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Integrated Design Process by Sequential Primary Generators

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ABSTRACT

This paper proposes, exemplifies and discusses a new design method that includes both artistic and scientific modes of working. It is based on the idea of integrated design processes driven by strategic implementation of what is termed sequential primary generators. The paper begins by discussing design and creative process research and then filters central aspects that are coalesced with a proposed three-phase early-stage design method. The proposed architectural design method has been applied in three university projects. In the last project, students were asked to respond to a questionnaire survey to identify the growth of design and creative capabilities from a student perspective. The paper presents the results and discussion based upon these projects and studies. Survey answers show that the proposed design method increases both design quality and design knowledge. This suggests that other creative processes may be addressed through this design methodology, which features both problem- and solution-driven procedures.

Keywords: Integrated design processes; Primary generators; Design knowledge; Advanced design processes; Design didactics

INTRODUCTION

Architecture can be understood as an interface of demands and desires. Arguably, the demands appear to become more strident as international and national building legislation pushes for, in particular, requirements for lowered energy use and specified indoor climate regulation based on climate change (IPCC, 2014; Klimakommisionen, 2010). The increasing requests on

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science/engineering aspects add to the many other factors that need inclusion in the artistic design process of buildings. This in turn injects a series of predefined problems for the creative process, pointing to a problem-based approach to design. The development is not entirely new, nor is the knowledge that the earlier the different factors are considered in the design process, the larger potential positive impact they have on the outcome of the design (Ulrich & Pearson, 1993, p. 160).

Such knowledge pushes the tendency to include ever more evidence-based design parameters and related ideas in the early artistic, open and conceptual-based phases of design. The approach of early specific problem inclusion promises an increasing awareness of all facets and supports the idea of building-information modelling for the control of and argumentation for informed design decision making.

The approach of extensively informed design processes creates evidently comprehensive design models, typically aided by different software systems and computational methods (Kalay, 2006; Kolarevic, 2003; Kolarevic & Malkawi, 2005), enabled by growing computational handling power. While the technical issues of such systems mature and become more fluidly applied and robust in their functionality, a gap between the *free* conceptual-based design process and the problem-based *constrained* building information-based design process, which ideally should cross-inform each other, is identifiable (Bernal et al., 2015). Rather than becoming a means for better design proposals, the increasing integration of multitude parameter sets, which relates to a design problem, may halt the underlining processes towards the combination of systematic informed and unstructured—and at times impulsive—creative design processes. Nevertheless, it promotes the idea of an integrative approach, which is intended to facilitate a more comprehensive understanding of the complexity of design processes, and the making and maintenance of buildings.

Hence, from a design perspective, this suggests a study that furthers an understanding of relevant design approaches and how these become instrumental design methods, facilitating both technical demands and creative making. This offers us two questions of inquiry. What design approaches are relevant for the integration of technical aspects into creative processes? And, how can these approaches be made instrumental in design?

Methodology

To address these questions, this study employs a hybrid methods model, using literary studies, case studies, observation of students' design processes through supervision, observation of design progression through design schemas and a questionnaire, which asked students 20 questions on the topics of design knowledge, design processes and design tools.

The background on previous solutions is based on the observations from the literature of how designers work and think. These studies have not necessarily discussed and elaborated on the notion of problem-based integrated design processes. However, if we consider the term *integration* as based on the definition of complexity, which states that *differentiation* is the number and differences of elements, and *integration* is the relations between these elements (Weinstock, 2010), we may have an understanding of integrated design processes as something that approaches design through the relations established between design elements. This, from the outset, suggests that all design activities intrinsically are kinds and parts of integrated processes.

Design processes

Christopher Alexander's (1964) *Notes on the Synthesis of Form* explores how design elements can be related and how they can be logically structured so as to understand these relationships. Alexander argues further for such relations and processes of design, which strive for a holistic design outcome through *harmony-seeking computation* (which are just as much logical processes as digital computational systems) that is based on progressive adaptive iterations (Alexander, 2009). The central argument is the idea of *wholeness* in which design aspects are structured as morphological transformations around a composition that is achieved primarily from formal relations, such as scale, dimensions, symmetries and so forth. To capture design relations, as illustrated by Alexander, is to try to visualise through schematic diagrams the often complex structure of a design process, whether it is a serial branching or a non-linear web of ideas and solutions.

