and Chandler (1994), an element is considered any distinct item of information that is used to learn topics and solve problems. Element interactivity refers to the complexity of a problem arising from the number of interrelated elements. In general, the more closely related the elements are, the easier the topic is to learn, and the easier the problems are to solve.

Using the earlier example, structural design is more intrinsically linked to the creation of architectural space, unlike the relationship between form and thermal comfort, which requires the understanding of building orientation, envelope composition, and other factors that influence thermal comfort. In this latter example, element interactivity is higher due to the number of interrelated elements that must be simultaneously held in the working memory to solve the problem.

Some topics inherently have higher element interactivity and, therefore, higher intrinsic cognitive load. These topics are inherently more complex and difficult to learn without the proper scaffolding of knowledge. Furthermore, designing complete instructional packages for technical knowledge must consider not only the element interactivity within the discipline, but also broader background training or skills if necessary.

3 A new methodological framework

Building on the discussion of cognitive load theory, this study translates the principles of problem-solving and the decomposition of complex knowledge into a structured framework for architectural education. Within an action-research approach grounded in reflective teaching practice, we propose a new methodological framework that supports the mapping, analysis, comparison, and reflection of teaching activities related to technical knowledge. Although it draws on principles of action research, the development of this framework and its testing through application in this paper is original and has not previously been formalised. Unlike other approaches, our framework is agnostic to pedagogical models and focuses solely on the topics, content, and problem structure associated with the learning activity, making it adaptable across diverse teaching contexts.

Drawing on the action research principles of documentation practices, as outlined by Ernest Stringer (2013), this section will define the four steps of the framework, provide guidelines for mapping key elements and relationships, and offer a step-by-step guide for using the framework. Methodologically, the framework provides an approach for making teaching practices explicit and comparable, from the perspective of how learning is structured and aligned to design problems. Section 4 applies the framework to the author's own activities to illustrate its use for reflective teaching practice, while Section 5 will use the framework to analyse exemplar activities from literature. The selection of activities will be explained in their respective sections.

3.1 Four steps for teaching technical knowledge

Our framework distinguishes four separate steps for teaching technical knowledge in architectural design, which form the basis of the analysis presented in this study.

Step one is the *Definition of the topic*, where *topic* identifies a discrete area of knowledge, distinguished from the broader discipline or subject area. Sweller (2010) suggests that topics should be restricted to as few elements as possible to ensure they are fully intelligible, and several interrelated topics and subtopics may be introduced to comprise a teaching activity. A topic may include:

- Key concepts or principles
- Methods, processes, or techniques
- Application of a method to a new problem

For each of these topics, it is necessary to define what students are expected to learn. We adopt the use of ILOs and Biggs' and Tangs' Structure of Observed Learning Outcome (SOLO) taxonomy (2011) to describe the expected learning stages. Prerequisite knowledge or skills that prevent learning progress, such as fundamental skills, knowledge, or techniques, should also be identified for each topic or subtopic.

Step two is the *Solved problem,* which describes the instruction of the topic using problems with known solutions. Based on the literature and our own teaching experience, we have defined four types of solved problems that are commonly used for this stage:

1. Analysis of a case study or design precedent, which includes, but is not limited to, completed buildings or designs.
2. Simulation or modelling, either through digital or physical means, of a well-known process, system, or real-world problem.
3. Demonstration of an established method, process, or technical skill.
4. Lecture about well-known principles, concepts, or theoretical foundations.

The solved problem expands upon Chandler and Sweller's (1991) worked examples by including case studies or design precedents, as well as other techniques and skills commonly used in architectural design. The lecture is also included as a solved problem to capture cases in which principles or concepts are taught through visual and verbal instruction.

Step three is the *Abstracted problem* and involves a simplified problem that tests the understanding or application of technical knowledge, independent of real-world constraints. The complexity of the abstracted problem varies substantially with the prerequisite knowledge and the number of elements being tested. In general, irrelevant constraints to the topic should be excluded from the problem space, allowing learners to focus on the topic. Additional prerequisites related to specific skills or techniques not previously taught, as well as any necessary information about the constraints and element interactivity, should also be identified.

Step four is the *Contextualised problem* and introduces a context-driven design problem that tests how designers reintegrate learned knowledge within a broader design challenge. According to Goel and Pirolli's (1992) work on how architects frame design problems, the application of technical knowledge can be distinguished from the broader problem. Therefore, developing contextualised problems for technical knowledge should separate the constraints related to the topic and broader architectural considerations.

Contextualised problems typically identify topic-related constraints, such as building scale, program or site, that affect how the topic is applied. These constraints can be fixed or flexible but must align with the defined ILOs. It may be necessary to divide problems based on where they align with specific topics or subtopics. Broader architectural constraints that don't relate to technical knowledge are not necessary to include, but it is worth considering their impact on the application of the topic. For example, rather than providing a specific project site, an orientation might be specified as a strategy to reduce the number of additional elements and the complexity of problems.

3.2 Graphical representation and use of the framework

We have developed a graphical representation for our framework, through which a teaching activity can be captured in a single diagram. The four stages of the framework are arranged vertically, and the diagram incorporates three layers of information: elements, sequence, and pedagogical strategies (Figure 1).

3.2.1 Elements

Elements are depicted as blue and purple blocks, corresponding to instructor-led and student-led activities, respectively. Each topic or subtopic is titled and includes an ILO, with prerequisite knowledge shown in orange below. Dark blue indicates key topics, and lighter blue indicates subtopics; arrows link and indicate hierarchical relationships

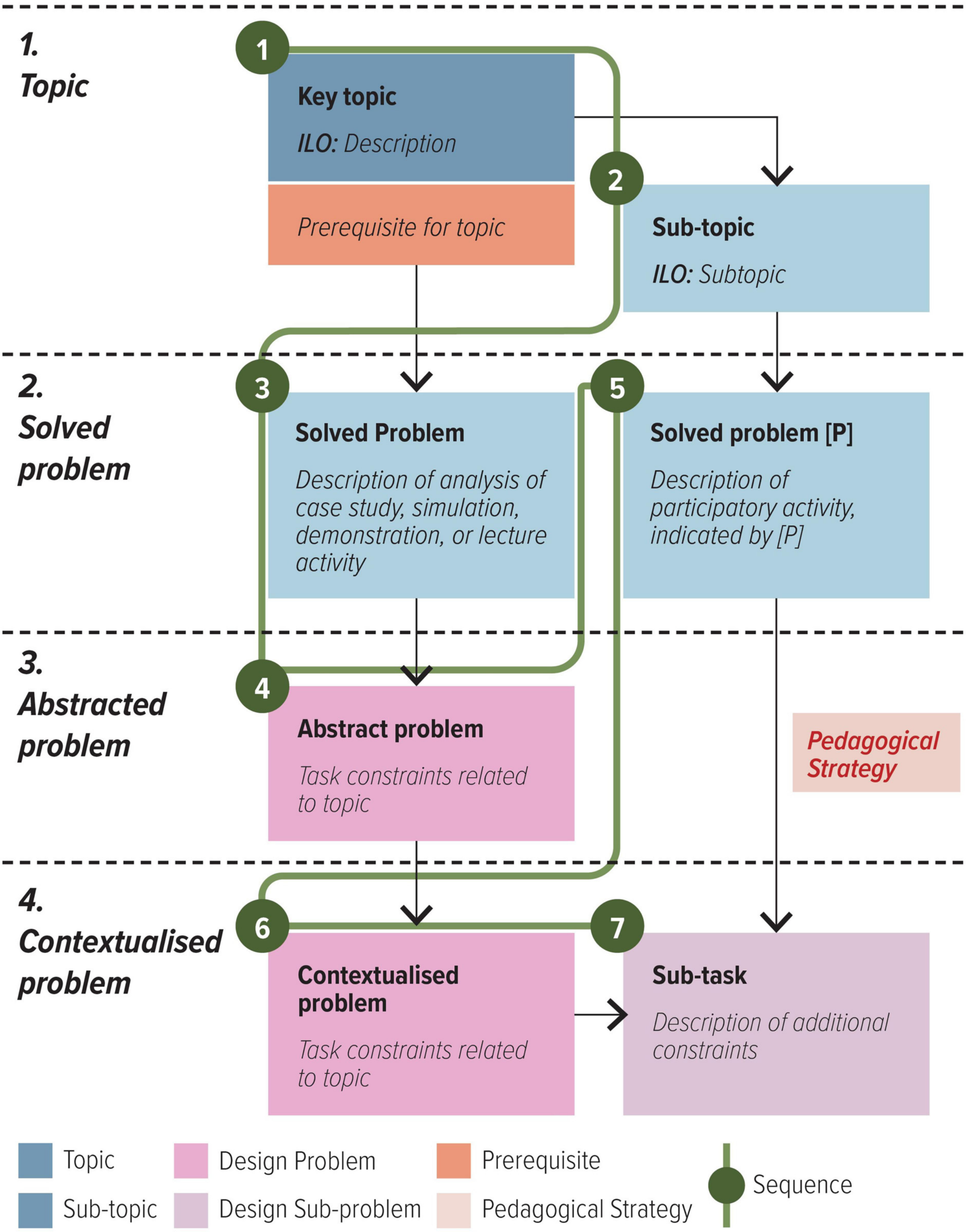

FIGURE 1
Graphical representation of the 4-step framework.

between elements. Topics are linked to solved problems that illustrate the application of the concepts and principles within the topic. Each solved problem is titled and described such that it can be interpreted by an instructor with similar expertise and can be designated as participatory (P).

For the design (abstract and contextualised) problems, dark purple elements indicate the core problem, while light purple elements indicate sub-problems associated with different topics. The topic-relevant constraints of the problems are provided within each element.

3.2.2 Sequencing

Sequencing is indicated using a numbered circle that indicates the order in which the element is presented in the teaching. A continuous green line connects the elements to aid in legibility. Indicating the sequencing of elements in a teaching activity is necessary to understand how they were ordered and grouped, and how learners are expected to acquire knowledge and approach problems. Each element can be referred to in the text description through the sequence number.

3.2.3 Pedagogical strategy

The pedagogical strategies are indicated with red boxes and text, and are positioned to provide additional context to the planning decisions of the teaching activity that may not be immediately apparent from the mapping. When the framework is used as an analysis tool, these annotations help identify pedagogical strategies not explicit in the description of the activity.

The graphical representation prioritises element interactivity, enabling other researchers to more easily adapt teaching activities to other contexts by adding, subtracting, or substituting elements to fill or provide additional knowledge areas or link with other teaching activities. A detailed text description supports the sequencing and pedagogical strategy.

3.3 Using the framework

The framework can be utilised as follows:

- Identify and name the technical topics and subtopics of the teaching activity, and specify the corresponding ILOs using the SOLO taxonomy and any prerequisite knowledge. For example, to teach orthographic projections, we expect students to learn how to accurately represent three-dimensional objects in plan, section, and elevation views.
- For each topic, identify what solved problems could be used to explain how the topic can be applied to a simple example with a known solution. It is useful to classify these solved problems as case studies, demonstrations, simulations, or lectures, and note whether they involve student participation. For example, to teach orthographic projections, a solved problem may involve demonstrating how a simple volume is translated into plan, section, and elevational views.
- Identify and describe relevant abstracted problems that test the student's understanding of the topic, linking them to the corresponding topics or subtopics; sub-problems may also be included where appropriate. While abstracted problems are usually more complex than solved problems, they are still independent of real-world constraints. For example, a typical abstracted problem to teach orthographic projections, we may ask students to produce orthographic drawings of an object composed of multiple volumes.
- Identify and describe one or more contextualised problems, outlining key constraints related to how the topic should be applied. The sequence is indicated by numbering the elements and linking them with a continuous curve, before noting any key pedagogical strategies where they apply. Please note that many teaching activities do not reach this stage and may stop at applying the topic to solved problems or abstracted problems. In the context of teaching orthographic projections, a contextualised problem may involve measuring and translating a real-world object into orthographic drawings.
- Assign colour to the tiles based on key topics (dark blue), subtopics and solved problems (light blue), core design problems (dark purple), sub-problems (light purple), and prerequisite knowledge (orange).
- Link the elements using arrows to indicate associations vertically to topics, and horizontally between tasks within the design problems associated with different topics as needed.
- Number the segments sequentially to indicate the order in which knowledge, applied examples, and tasks are introduced, and draw a continuous line to connect the tiles across the diagram, tracing the pedagogical sequence.
- Prepare a written description of the teaching activity that explains the key decisions behind the problems, sequencing, and pedagogical strategies.

4 Applying the framework for reflective teaching

We have documented one sample teaching activity for each author—in structural design, energy and thermal comfort, and acoustic design—to illustrate the framework's application. Each activity incorporates the delivery of technical knowledge into an applied design scenario within architecture coursework and includes a reflection on its design and the teaching and learning experience.

These examples were drawn from our own teaching practice to provide detailed knowledge about the activity design, sequence, and intended learning outcomes. While these perspectives provide an authentic demonstration of how the framework can be applied, they also introduce limitations and bias due to self-analysis. As a result, we do not present these as empirical evidence of the framework's absolute effectiveness, but simply as illustrations of how it can be used for reflective teaching practice.

4.1 Activity 1: architectural structures design studio

How virtual becomes real (HVBR) is a master's design studio at the Faculty of Architecture, Building and Planning (ABP) of The University of Melbourne (UoM), which was delivered eleven times between 2013 and 2025. The studio explores design-to-construction workflows for free-form, large-span, and 'blob' architecture, employing both analogue and digital, performance-oriented approaches for shell and spatial structures. Starting from Greg Lynn's assertion that "no two blobs are identical" and that "blobs cannot be reduced to a typological essence", the studio requires students to investigate how architectural and structural concepts that cannot easily be translated into built form through conventional techniques can become performative and acquire tectonic qualities. This challenge forms the central research question of the studio.

The primary goal is to apply structural form-finding and optimisation tools and strategies—using both physical models and digital simulations—to explore spatial configurations for lightweight (shell and spatial) structures (Figure 2). However, as

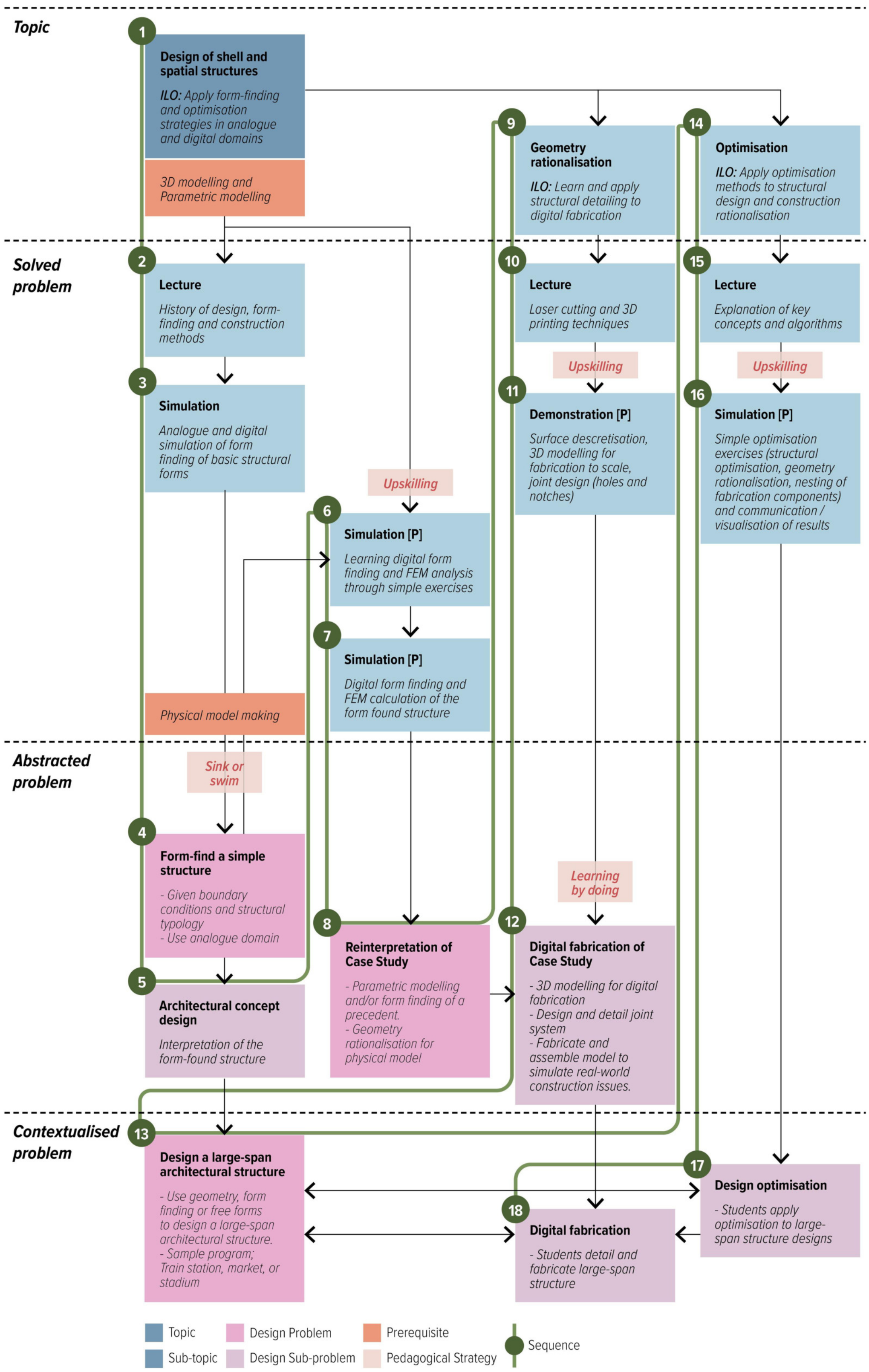

FIGURE 2
How virtual becomes real structural design studio mapping.

3D modelling software is now ubiquitous, most students tend to approach concept design freely in the virtual domain, often disregarding structural or material constraints. The studio, therefore, targets additional learning outcomes to address this contemporary approach to architectural design. Students are required to learn and apply strategies for geometry rationalisation, from digital optimisation to testing construction techniques and detailing through drawings and physical prototypes. The final brief challenges students to synthesise their learnings by designing a large-span architectural structure, such as a train station, market, or sports centre (Figure 2, element 13).

4.1.1 Sequencing

The expected design workflow that students are required to master by mid-semester is introduced in an initial lecture, which presents design precedents and guides students through simple, solved exercises in structural form-finding before progressing to the abstracted problems.

4.1.1.1 Weekly design exercises

In the first few weeks of the semester, learning activities are characterised by low element interactivity, due to the fundamental relationship between architectural and structural form in conceptual design explorations based on form-finding exercises.

Each week, students employ a different form-finding technique, starting with traditional physical models and then learning to replicate these analogue processes and their associated formal outputs through digital simulations (Figure 2, elements 2–4). Students work iteratively and simultaneously across both domains, progressively developing an awareness of the opportunities and limits of the analogue and digital design tools. While the analogue space fosters free exploration due to the more natural, interiorised physical interface between students and models, the digital realm allows them to achieve much greater accuracy at a higher speed, particularly when generating a large number of design variations.

Students work on small, geometrically simple problems, such as designing a structurally optimal symmetrical elastic timber gridshell to cover a given footprint. The studio leader provides materials and explains the techniques required to make the physical models, allowing students to focus on the specific form-finding method rather than on model-making skills. Working within these constrained environments immerses students in a new design methodology. These exercises encourage students to develop new mindsets towards design, as formal design outputs are intrinsically associated with optimal structural performance.

These weekly abstracted design tasks are based on a sink-or-swim approach in which students begin working on a task with minimal instructions, and guidance is provided as they produce design solutions. Playing with physical models also promotes teamwork and serves as an effective icebreaker, helping students connect with one another while engaging in hands-on activities.

Digitally reproducing work in the analogue domain, alongside sketching how the structural forms generated could translate into architectural proposals at different scales, serves as both a software-learning strategy (upskilling) and a means of developing design concepts (Figure 3). Sketching hero shots of abstract structural forms also fosters analogical reasoning, visual abstraction, creative interpretation, and spatial reasoning, thereby increasing the germane cognitive load of the task (Figure 2, element 5).