A diagrammatic and possibly simplified version of a semi-linear process is depicted by Bryan Lawson's pyramid (2006)(first published in 1990), which consists of an axiom *problem* that enters a three-part process of *evaluation-analysis-synthesis*, which proceeds to a *solution* to the problem. The looping nature between the three design activities takes part in shaping a central characteristic, that of iterative processes. The iterative process is additionally argued to increase the level of novel design decisions within a project, and not only the quantity of design proposals (Akin & Lin, 1995), which serves to cover a field of solutions by the making of design variations. Aligning this structure closely with a *problem-based-learning* idea, Mary-Ann Knudstrup (2004) illustrates a similar diagram starting with a *problem/idea*, which constructs the basis for *analysis*, then *sketching*, *synthesis* and lastly *presentation*. Each phase has return loops to the previous phase, just as *synthesis* can return to *analysis*. The design process organisation resembles that illustrated by Lawson.

Seemingly, rather than unveiling the mechanisms of design process actions in the proposed diagrams, as attempted by Alexander, these general design schemes appear to become idealised organisations to decrease and capture a more nuanced and less problem-oriented approach among designers. Nigel Cross states that, from his studies of expert designers, successful design outcomes are not driven by extensive problem analysis, hence providing another perspective than that of the axiom problem within the above schemes being the initial starting point (Cross, 2004, p. 439). Kees Dorst argues more unambiguously that a design problem is not knowable at any specific point and that, in principle, it is irrelevant in defining a problem (Dorst & Cross, 2001; Dorst, 2006, p. 16).

This intuitively challenges our understanding of working from a problem-based axiom that is defined within a problem formulation. This is when a project is initiated and directed in response to the formulation of a specific problem to be solved, specifically in the tradition of and studies conducted based on the PBL-method. However, it may also offer the possibility of reconceptualising what the problem *is* and how the problem is *understood* and *instrumentalised* as a vehicle for an idea and project to progress. Such considerations point to two conceptual frameworks for working with creative processes, wherein implicit and explicit problem framing and solution search processes are entangled. These are *systems-thinking* and *co-evolution* processes, as discussed below.

While the specific characterisation of a problem may be omitted in creative processes, such as within a more artistic and subjective-based design approach, certain instrumental structures are utilised in these processes. Cross suggests from his studies that expert designers attempt to apply a *systems-thinking* approach, which helps them to construct a *problem framing,* wherein they can apply the solution methods of *first principle*. This in turn allows them to employ a fast and progressive approach (Cross, 2002, p. 18). This indicates that *systems-thinking* is instrumental in the understanding of potential problem frame identification and its creative and artistic design solution conjectures.

Aligned with these propositions, Birger Sevaldson (2013) argues for the strategic integration of systems-thinking towards meeting real-world complexities, which inherently become part of design processes, rather than the implicit design activity that expert designers have posited. Consequently, Sevaldson states that systems-oriented designers are predominantly interested in looking at patterns of relations across vast fields, rather than creating hierarchical and boundary-based design processes, through methods such as GIGA-mapping that expose a multitude of design-influencing parameters (Sevaldson, 2011; 2013, p. 3). However, even if the intention of systems-thinking is not to construct hierarchies, it may nevertheless help to identify design aspects that are of central concern, and what their relations and boundaries are.

Even if designers generally do not apply systems-thinking consciously, this aligns with the notion that expert designers apply parallel processes of thought to explore different preliminary solution paths (Cross, 2004) and evaluate these continuously through mental simulations (Dogan & Nersessian, 2010) to better understand a design context. The structure of these cognitive design processes seems then to form the underlying design progression enabled by what Lawson (2004a) terms *design schemas*. These are patterns of organisation representing both design-specific elements, which could be of a physical and metaphysical nature, and their relations. Whereas structuring processes in a systems-thinking approach, as presented and discussed by Sevaldson and others., search and map a very large number of existing aspects, design schemas seem to search and map ‘non-existing’ aspects, or the output of the design cognition process. These are then reinstated as means for further design thinking. The relative structured process of both systems-thinking mapping and design-progression mapping support then the four design modes of *solution*-, *problem*-, *information*- and *knowledge*-oriented approaches (Cross, 2002; 2004; Kruger & Cross, 2006), with the former two being prevalent.

Cross’ studies suggest that designers apply various forms of design cognition and that a solution-oriented approach increases creativity, while a problem-oriented, or problem-based, approach increases quality. It is, however, less unambiguous which orientation can be considered more favourable when looking across different design tasks. A singular focus on either of the two dominant design activities appears thus to reduce the design process quality, which is supported by the statement that expert designers apply *co-evolution* processes (Dorst, 2007) that alternate between problem- and solution-based techniques.

The idea of co-evolution was originally described by Mary Lou Maher and Josiah Poon (1995, 1996) as a way to explore the parallel development of a problem- and solution-space through genetic algorithms, and its successful computational implementation can be meaningfully transferred to the nature of design-cognitive strategies.

Thus, problem-solution by co-evolution as a process marks itself as a ‘natural’ cognitive procedure in creative design processes. Nevertheless, both propositions of systems-thinking and co-evolution can immediately be understood as in contrast to the findings of *primary generators* in design recorded by Jane Darke, who published her paper, *The Primary Generator and the Design Process*, in 1978. In it, she outlines the relative singularity that expert designers apply within their process. This argument has been supported by the aforementioned Lawson (2004b, 2006) and Cross (2004) positing the apparently opposite behaviours in terms of vast non-targeted field searches as a creative and artistic approach to making. These approaches found among expert designers are singular design focal points towards a solution. However, the application of focal aspects, *primary generators*, are, as discussed by Cross above, based on a preliminary systems-thinking approach that filters and selects those factors that are primary for the creative design evolution.

From the above, a set of expert design processes appears essential. These processes apply both a problem- and solution-based approach (co-evolution) and are not necessarily focused on a given problem but rather on the exploration of aspects that frame a problem field. This appears paradoxically to be achieved through solution-based fast iterative processes of versioning, rather than the making of a large series of very different proposals. This points back to Alexander’s notions of *structured transformational morphologies*. Concerning the iterative design process, Michael Speaks (2002; 2006) argues that such procedures do not only advance a design proposal, as stated above, but equally increase processes of learning, what he refers to as *design intelligence*. This is central as making becomes a fundamental method of learning, which exceeds design fields into how humans generally develop deep knowledge, according to anthropologist Tim Ingold (2013). The objectives of iterative design procedures become therefore both to advance a specific creative design conjecture and to develop the ability to increase learning to construct other proposals in future design tasks. Speaks reciprocally problematises creative processes that are not based on iterative design, as these will lead to a lack of competence growth that prohibits future advancement and proficiency in solving similar creative design tasks.

From the literature discussed above, the creative design process applying both scientific and artistic modes of working, and which aims to create novel design contributions and extend design intelligence, is based on:

- Rapid iterative versioning procedures
- Co-evolution processes
- Primary generators to drive the process
- Design schemas structured potentially in the form of systems-thinking methods to capture complexity

A THREE-PHASED SEQUENTIAL PRIMARY GENERATORS DESIGN METHOD

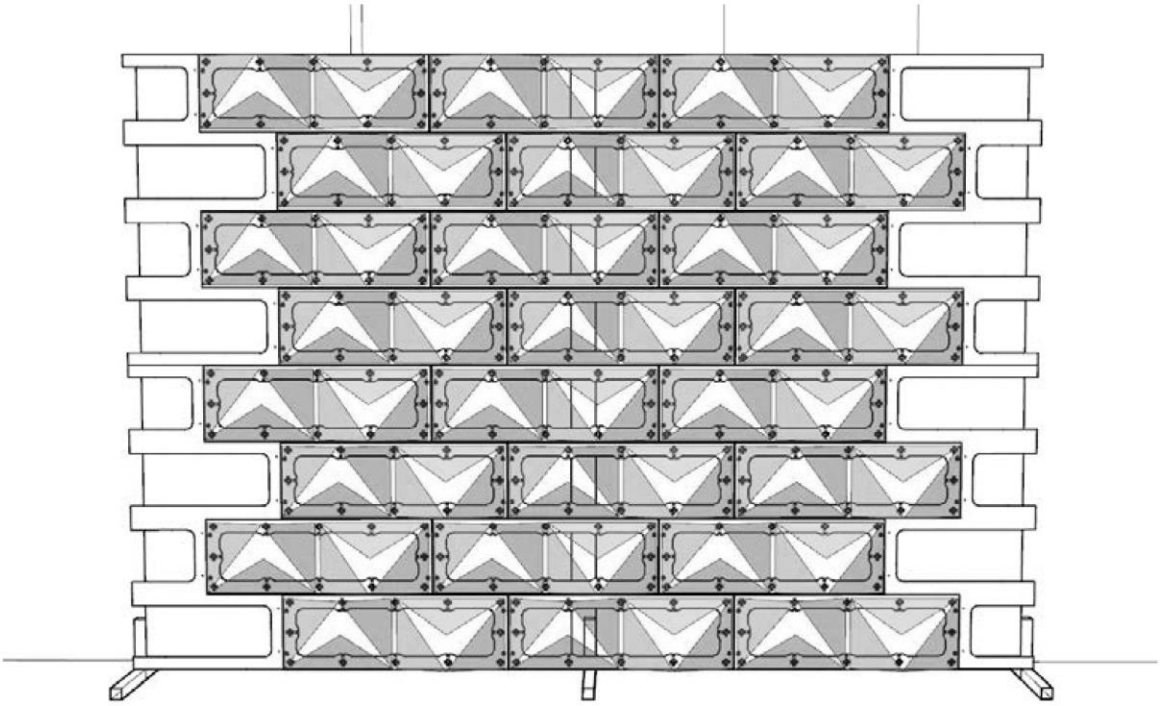
The background for a potential solution in advancing a new integrative design method is based on the four design process aspects listed above. In the educational setting of a university, where the objective of the course or project is open, such as the design of a large sustainable housing complex with a multitude of parameters, all four design strategies seem instrumental. In a more narrowly defined project, it can be proposed that an initial filtering of primary aspects to integrate may have taken place, omitting the vast search through systems-oriented methods. This, however, does not necessitate the exclusion of systems-thinking and design schemas in the iterative co-evolution processes driven by preselected (i.e. by the teacher in a pedagogical context) primary generators. The latter approach is the focus here and suggests integrated design processes through the application of *sequential primary generators*. From this, it is hypothesised that primary generators can be a strategic didactic approach to balance between the artistic conceptual clarity and building science integrative necessities in contemporary and future architecture and design while increasing design knowledge and design intelligence.