4.1.1.2 Precedent analysis

Following the weekly design exercises, students learn how to design and construct more complex architectural and structural systems by first analysing, then reproducing and reinterpreting design precedents from the past century as an abstracted problem. Students commonly arrive at distinct interpretations of the case studies, reflecting individual perspectives, attitudes and design approaches.

In earlier iterations of the design studio, this activity was carried out at the start of the semester. However, it has proven more effective to first ensure that the key principles and concepts of the main form-finding techniques are learnt and mastered through dedicated weekly abstracted design exercises. These simple design problems enable students to grasp both design and construction fundamentals, and the subsequent abstracted design task of reinterpreting a complex design precedent introduces more resolved and sophisticated design concepts and construction details that, at the time of their ideation, had challenged and expanded knowledge in the field (Figure 2, elements 8 & 12). Placing the precedent analysis at the beginning of the semester is effective only if all case studies are based on similar design concepts and construction strategies.

The simple acts of redrawing, 3D modelling, and re-simulating the form-finding or form-generation processes of complex design precedents—alongside making a physical model of the project—compel students to develop deeper analytical skills, moving

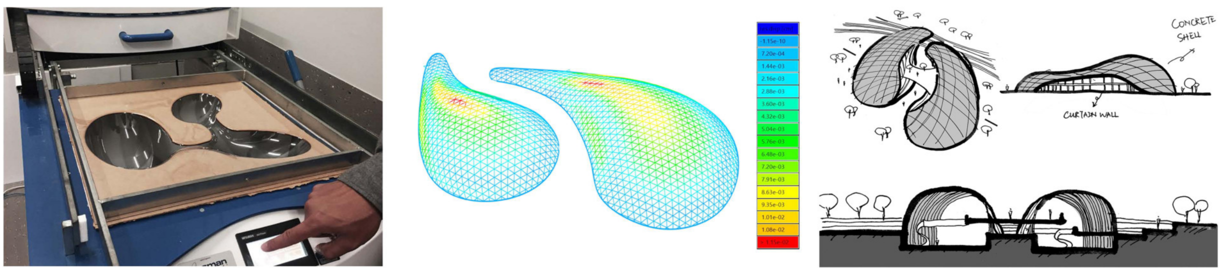

FIGURE 3
Workflow between analogue and digital domains, with architectural interpretation. Reproduced by permission.

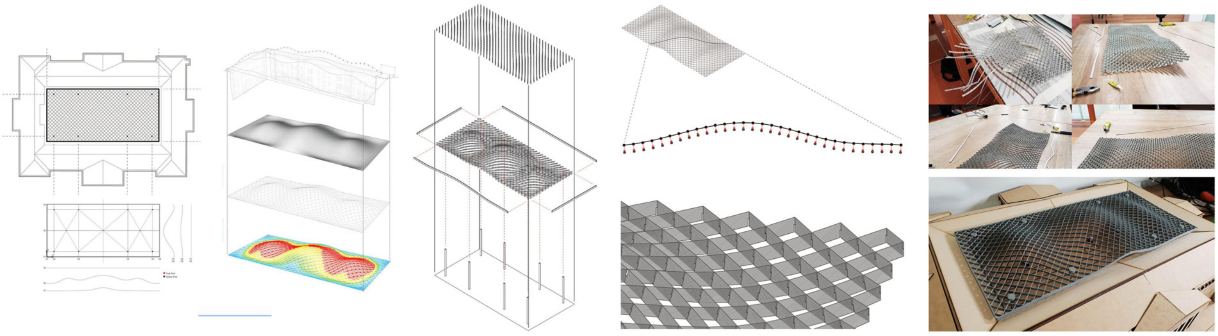

FIGURE 4
Analogue and digital reproduction of design precedent. Reproduced by permission.

beyond the superficial observations typically drawn from photographs or other easily accessible online visual material (Figure 4). This task presents a significant challenge as complex, doubly curved forms may appear similar at first glance but, in fact, result from different, even contrasting, design approaches and have been constructed using entirely different methods and techniques.

4.1.1.3 The brief

The second half of the studio is dedicated to a contextualised design problem, responding to a realistic brief that requires the design of a large-span and lightweight architectural structure. By this stage, all students have been sufficiently exposed to a range of design precedents and associated form-finding or optimisation techniques, and should be sufficiently confident to begin the conceptual design phase with the appropriate mindset and approach. Students are encouraged to openly explore structural typologies and systems of their choice and consider which one is most suitable for the design brief. Students also have free choice of materials and construction techniques. As such, this is the least structured part of the studio, and time management has proven to be one of the most challenging aspects, particularly when students must address a complex, real-world brief. As a result, the weekly pace of the project is prescribed, following the logical steps of project development: from conceptual design, through small models and sketches, to hero shot production, design development, optimisation, resolved drawings, and detailing.

4.1.2 Reflections

When analysing the outcomes of HVBR, it is evident that the most recent iterations of the studio were structured in line with the increasing complexity of the pedagogical framework presented in this paper (Figure 2). This alignment was achieved through trial and error and reflection on prior positive teaching experiences, despite being completely unaware of the four stages identified by the framework at the time.

A key observation from this studio structure is that the problems have several constraints that limit the solution space, even during the final stage when students are given a real-world brief. They are required to respond to the brief using a limited set of structural typologies, which significantly reduces the risk of failure and contains the range of possible outcomes. This narrowing of options also gives students sufficient time to address the research questions of the studio and to explore the architectural, structural, and tectonic qualities of lightweight structural systems. This targeted method of design and inquiry supports deeper engagement with both design and technical requirements, as structural behaviour and construction requirements are used as integral parts of the creative process.

Another key observation is that the weekly abstracted design tasks play a pivotal role in the studio. While their effectiveness could be assessed independently, these exercises enabled students to respond to complex design briefs within a limited timeframe: just half of the twelve-week studio.

Compared to design studios that do not prioritise technical requirements, the design outcomes from HVBR may appear less visually striking. However, the projects developed by students are generally more realistic and closer to what can actually be built. This intrinsic aspect of the studio can be perceived negatively, particularly as students often take this subject alongside other studios, making comparisons inevitable throughout the semester and especially during final crits. As a result, the depth and quality of learning achieved in this studio may not be immediately apparent, since the graphical presentation is often less polished than in other studios.

As students learn to design shells and spatial structures early in the semester, they often develop the expectation that curved forms are essential for producing a successful design. However, this is not always an appropriate response to the brief; in some cases, the curved lightweight structure should be reduced in scale and incorporated as part of a larger building complex that includes more conventional "boxes." While the requirement to integrate a lightweight structure in the final design has consistently presented a significant constraint, it has also served as an important and valuable design challenge.

4.2 Activity 2: thermal comfort design studio

Passive Aggressive (PA) was a Master of Architecture design studio established in 2019 at ABP, at UoM. The studio combines high performance with high design, technical aptitude with design skill via the introduction and application of the

German-based Passivhaus standard. The studio was created in response to a perceived lack of studio offerings that explicitly engaged with the thermal comfort and energy efficiency consequences of architectural design. It also reflected the instructor's position that design studio should not ignore external realities—such as environmental performance—that are shaping the profession and contemporary creative practice. Since the studio's first iteration in 2019, it has repeated four times using varied design briefs, most recently in 2024.

The key topic for this studio was the thermal performance of the building envelope (Figure 5). This topic is central to defining thermal comfort and energy efficiency performance in architecture and is a key tenet of the Passivhaus standard. The structure of the studio explored this topic through translating foundational knowledge of heat principles (conduction, convection, and radiation), heat transfer mechanisms (including thermal conductivity of materials), and factors influencing human thermal comfort into practical design considerations. By exposing students to both high-performance and low-tech solutions, the studio sought to illustrate that the standard can support a more design-led approach, rather than one solely driven by engineering.

In the studio's first iteration, the brief was for students to design a 60 square metre cabin on a greenfield, rural site that could achieve the energy demand required for Passivhaus certification. Demonstration of reaching this threshold of performance utilised a custom calculator tool based on a simplified version of the Passive House Planning Package (PHPP), software that is currently used for the certification of Passivhaus projects. As part of the process, students were expected to draw on previously acquired knowledge pertaining to passive design (aka passive solar design) to inform initial form and orientation exploration.

4.2.1 Sequencing

The course placed a high intrinsic cognitive load on students due to multiple dependencies, complex subject matter, diverse interpretations of 'performance' (i.e., comfort vs. energy), and broader sustainability implications their projects were engaging with. To support deeper learning, the learning content and activities were modularised to improve information retention, with a linear, scaffolded process shaping the overall pedagogy.

4.2.1.1 Lectures + demonstrations

At the start of the semester, learning aimed to ensure that all students were operating on a common foundation of knowledge. It was anticipated—and subsequently, experienced—that students would have different levels of knowledge relating to the basic principles of heat transfer and thermal comfort. Three sessions in the early weeks of the studio were dedicated to teaching the core topic and subtopics to ensure that students understood these prior to entering calculations and design exercises.

Alongside lectures, practical demonstrations illustrated some of the principles relating to heat transfer (Figure 5, elements 3 & 6). The first demonstration illustrates modes of heat transfer as an abstract concept—that is, without direct reference to buildings. Everyday household objects illustrated conduction (metal spoon in hot water), convection (ribbon held above a hot object), and radiant (a home radiator heater) modes of heat transfer. To contextualise some of these principles within building technology, a second demonstration illustrated the heat transfer properties of common construction materials of different heat capacities and densities by exposing them to heat sources (e.g., sunlight). Following these demonstrations, the Passivhaus standard, its principles, and performance criteria were introduced as an applied framework. The standard was explored through case studies, ensuring that contrasts between high-performance and low-tech solutions were demonstrated to illustrate that the Passivhaus can support a more design-led approach, rather than one solely driven by engineering.