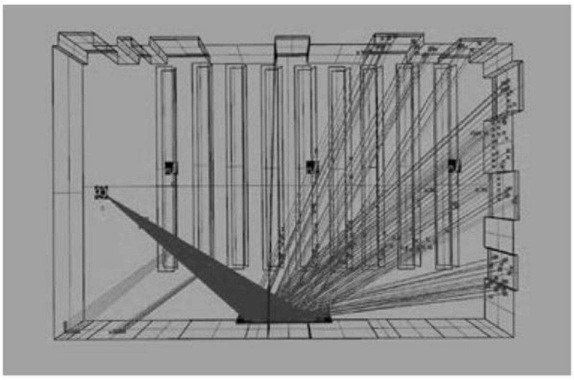
What is distinctively new is the idea and method of a sequential integration of primary generators, rather than the primary generator being maintained throughout the creative conjecture. In the case studies presented below, primary generators are based on a topic, that being tectonic-based architecture, aerodynamic tectonic-based architecture or acoustic tectonic based-architecture. Key aspects within these topics are then sequentially addressed in a three-phase design model, starting from a bottom-up approach, where an *Element* is developed, organised into a *System*, which then allows for the processes of *Formations*.

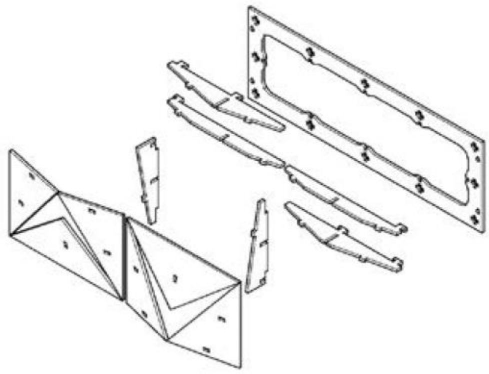
In the case studies presented, the attempt was made to apply the proposed fast iterative design process method, which is based on a sequential integration of primary generators. The context of the implementation was a university bachelor's and master's programme in architecture and engineering. The three design projects presented were three to four weeks in length, amounting to 13 to 18 working days. The period was separated into the above-mentioned design phases, and students were asked to create design proposals based upon a narrow set of primary generators related to the subject studied. Students were asked to develop three to five design proposals in each phase, thereby promoting the concept of a rapid succession of design development. Each design version was registered in a design schema (Figure 1), including artistic-, design- and science-oriented representations, such as hand drawings, physical models, textual descriptions and computational models and simulations if applied in the specific project.

Tectonic Studies and Experimentation // Sheet 2 // System ***2016***

Student: [redacted]







Since the last sheet the design has now been placed in a modular system, which reveals a horizontal repetitiveness and a subtle directional seriality along the vertical axis. The left and right sides of the panel are flipped in relation to each other, which makes it hard to determine each specific panel from the one next to it.

The concept behind the support structure is similar to the model pictured in Sheet 1, but it has since been modelled in Grasshopper, making it parametric. Each acoustic panel connects to the support structure through one or two mortise and tenon joints but are not otherwise connected attached to one another.

To make for a bit simpler analyzes, the variation of the panels has been limited to two factors – the protrusion of the triangles and the size of the gaps between them. Each half of the panel protrudes and shows as much as the other. The geometry allows the panels to spread sound and / or absorb it.