4.2.1.2 Case study analysis

Inquiry-based learning was the pedagogical principle used to bridge the concepts of heat, heat transfer and materiality to an architectural outcome. The analysis of a real-life documentation package that implemented the Passivhaus standard was used to stimulate student thinking of their own personal framework to approach the abstract problem. Using documentation of a completed project in Tasmania, Australia, instructors guided students through a review of how the designers tackled the five primary principles of Passivhaus design—airtightness, insulation, high-performance windows and doors, thermal bridge-free construction, and mechanical ventilation with heat recovery. The case study documentation package was carefully selected to ensure that there were multiple instances of principle implementation that could be identified. As a pedagogical approach, using guided practice ultimately led students to independently identifying these principles (Figure 5, elements 10–11).

Students were provided with a custom calculator tool that allowed them to simulate, through calculations, the heating and cooling loads of the same case study. Again, using guided practice, studio leaders iteratively led students through the influence of different design decisions (i.e., insulation values, u-values, orientation, shading) on heating and cooling loads for the case study. The step-by-step approach and live feedback of the tool allowed students to observe the influence of different actions and inform their own decision making in the subsequent abstracted problem.

4.2.1.3 Pushing the envelope

With demonstrations, guided practice and simulations completed, students were then challenged to calculate and optimise the thermal performance of a building envelope for a provided design and site for the abstracted problem (Figure 5, elements 12–13). In this exercise, students were tasked with only modifying building envelope parameters (insulation, glazing, shading) rather than adding the complexity of form and form generation to the learning process. This exercise required students to study the given design for a single-room pavilion, identify the current heating and cooling loads, and subsequently propose alternatives to building materiality, fabric, and shading to lower the energy demand. Students tested two envelope and shading configurations, then reflected on the drivers of the results that they obtained. The aim of this exercise was for students to understand the role of optimisation and iteration in improving environmental performance. Optimisation was

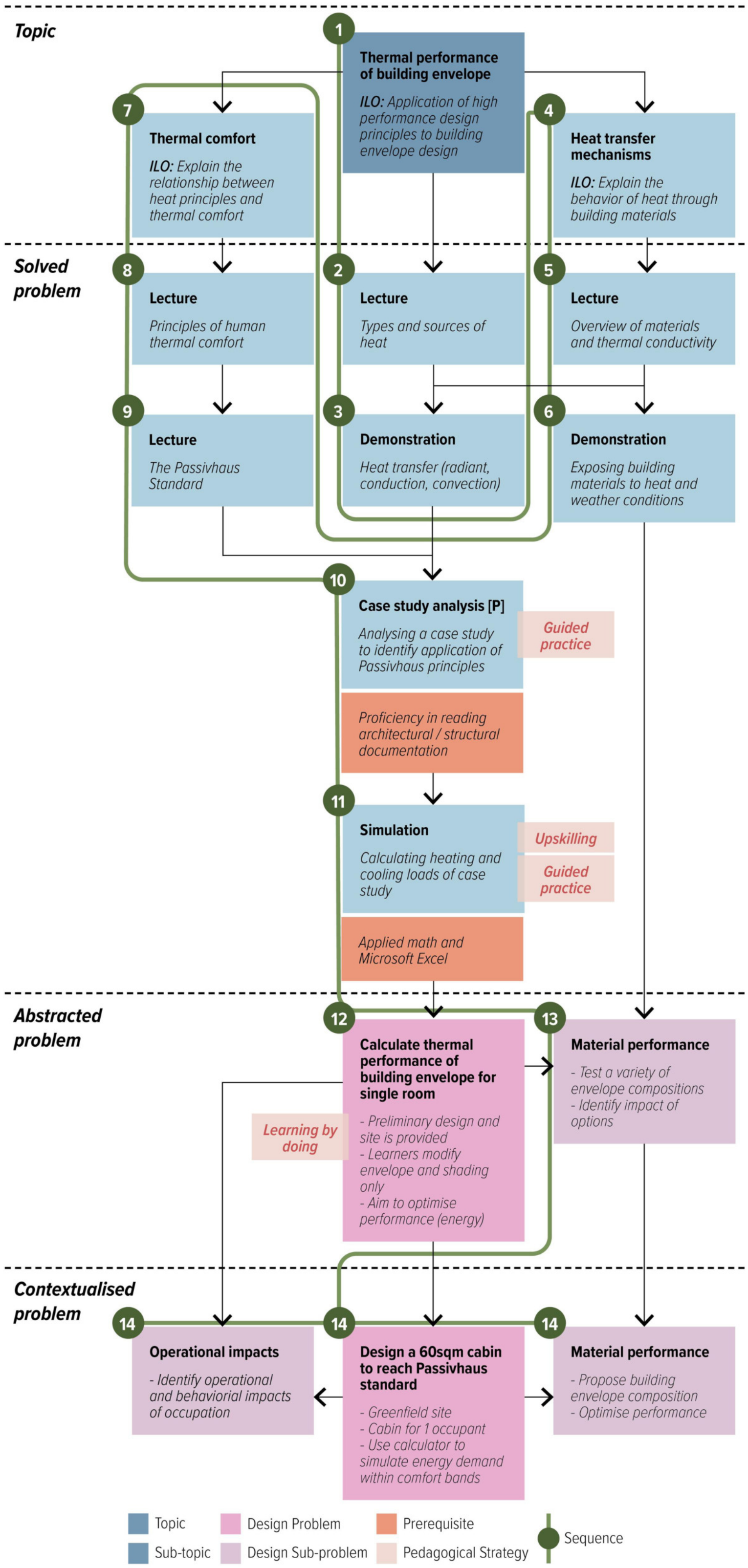

FIGURE 5
Passive aggressive design studio mapping.

intended to be done independently, but could be guided based on the student's skills and competency level.

Following this exercise, students translated this learning into the contextualised problem. The process and skills are the same as the abstracted problem but are balanced against the student's aesthetic and conceptual design intent. As previously mentioned, the final design brief was to challenge students to design a 60sqm cabin for a single person on a greenfield rural site. The selection of a rural site aligns with the documentation package for the case study and limits the influence of uncontrollable contextual factors on performance.

4.2.2 Reflections

PA was designed to follow an explicit, linear structure due to the complex interdependencies that exist at the intersections of thermal comfort, energy efficiency and design. The linear approach of introducing basic principles, demonstrating how they work in abstract and in practice prior to delving into any form of design exercise was deemed to benefit students' skill and knowledge acquisition, simplifying the complex discipline to understand and apply.

However, the significant portion of teaching time that was dedicated to the preliminary topics did delay the instructor's ability to assess students' understanding of the relationships between the building envelope, thermal performance, and design. This understanding only became evident in earnest once students began engaging with the contextualised design problem. Achieving a successful balance between design intent—particularly in an educational setting that places strong emphasis on visual appeal of the architectural proposal—and technical competency was rarely accomplished by the students. Most students tended to lean heavily toward either aesthetic presentation or technical resolution, rather than integrating both effectively. Reflecting on the linear sequence of delivery, one way to address this challenge would be to include solved problems that integrate aesthetic and technical aspects after the contextualised problem is introduced.

Nonetheless, this issue was further compounded by the short duration of the activities. These elements of the studio were conducted within a six-week period, with students meeting with instructors twice weekly for three hours. Furthermore, students' prerequisite knowledge was inconsistent. As an internationally recognised school of architecture, the program attracts students from around the globe but more importantly, from diverse educational backgrounds. This diversity added complexity to the educational process, as it was unclear from the outset what students' gaps in knowledge were, including areas they were unaware they lacked understanding in.

Another concern was observed after introducing the calculation tool. Students who had demonstrated limited engagement with the underlying principles attempted to gamify the calculation tool during the optimisation task. This issue carried over into the contextualised problem, where calculations shifted from being used as a meaningful design tool to a superficial exercise focused on achieving the lowest numerical result, rather than informing design decisions. For most students undertaking the studio, previous exposure to calculating building performance was mostly relegated to technical subjects, rather than being a requirement within a design context. Encountering this issue further emphasised the need to introduce integrated technical learning within the design studio context earlier in students' education, or risk it being continually perceived as an 'add-on' to a predominantly aesthetics-driven pursuit.

4.3 Activity 3: acoustic design elective course

DF_Lab: Designing Making (DF_Lab) was a Master of Architecture elective course delivered at ABP, at UoM, in 2025. The elective explores digital design and fabrication technology, with a particular focus on CNC routing, to augment traditionally used craft and making techniques. The 2025 iteration of DF_Lab was the first that incorporated a focus on acoustic design. While usually left as an afterthought, the course presents acoustics as a design driver and investigates how architectural design can incorporate acoustic considerations from the early stages of the design process.

The design brief for the elective was to apply acoustics, structural, and digital fabrication principles to the design and construction of an outdoor acoustic pavilion for live music performance (Figure 6). There were many constraints on the pavilion, including the modularity, transportability, and deployability of the structure. However, for the purpose of this analysis, focus will be placed on the acoustics content. Students were expected to learn and apply the principles of sound propagation and geometric acoustics, as well as acoustic simulation through digital and physical models, and material affordances in relation to their acoustic properties.

4.3.1 Sequencing

The structure of the course is designed to compartmentalise learning and manage the high germane load due to parallel knowledge areas that students needed to learn and apply before designing the pavilion. For the acoustic knowledge, the course was divided into two phases. The first four-week phase scaffolds all the necessary foundation knowledge about acoustic principles, which the students learn through a series of lectures and exercises, and then apply it to a progressively abstract problem. In the second phase, students combine acoustics knowledge with instruction on structural design and digital fabrication to propose, build, and assemble the acoustic pavilion.

4.3.1.1 Acoustic amplifier

In the first phase, groups of 3–4 students design an acoustic amplifier for a small Bluetooth speaker in an outdoor setting. A structural design technique, namely folding, interlocking, panelling, and bending, alongside design precedents of those techniques, is assigned to each group, so that attention is focused on learning and application of acoustic knowledge. The core premise of the acoustic amplifier problem stage is the integrative mediation between digital and analogue acoustic design workflows. By comparing the two domains, students are compelled to reconcile the sometimes contradictory feedback from each domain, thereby fostering a deeper, more holistic understanding of acoustics. To reflect this, the abstract and contextualised problems are annotated with the same sequence number to indicate that all topics and subtopics should be simultaneously considered (Figure 6, elements 9, 12, 20).