The aim of the acoustic simulations has been to analyze the results of different combinations between protrusion and opening. The result of the ray tracing shows an agreeable spreading to rows in the back of the lecture room.

The nature of the geometry makes it difficult to control the direction in which the sound is spread out.

Figure 1. A design schema showing different forms of documentation, representation and communication. The schema also serves to encourage students to reflect on the work produced through the 'reproduction' within the schemas.

Each phase was initiated with a short brief presenting the primary generators, followed by a short evaluation of each phase, discussing and concluding with design propositions. This served to clarify the necessity to stay within the prescribed theme and the primary generators applied to the specific design phase.

Furthermore, switching between design media, design modes and design focal points (primary generators) within the proposed design method strategically attempted to avoid *circumscribed thinking* ('A serious problem may be that the design ideas were limited not only to what is possible with a given tool, but what is easiest. In the case study, time pressures often forced the designers to generate intended designs in the easiest way possible'), *premature fixation* ('A resistance developed to ideas that would lead to too many changes to the model itself or to its underlying structure') and *bounded ideation* ('It seems that the mundane nature of drafting on a computer, exacerbated by technical problems and software bugs, is a distraction from the actual process of designing, and especially from idea generation and creative problem solving'), which have been detected as potential problematic issues when applying the computer as a design instrument (Robertson & Radcliffe, 2009, p. 137). It should be noted, however, in the critique presented by Robertson and Radcliffe, that such problems related to computation may be rooted in lack of experience with creative computational design processes and the requisite fluency for application in the creative processes of making. This discussion is further addressed later in the results and conclusion sections.

DESIGN METHOD APPLICATION

Following the introductory discussion and a partial conclusion on the four aspects that form the proposed integrated design process, and the general description of the proposed design method, the three design projects subjected to the method are briefly presented below. Of particular interest is the latter project, a survey conducted among students to obtain feedback on the creative process to determine design knowledge and design competencies growth based upon the proposed didactic model applied in all three projects.

The common design process model used was based on the above-mentioned three phases: *Element*, *System* and *Formation*. The intention was to segregate aspects to allow integration. This contradictory approach was based on the need to understand the separate aspects (differentiation) before they could be meaningfully combined (integration). And, importantly, it allowed one or a small number of primary generators, which gradually increased in number throughout the phases, thereby increasing the integration systematically.

An *element* can be, but is not limited to, a single geometric/material entity. It constitutes an elementary module. It is termed an *element* despite its potential multi-entity constellation, because any element, in principle, can be broken down into smaller entities. The primary generators for an *element* are typically material properties, geometrical definition and assembly logic (if comprising multiple entities).

A *system* is a cluster/assembly of *elements*. It describes how elements are combined and nested as a non-hierarchical or hierarchical system. The clustering of two *elements* is the minimum configuration, whereas the maximum depends on the constellation of the *element* to form potential complex *system*-level assemblies. The primary generators for a *system* are typically geometric definition, assembly logic and boundary conditions.

A *formation* is an organisation of *elements*, enabled by the *systems* definitions. A *formation* constitutes the entire organisation and is defined by the properties of the *element* and *system*. A *formation* is typically perceived in the architectural scale. The primary generators for a *formation* are typically environmental constructions and boundary conditions.

In essence, the *element*, *system* and *formation* structure is a nested organisation with different primary aspects situated within each level that, when combined, offers a creative mode, within a systematic and goal-oriented integration of aspects that define the architectural solution conjecture. It often follows a modular organisation, but is not limited to visual perceived modularity.

Case 1: Tectonic Studio

The *Tectonic Studio* is a master's programme studio carried out over four weeks, focusing on tectonics in architecture from a structural and joint detailing perspective. The design task was to propose a pedestrian bridge. It should be noted that structural integrity and exploration does not equal structural optimisation in this project. Students were not asked to perform calculations/simulations of the structural behaviour, but rather to work from *first principle* when freely generating proposals (Figure 2). The primary generators for the three phases were:

Element: Wood joint, wood material properties, rod material properties, geometric definition
Systems: Assembly logic, wood joints, structural force transfer
Formation: Bridge boundary conditions (landing), environmental influence (views and wind loads)