In the first class, students learn about basic sound physics and sound propagation through geometric acoustics (Figure 6, elements 1–8). They are introduced to the digital workflow through visualisation of raytracing and an acoustic simulation

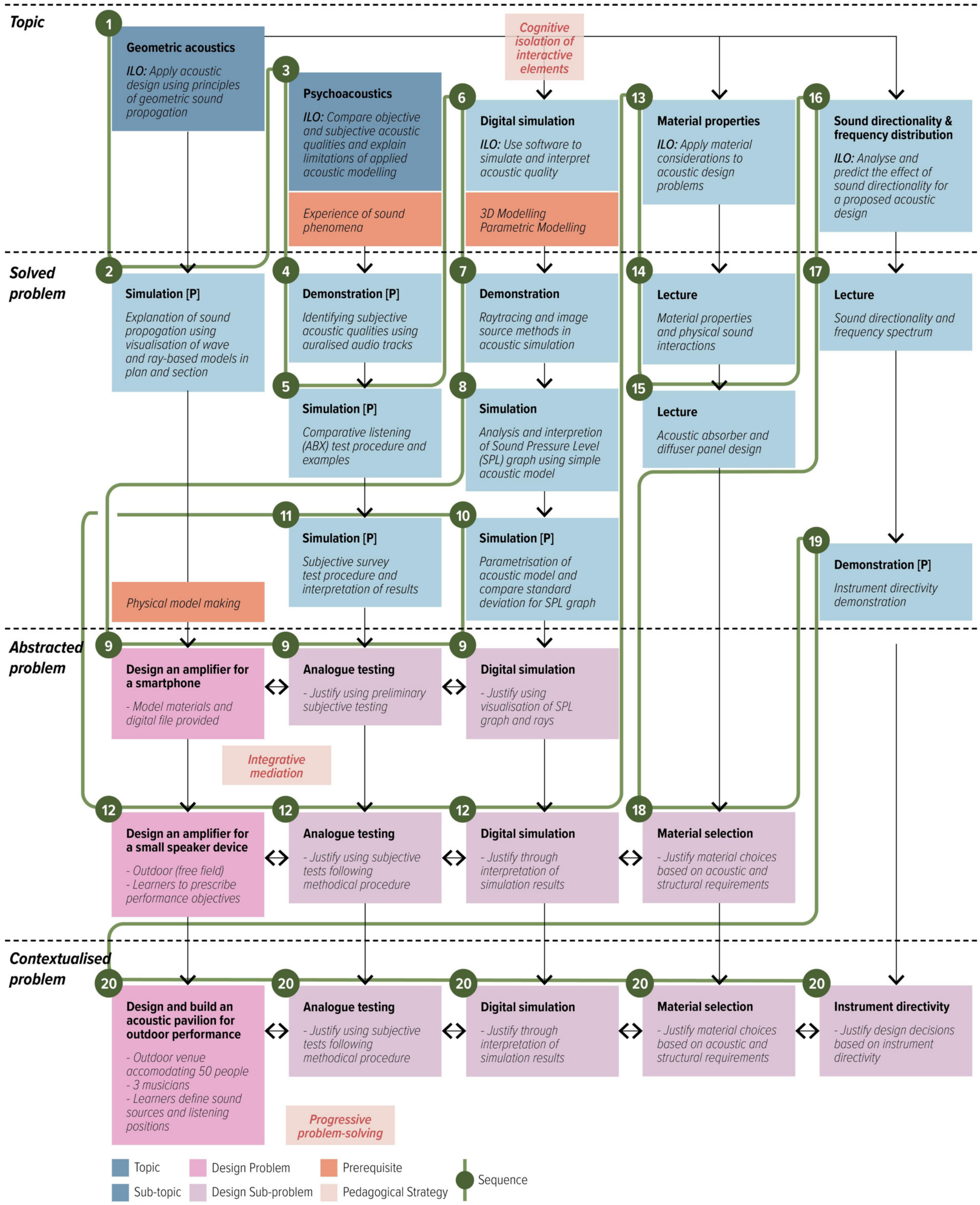

FIGURE 6
DF_Lab elective course mapping.

example in a provided 3D model. The analogue workflow, introduced through psychoacoustics, involves a demonstration of critical listening and perception test procedure using physical models. In groups, students apply these two workflows in parallel to the design of a smartphone amplifier in class, using the qualitative feedback from both workflows to improve the design (Figure 6, element 9). Due to the diverse skill requirements needed, groupwork offers an effective way to informally support peer-to-peer learning. Through this low-stakes design exercise, students immediately gain an awareness of the limitations of the analogue and digital tools by comparing the results gained from each, which they then apply to their own assignments.

The second class builds upon the complexity of the two workflows by formalising the iterative and testing procedure

(Figure 6, elements 10–11). Parameterisation for the acoustic models is introduced, so that the design space can be specified and made consistent across digital and analogue models. Students are shown how to calculate the standard deviation across Sound Pressure Level (SPL) graphs in the digital workflow and are walked through the formal listening testing procedure to support the analogue workflow. These layers provide a way to numerically compare the results (Figure 6, element 12).

The third class introduces sound directionality and frequency distribution, as well as covering material absorption and acoustic panel design (Figure 6, element 13–18). Both these topics provide additional context to their physical model prototypes, differences in subjective testing compared to simulated results, and highlight the limitations of using omnidirectional sources in digital simulation. Successful projects were able to discuss their projects with comprehensive reference to the limitations of both workflows.

4.3.1.2 Acoustic pavilion

By the start of phase 2, students have effectively learnt all the relevant acoustic principles but are challenged by integrating them with other constraints from the structural design and fabrication domains. For example, the effect of density and thickness on materials' acoustic reflectivity and absorption must be considered alongside structural weight, flexibility, fabrication time, costs, and aesthetic qualities.

Although the digital workflow can be continuously achieved through 3D models and simulation, the analogue workflow is more difficult to practically apply at a larger scale. The application of analogue testing to the pavilion design proposal is also supported through collaborative design sessions and live demonstrations of acoustic principles by musicians, who acted as clients and collaborators for the brief.

In the early stages of phase two, musicians with different instrument directivity play short excerpts to provide a baseline of the site's subjective acoustic qualities. Students also experiment with a movable plywood reflector panel to modify the acoustic reflections of each instrument to understand their directivity at a deeper level, reinforcing the learning from phase one. The students record these observations to guide early decision-making on the pavilion's acoustics, before proceeding with the iterative design process (Figure 4, element 19). The unique nature of the collaborative and integrated design process and brief meant that there were very few design precedents, meaning students had to rely heavily on technical principles to conceptualise and develop the design.

4.3.2 Reflections

A key feature of this teaching activity is that while students used the same digital and analogue workflows throughout the semester, the complexity of their application increases over the three problems. For example, students first qualitatively use digital simulation tools to visualise ray tracing in the smartphone amplifier problem, then are taught to interpret SPL graphs and standard deviation to justify their acoustic amplifier assignments. In the acoustic pavilion, complexity is introduced by simultaneously considering three sound sources (Figure 7). This progression is shown intrinsically in the mapping through the scaffolded progressive problems.

The repetitive structure is particularly effective for acoustics, which inherently involves a high degree of interactivity among elements and many aspects of architectural design. By progressively applying the same workflow to increasingly complex problems, the instructor can readily identify gaps in understanding. However, this is challenging using group work, which is employed to address the high intrinsic workload associated with a design-build project. In group work, it is highly likely that students cannot engage with every aspect of the technical knowledge.

When approaching the acoustic amplifier problem, many students became preoccupied with designing new forms, despite the structural design techniques and precedents provided. As a result, those students tended to compare drastically different forms rather than identify incremental improvements to more successful designs, thereby limiting the usefulness of the simulation and testing tools within the workflows. Similarly, model-making and prototyping proved limiting in the early stages of the pavilion, as students delayed prototype fabrication, reducing the number of analogue tests that could be performed. This delay could be attributed to the perception that model-making traditionally occurs towards the end of the teaching course. These observations suggest that a deeper understanding of interactivity among elements across subdisciplines and the identification of potential learning

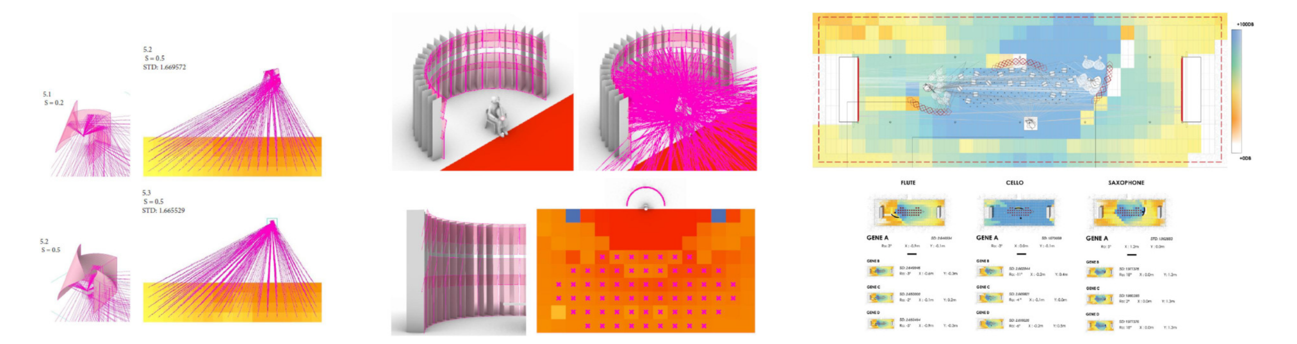

FIGURE 7
Increasing complexity of the digital skill application through the abstracted and contextualised problems. Reproduced by permission.

barriers could benefit the design of problems that meet specific learning objectives.

Although the contextualised problem of the acoustic pavilion is difficult to replicate in other circumstances, the framework highlights how an activity might be designed that can test the execution of learned principles in a creative way that involves an architectural design component.

5 Using the framework to analyse exemplars activities

In addition to analysing our own teaching activities, we have also applied the framework to selected exemplars by other educators to provide pedagogical and structural contrast outside of the authors' own activities. The inclusion of these activities illustrates the framework's utility as an analytical tool across a range of case studies chosen to represent different domains of technical knowledge, including fundamental skills such as drawing, as well as pedagogical approaches across varying instructional contexts. This analysis demonstrates how the framework can be generally applied to identify, examine, and compare different teaching activities; however, it is currently limited by the information available in published descriptions of those activities. Future research should expand this work by involving additional educators through interviews and focus groups, allowing activities to be analysed through the framework with more complete and detailed information.

5.1 Exemplar 1: how to lay out a croissant

Developed by Enric Miralles (1991) at the Escola Tècnica Superior d'Arquitectura de Barcelona (ETSAB), this exercise teaches architectural drawing techniques and conventions. The croissant exercise is a learner-centred experience that is based on direct observation of an everyday object. It teaches students how to observe and abstract visual information from that object, and document it accurately using those drawing conventions.

Variations of this exercise appear at University of Buffalo (Rodríguez, 2014) and has been used as inspiration at ETH Zurich (Killer, 2019). For this paper, we focus on its adaptation in the Foundations of Design: Representation (FoD:R) course at UoM between 2017 and 2022, drawing on the experience of one of the authors who taught in the course. FoD:R is a first-semester core course that focuses on teaching fundamental technical skills. This version of the exercise includes technical drawing, photography, digital photo editing, and layout skills (Figure 8).

5.1.1 Sequencing

The croissant exercise runs over three weeks with three scaffolded in-class demonstrations that introduce core skills, and weekly tasks that students complete independently. The demonstrations are participatory and completed in class to replicate the skills needed to complete the exercises, which students then translate to the abstracted problem.

Students are first introduced to the topic and abstracted exercise through a reading of Miralles' text, alongside an introduction to basic orthographic drawing principles and conventions. The exercise introduces observation, surveying, precision and conventions through the task of producing orthographic drawings of a croissant, which are delivered over three pages as shown in Figure 9. Students capture views of the croissant through photography, then learn drawing technique following drawing conventions (Figure 8, elements 1–10).

The second stage involves scale and drawing resolution, where they are expected to lay out their drawings at a 1:1 scale, then dimension and label them by hand, introducing students to line types and line weights. At this stage, students are also introduced to rendering techniques, although the emphasis is not on photo-realistic rendering but on abstracting and representing three-dimensional form (Figure 8, elements 12–17).

The final stage of the exercise asks students to use an outline of their section drawings to construct an axonometric projection. Unlike the previous two stages, the axonometric projection relies on the student's ability to abstract, then reimagine the croissant as a three-dimensional object (Figure 8, elements 18–19). The three stages are intentionally scaffolded to provide early support to students at the preliminary stages of the exercise, where skill acquisition is higher, and to reduce support as students move onto the abstraction and representational aspects of the task.

5.1.2 Analysis

The framework highlights the progressive nature of the weekly exercises, which is emblematic of a first-year course. These solved problems are designed as low-stakes tasks that students can complete in the relatively short class time. However, these are pivotal in ensuring that students have a full grasp of the technical skills required to complete the task. Similarly, the overlap among the skills required for each weekly task provides a particularly useful degree of redundancy, enabling the identification of errors in students' skills before they proceed to the next stage.

As it was introduced alongside the technical drawing, there was a tendency for students to prioritise highly realistic rendering and spend less time ensuring the accuracy of their drawing conventions. Based on the sequence of the activity, this problem was likely caused by the chronological separation of when the orthographic drawings and rendering skills were introduced. Future iterations could prioritise distinguishing the abstraction from the rendering and representational skillsets.

5.2 Exemplar 2: robotic fabrication of acoustic geometries

The Robotic Fabrication of Acoustic Geometries (Jensen, 2019) (RFoAG) course was a 3-week design studio run at the Department of Architecture, Design and Media Technology at Aalborg University in Denmark. This course was a good example of a short design studio teaching activity that attempted to combine a broad range of technical knowledge areas, to teach and emulate an existing design method that the instructors developed and used within their research practice. The instructors provide a clear breakdown of weekly tasks and useful reflections on the problems that the students encountered, which this framework can analyse (Figure 10).

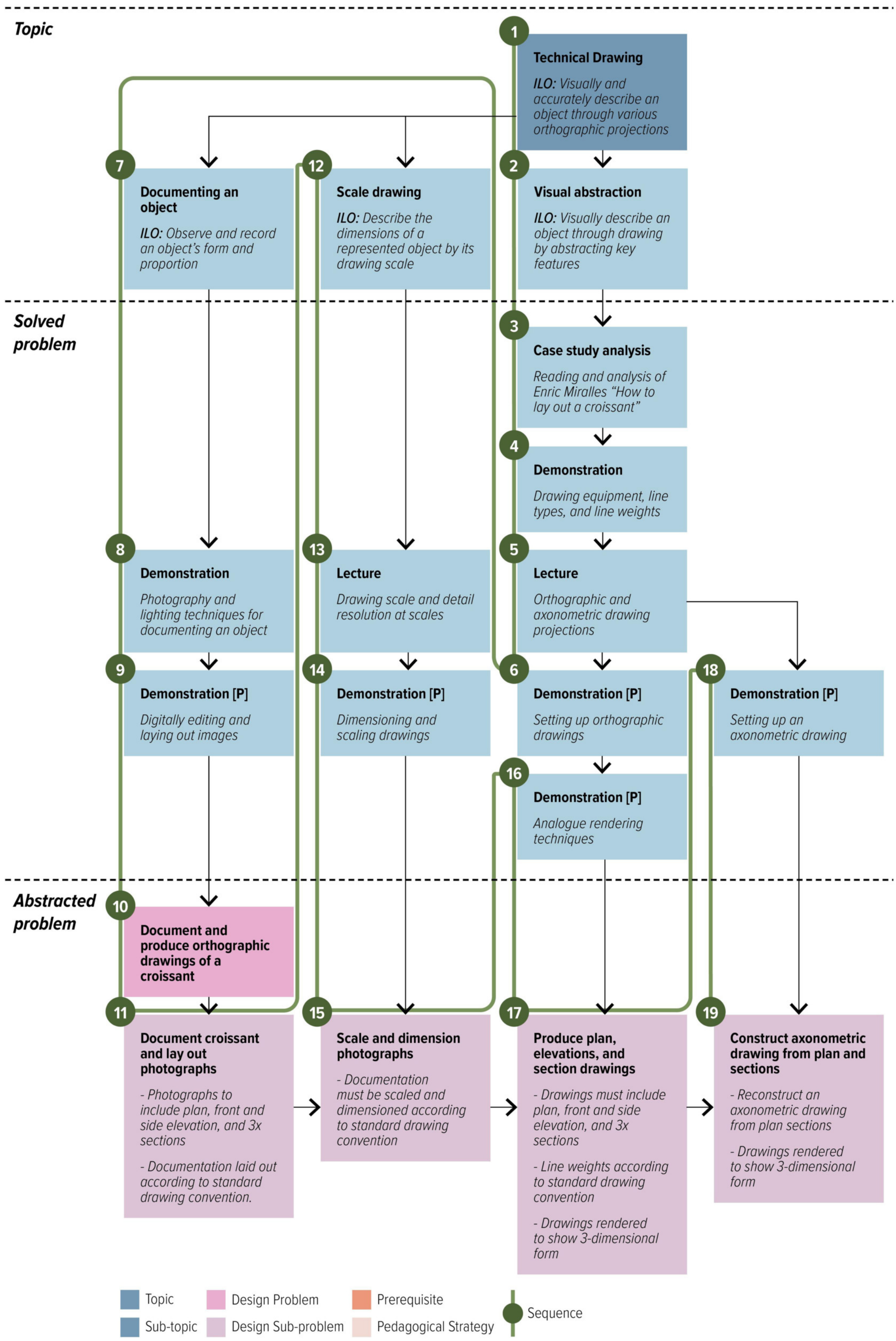

FIGURE 8
How to lay out a croissant mapping.

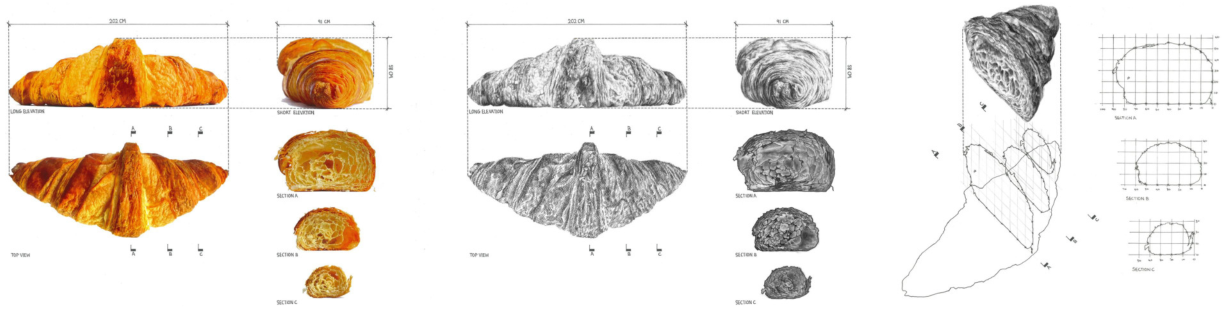

FIGURE 9
Croissant drawings. Reproduced by permission.

The robotic design method comprises of defining the architectural geometry, simulating the robotic process, and acoustic analysis. Students are given the contextualised problem of designing and milling an acoustic panel for a mobile library.

5.2.1 Sequencing

The topics of architectural geometry and materials, robotic manufacturing, and parametric modelling are introduced concurrently, with students given access to the prepared parametric design (Figure 10, elements 1–6). They are provided with some basic geometry, which is used to demonstrate how the design system works, and they spend a week understanding and exploring the design system through these examples. In the second class, they are introduced to the simulation of acoustic performance and the simulation of robotic milling and manufacturing (Figure 10, elements 8–10). This separation from the first week implies a separation of the design theory and generation of geometry from the analysis, performative, and production aspects. In the third week, students begin working on their own design system, with the intention that they will iteratively improve basic geometries based on acoustic and robotic simulation and analysis tools, following an interleaved practice approach (Figure 10, elements 11–14).