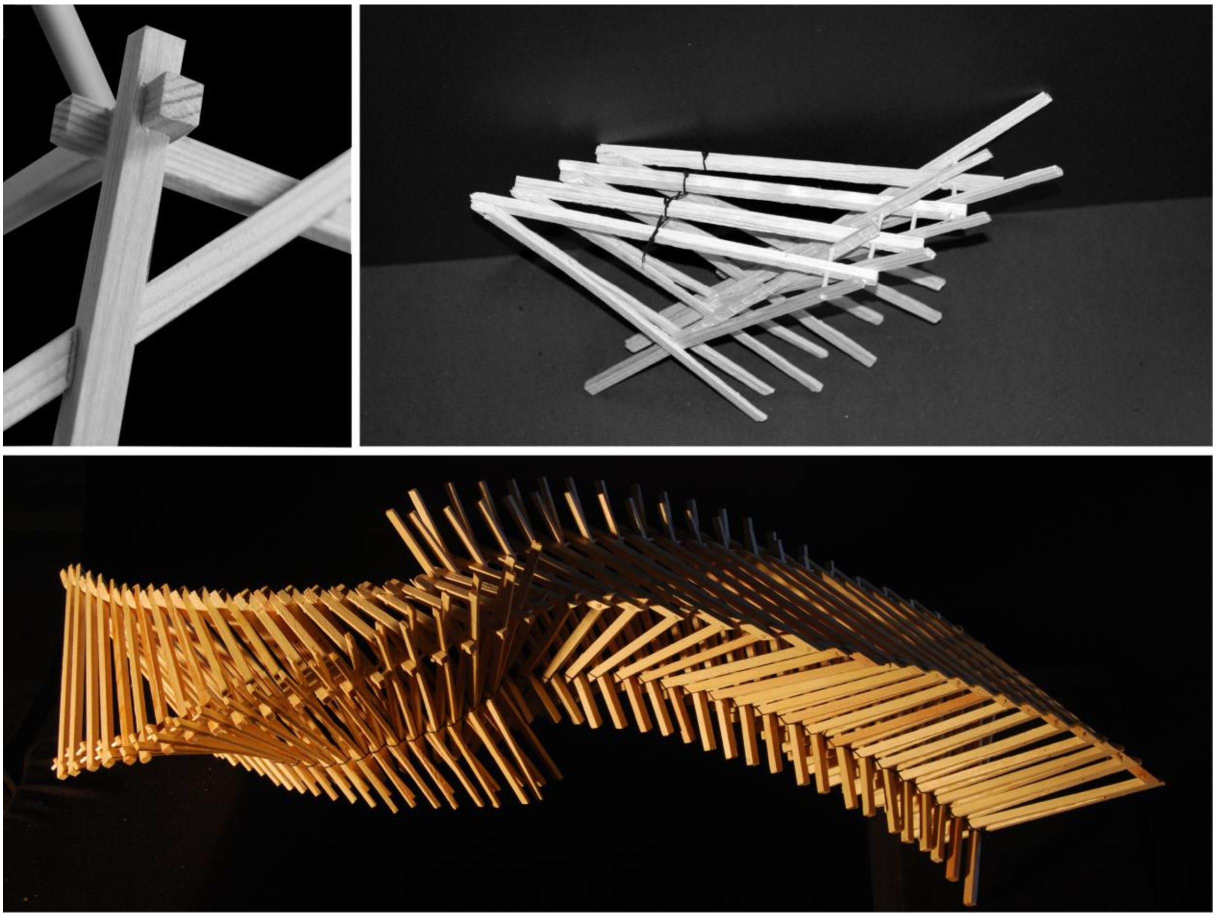


Figure 2. Three phases of the Tectonic Studio design process, moving from element *design, to* system *design, to full* formation *design. Photographs by student A and author.*

Case 2: Aero Tectonic Studio

The *Aero Tectonic Studio* is a bachelor's programme studio carried out over four weeks, focusing on tectonics in architecture from an aerodynamic and assembly logic perspective. The design task was to create a small shelter. Aerodynamic assessment was conducted in elementary physical experiments and in a wind tunnel constructed for the specific course, allowing studies in a 1:100 scale. The physical experiments served to increase the understanding of the aerodynamic complex phenomena, which in turn allowed informed design proposals (Figure 3). The primary generators for the three phases were:

Element: Geometric definition of planar wooden entities, local aerodynamic behaviour
Systems: Wood assembly logic, wood joints, structural force transfer, aerodynamic regional behaviour
Formation: Shelter boundary conditions (foundation), environmental influence (aerodynamic global behaviour)

Figure 3. Three phases of the Aero Tectonic Studio design process, gradually integrating primary generators that allow a final understanding and design proposal of complex aerodynamic behaviour in a fabricated planar plate with interlocking wood construction. Photographs by student B and author.