At the end of the teaching period, the panels are milled and acoustically measured, with the data being theoretically fed into further iterations of the design.

5.2.2 Analysis

According to the instructors of RFoAG, there were many problems with aligning the knowledge domain of the students with the workflow. They observed that students relied heavily on aesthetic concepts, rather than feedback from the parametric design workflow, leading to narrow design spaces that were not justified based on the knowledge learnt. Similarly, students attempted to pursue advanced geometric designs, which they did not necessarily have the parametric design skills to resolve. It is not clear what technical skills the students had coming into this design studio, as the context for the studio is not provided. However, these problems were likely caused by the short time frame of the studio and the subsequent lack of time to either reinforce the technical skills or identify gaps in student knowledge.

While the contextualised problem is relatively constrained, the complexity of the topics likely resulted in a high cognitive load. Using the framework, two possible solutions become apparent. First, adding abstracted design exercises that scaffold the learning may help reinforce understanding before jumping straight into the parametric design system, which students may interpret as a black box. The second possibility, given the inherently high level of interactivity, would be to simply reduce the number of overall topics that influence the design. For example, due to the limited time, acoustic and robotic simulation could be treated as linear processes for this design studio, rather than feedback systems to inform the design. Changing this would mean student focus can be placed on geometry and path generation for milling instead, reducing attention being split between four influences to two.

5.3 Exemplar 3: machining aesthetics

Machining Aesthetics (MA) was a Master of Architecture design studio delivered in ABP at UoM in 2016 and 2017 by Paul Loh and David Leggett (Loh and Leggett, 2018). The design studio's focus was on making as a form of research, where students designed and built a novel CNC fabrication machine using open-source technology that formed the basis of an architectural proposal (Figure 11).

This studio is included as it spans a breadth of topics and is a well-documented example of a PBL approach where the core aspects of the teaching are led by student enquiry. The original paper by Loh and Leggett (2018) presents the activity predominantly through three student projects and the elements are not precisely specified in the article. However, we have made our best attempt to synthesise the activity from the three student projects for this analysis.

5.3.1 Sequencing

The goals are stated explicitly alongside the contextualised problem at the commencement of the studio. Early instruction covered conventional CNC approaches, basic programming, and physical computing, enabling them to pursue the design and construction of their own bespoke machines. The last two topics are taught through Arduino, an open-source electronics platform that can be easily connected to conventional physical computing sensors and combined with mechanical hardware such as motors and actuators, forming a cohesive ecosystem of

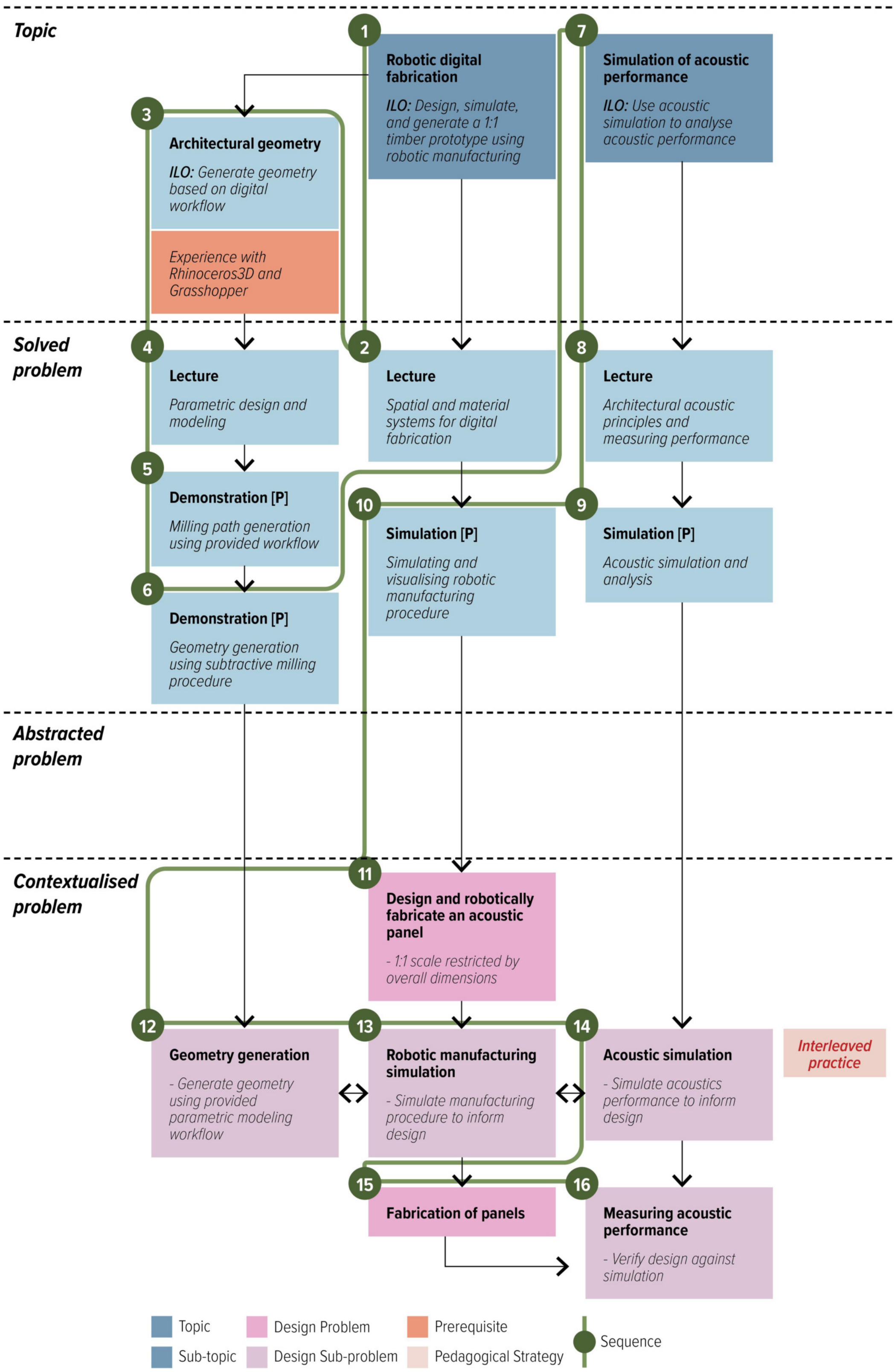

FIGURE 10
Robotic fabrication of acoustic geometries mapping.

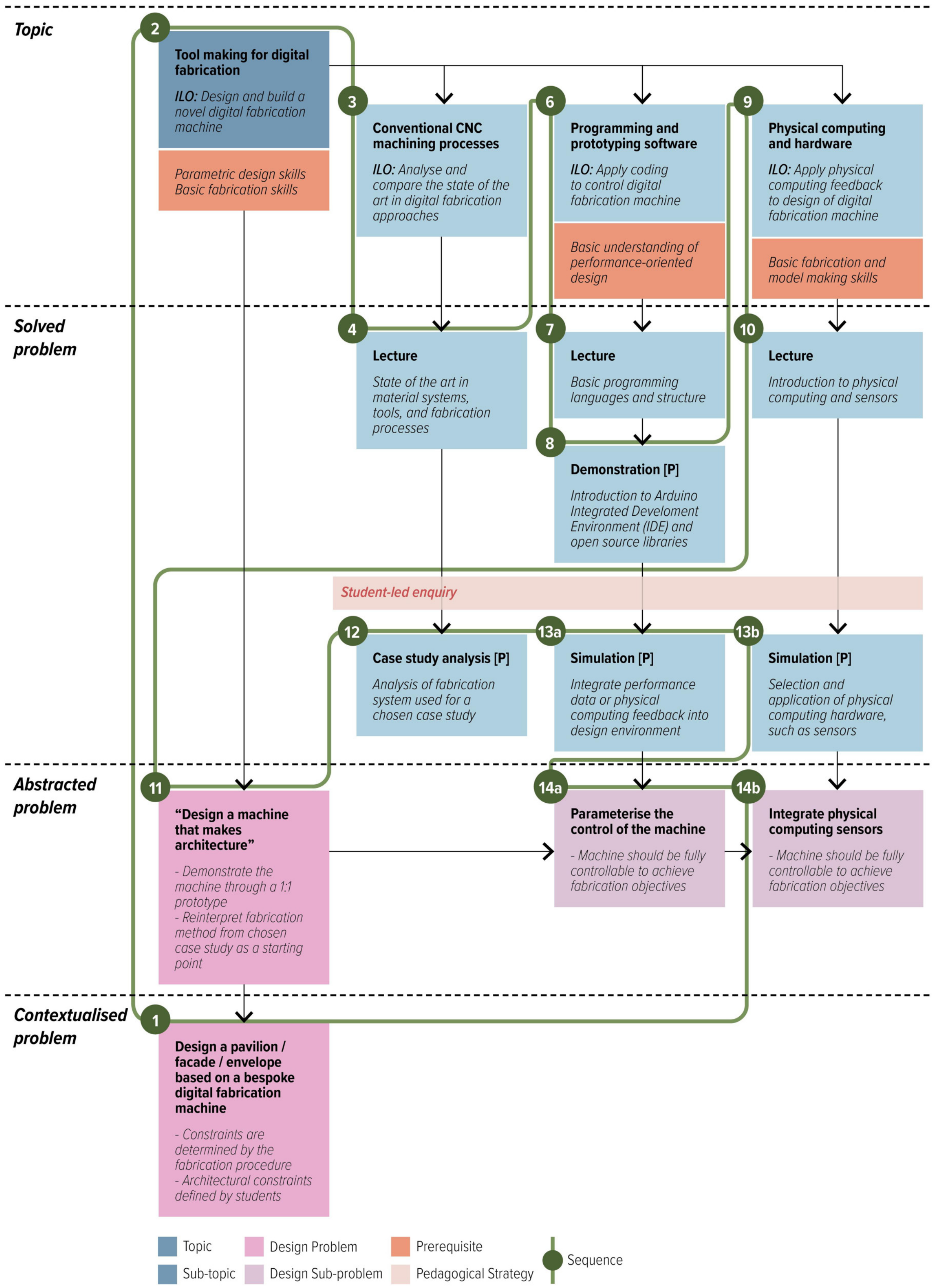

FIGURE 11
Machining aesthetics mapping.

software and hardware. The open-source nature of the platform makes it suitable for self-guided learning through the wide availability of online tutorials and instructions for community-developed projects (Figure 11, elements 2–10).

Designing and building the machine is not explicitly taught, but it is expected that students will be able to synthesise designs from conventional CNC approaches and case studies. It is also not expected that the machine itself be novel; instead, novelty may come from integrating building performance data obtained digitally or from physical computing sensors. It is at this stage that the student-led enquiry is necessary to drive the project, requiring them to identify areas of interest to individually pursue (Figure 11, elements 11–14).

One group analysed an inflatable membrane precedent, which they recreated the system to design a PVC inflation device for a series of cells. Light sensors are used to regulate airflow, with learning drawn from online tutorials, precedent studies, and online making instructions, suggested by the instructors. However, the innovation came with the incorporation of an opaque layer that could be deployed to block out the sun, thus making the cells responsive to daylight. Once student groups developed and demonstrated their machine through a 1:1 prototype, they speculated on an architectural proposal, with the constraints being set through the prototyping of the abstract problem.

5.3.2 Analysis

MA is a good example of a technical knowledge blended with a PBL approach. As illustrated in the framework map, the instructors of MA initially teach foundational knowledge related to the agenda but there is a clear delineation where student-led enquiry is necessary to respond to the problems. The approach requires instructors to be reactive to student needs and facilitate the identification of learning resources, as suggested by most PBL models, meaning that the onus of expertise grows exponentially with the complexity of the topics. Though, in MA's case, this is supplemented by good open-source resources.

The delivery of technical knowledge learning is difficult to assess without clear assessment criteria, especially when the subtopics are optional or supplementary to the main objective. Furthermore, there is also no evidence in the publication that abstract problems are used in teaching fundamental skills in the early stages, but these could have been omitted from the publication or easily embedded through the demonstrations. One way to address the assessment, and similar issues, would be to incorporate more structured assessment tasks or abstracted problems earlier in the teaching activity, to document and verify learning of the core skills. However, this may not align with the instructor's pedagogical approach.

6 Discussion

Our four-step framework provides a consistent approach to describing technical knowledge across disciplines, teaching activity lengths, and delivery modes, demonstrating its high adaptability and applicability across diverse knowledge domains. It is equally applicable to whole activities and to smaller teaching sequences in which technical knowledge is delivered. These outcomes align with prior work in instructional design as discussed in Section 2, as well as the objectives of action research to improve teaching practices through systematic action and reflection (Leitch and Day, 2000). Similarly, the framework adopts principles of "use-inspired basic research" (McKenney and Reeves, 2018, 7), as it is grounded in the practical problem of technical teaching in architectural education, and tested through its use as a reflective teaching and analysis tool.

However, this methodological framework departs from conventional instructional design models, which typically apply predefined pedagogical models or strategies to teaching activities. Instead, this framework shifts focus to how the knowledge itself is organised within teaching activities, allowing pedagogical modes to emerge from the relationships between topics and design problems. This reversal may be particularly advantageous for academics whose expertise lies outside education, as it reduces reliance on education and instructional design training (Allen and Sites, 2012).

In this context, our proposed framework offers a complementary analytical structure for mapping how knowledge is organised, structured, and applied to problem-solving within teaching activities. Its application in both analytical and reflective capacities reinforces the value of systematic documentation for improving teaching practice regardless of format, duration, delivery mode, or disciplinary context.

6.1 The framework as an analysis and comparative tool

The framework enables both in-depth analysis within a specific group of topics and comparison to other areas of technical knowledge in architecture, in terms of structure, sequencing, and content design decisions, highlighting how disciplines with different topics approach designing content for different levels of element interactivity. Differences observed between PA and DF_Lab highlight the variety of pedagogy structuring strategies, and how they are linked to the complexity and interactivity of the topics taught.

Decomposing teaching into discrete elements provides a systematic way to analyse the structure of teaching activities, revealing the instructor's pedagogical approach to delivering content and, in particular, how cognitive load was managed during problem-solving at the abstract and contextualised problem stages. It should be noted that a similar analysis of alignment with learning outcomes could be achieved using Constructive Alignment (Biggs and Tang, 2011). Doing so would similarly require decomposing the overall activity into the separate exercises, which would then be aligned with parts of the ILOs, assuming that these have been provided. As such, operationalising a framework like Constructive Alignment for analysis is difficult without significant interpretation. Instead, by focusing first on identifying and mapping the sequence of knowledge and the progression of learning, our framework shifts emphasis from verifying alignment to the structure of knowledge, after which alignment between learning outcomes and design problems can be analysed.

The modular description of the content also allows adjustments to curriculum planning or to the timing and sequencing of activities, while maintaining both a broad overview of the structure and a fine-grained understanding of the content to be delivered. These flexible qualities enable the documentation of innovative pedagogical techniques and activities, while still providing a generalised overview of the core content for other instructors to replicate. Furthermore, the framework is neutral with respect to pedagogical approaches, meaning that preferences for specific techniques are primarily explained through the graphical relationships between elements and tasks. Instructors who favour direct instruction or didactic approaches can rely more heavily on non-participatory, solved problems, while a constructivist approach may transition to participatory, solved problems or simple, abstract problems at earlier stages.

6.2 Visualising learning pathways and element interactivity

The graphical representation of the framework provides a clear understanding of how content, tasks, and associated knowledge are structured and interrelated, highlighting learning pathways. While other instructional design models are often represented diagrammatically, they typically do not employ a consistent graphical convention. However, consistency is a critical component of our framework, allowing visual comparison of teaching practices. The map is also a useful diagnostic tool, helping to identify how the sequence of learning activities might be adjusted, or new ones introduced, to address possible knowledge gaps or problems. This application was illustrated in both the DF_Lab and RFoAG courses, where a gap in prerequisite knowledge was made visible through mapping, extending the framework beyond a strict documentation tool to an analytical one.

Although these connections within the framework are grounded in cognitive psychology, a deep understanding of the underlying theories is not necessary to utilise the framework for documentation and reflection. However, even if the underlying complexities of topics with higher or lower element interactivity are not fully understood, mapping can inherently highlight points at which students are likely to experience high cognitive load or where further scaffolding is required.

It is worth noting that this study assessed the framework's effectiveness and applicability across a wide range of technical knowledge domains. However, mapping teaching activities across the same disciplines could reveal patterns or sequences unique to those topics.

6.3 Supporting reflective practice

It should be emphasised that mapping each activity proved to be a valuable tool for self-reflection, where making implicit decisions explicit supports deeper professional learning (Schön, 1983). By methodically breaking down our teaching activities, we not only identified gaps and weaknesses but also gained a sharper awareness of where and why our students experienced difficulties, supporting a structured reflective process.

By making each activity's elements explicit, we were forced to reflect on assumptions embedded in their structure. These assumptions are centred on best practices for teaching our respective disciplines, including how content was selected, grouped, and defined across topics and subtopics. For example, by comparing the maps of our activities, we identified how optimisation can be learned as a topic, subtopic, or skill, depending on the scope and context of the content being taught. This observation highlights the variability of disciplinary boundaries, underscoring the need for explicit, consistent documentation practices to capture these contextual differences. Furthermore, distinguishing these differences requires clearly defining ILOs and reflecting more deeply on the relationships among the elements.

Although this framework is not intended as a broader instructional design approach, the mapping process supports ongoing pedagogical reflection by making embedded tacit knowledge explicit and aligns with existing reflective and instructional models that emphasise transparency in teaching design. However, unlike those models, this framework specifically foregrounds the relationship between knowledge acquisition and its application to problem-solving. This distinction is particularly significant in architectural education, where such relationships are often implicit.

6.4 Limitations and future studies

A limitation of the framework is that it does not explicitly capture social or affective aspects of learning, such as collaboration and group work, which shape how certain activities are designed, particularly when a high cognitive load must be distributed among team members in group projects. These are also known problems associated with cognitive load theory, and reliance is placed on the instructors to emphasise this distinction in the descriptions.

In this paper, the framework is applied retrospectively to analyse activities, whereas future studies will be able to apply the reflective process to design new activities. One key area to evaluate is how problems are designed with specific learning objectives in mind. For instance, in Section 3, we identified how problem constraints can be defined by topic areas and suggested that these should be balanced against the imposed cognitive load, particularly in the contextualised problem. Use of the framework in future studies will continue to provide empirical evidence supporting its effectiveness as a mapping and analytical tool.

It is worth acknowledging the risk of over-structuring activities, which may lead to overly prescriptive teaching sequences and a lack of agency and creativity for students. All six activities described in this paper were designed and iterated without prior knowledge of the framework presented here, demonstrating that its primary intention is to map and analyse structures that already exist within courses. Although it may also inform the design of new courses, the framework functions primarily as a reflective and comparative tool, and its main value lies in helping instructors identify potential imbalances or limitations in teaching sequences and supporting critical reflection on their design.

It is also likely that a more sophisticated categorisation of problems would be valuable, providing additional context for the design of the activities, as well as how constraints are defined. The design of the abstracted problems likely depends on how instructors align their pedagogical strategies to the complexity of the topics. Focusing on small, self-contained tasks can help students build expertise, but limit broader application. Conversely, open or progressively solved problems encourage a broader, more holistic understanding of the element's interactivity, at the risk of a surface-level understanding. Problem-based learning approaches, such as those resembling practice-based design briefs, support students by contextualising learning and providing a clear end goal, but they can impose high cognitive load due to student-driven inquiry.

Future teaching activities using this framework should also discuss the development of assessment alongside student outcomes. Comparing student outcomes alongside the mapped activities will reveal additional information about the activity's success, help reflect on and refine the pedagogical approaches used, and provide valuable resources for other instructors.

Finally, this paper has focused on the technological and performance aspects of technical knowledge; however, future studies could evaluate the applicability of this framework to other technical skills, such as site analysis or communication. Testing the application of the framework to the learning of non-technical knowledge, such as that related to societal or cultural domains, may also yield useful results.

Data availability statement

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article. We have received written permission to reproduce the student work in this article as illustrations of the teaching activities.

Author contributions

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