Case 3: Acoustic Tectonic Studio

The *Acoustic Tectonic Studio* is a master's programme studio carried out over three weeks, focusing on the tectonics in architecture from an acoustic and assembly logic perspective. The design task was to create an acoustic spatial enclosure with a student-defined acoustical phenomenon. Acoustic assessment was done through computational simulation and assembly logic was studied through physical 1:2 and 1:1 scale prototypes (Figure 4) and digital parametric modelling. The shift between media (physical and digital design making) was intended to circumscribe the issues that may arise in the singular computational-oriented design processes described (Robertson & Radcliffe, 2009). The primary generators for the three phases were:

Element: Wood joint, wood material properties, acoustic behaviour, geometric definition
Systems: Assembly logic, wood joints, structural force transfer
Formation: Space proportions, environmental influence (acoustic phenomena)

Figure 4. Acoustic Tectonics project pavilion derived from the proposed design process. The structure of elements, *which are organised in a* system *that allows* formations, *are detectable, yet the structure allows a plethora of design outcomes despite or due to its structured explorative process. Photographs by author.*

RESULTS

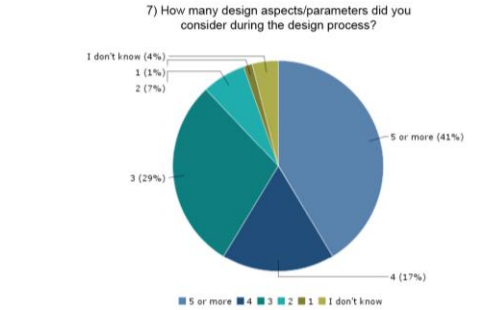
The design proposals and knowledge growth as a result of the proposed design method can be evaluated based on final design propositions, on the iterative processes and applied media registered in the design schemas and through the questionnaire survey.

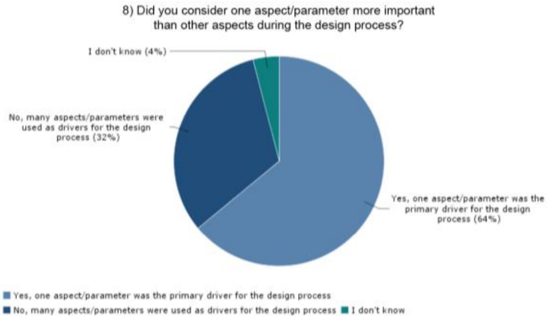
From the survey (Figure 5a, b, c), strong suggestions were registered concerning the relevance of the design method used and the use of integrating performance-based engineering aspects in early creative and artistic-oriented design phases. The number of students (74/95) responding to the survey amounted to 76 per cent. It shows that the use of parametric modelling and computational simulation techniques are key resources for achieving this. Only 1 per cent of students did not find it relevant to use digital parametric modelling in the creative architectural design process integrating engineering aspects and 85 per cent responded that the use of the techniques supported the creative process, with 32 per cent ranking ‘high support’. A high percentage, 78 per cent, stated that the difficulties with applying and integrating the techniques were based on lack of experience or knowledge of digital parametric modelling. This challenges the suggestions in the literature that computational design processes limit the creative process. It points towards the limitation perhaps being found in the lack of skills, knowledge and competencies in digital design processes, which would otherwise enable a similar fluency in the generation of creative conjectures to that of more common artistic methods of sketching/drafting and physical model building.

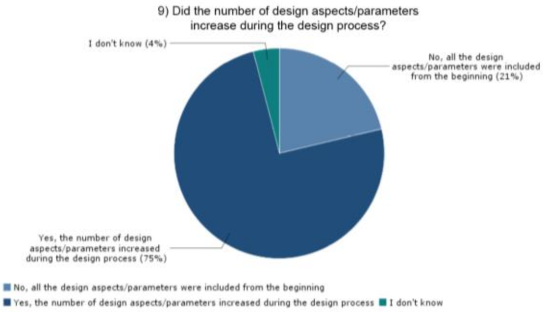
One problematic aspect associated with integrating complex phenomena into early iterative design phases, such as architectural acoustics, is the large set of parameters that simultaneously influence the design. In the literature, expert designers have been reported to immediately apply primary generators, limiting the large set, which directs the design process, based on an earlier systems-thinking approach. The integration of aspects is thus based on a rapid preselection of key parameters that, in turn, provides the basis for iterative versioning processes. The preselection of key aspects for the projects is intended to allow this iterative versioning procedure for novel design conjectures. With 86 per cent of the students following the prescribed design method of three phases, *Element*, *System* and *Formation*, and the use of the proposed primary generators in each of the three design phases, the design method applied appears to have supported this approach. Of the students surveyed, 69 per cent stated that early design iterations were increased, with 17 per cent reporting a ‘greatly increased’ number of design iterations towards design solutions. This number should be compared with the students’ prior experience with design processes at university that strongly focused on integrated creative design processes that emphasise upfront informed iterative design progression. This means that 58 per cent of the students created a minimum of seven design iterations, looping between physical sketching/model building, digital simulation and synthesis, in 12 working days. Also, it can be noted that 75 per cent responded that the design aspects/parameters (integration) increased throughout the design process. While this integration increased, 45 per cent maintained the same aspects as the primary generator.

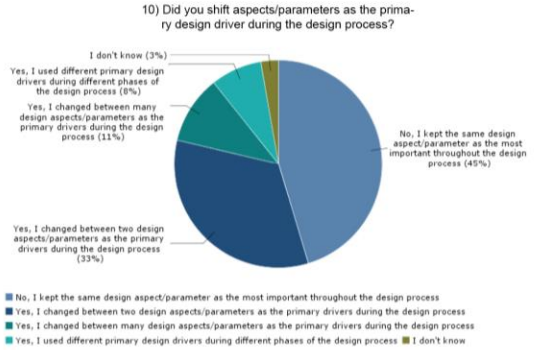
The sequential three-phased design process appears moreover to have increased knowledge, competence and skill level. Of the students surveyed, 90 per cent reported that their knowledge of parametric modelling had increased, and 91 per cent reported increasing their competences with parametric modelling. Knowledge of architectural acoustics increased for 83 per cent, and 96 per cent reported having increased their competences with acoustic simulations.

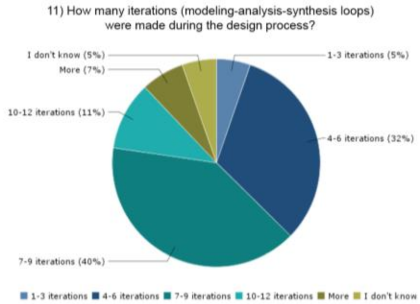
Design Process

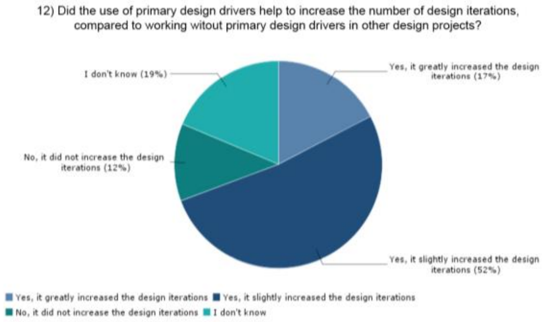


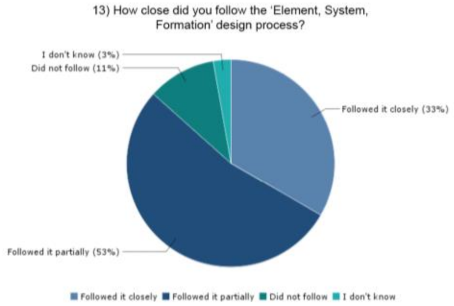












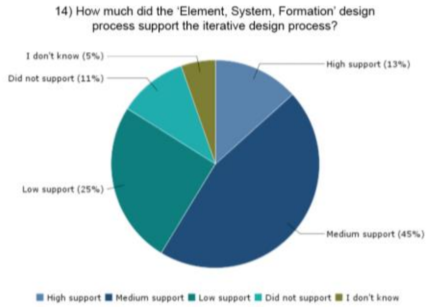


Figure 5a, b, c. Pie charts of the survey responses within the three questionnaire topics of Parametric Modelling, Design Process and Design Knowledge. Survey and graph figures by author.

DISCUSSION

Based on the responses obtained from the survey and the registered iterative processes in the design schemas, it can be concluded that the proposed design method: a) supports the complex integrative design process; b) increases the creative/artistic capacity in the design process; and c) increases the number of iterations towards novel design conjectures. Equally important in the learning context, the method appears to have d) significantly increased the design knowledge and design intelligence of the topics studied within the very short time frame of three to four weeks, lifting the students one to two levels on the Dreyfus scale. This suggests also that the described and tested method for creative processes is a possible approach to teaching practices in which both artistic and scientific aspects are part of the curricula as a cross-disciplinary and cross-methodological study, including PBL environments.

However, it is also noted that non-expert designers (such as students) appear to have difficulty in concentrating the creative process around a small set of primary generators, despite such an approach potentially reducing the initial complexity for design progression. This observation is particularly visible when the primary generators are not visually based, such as aerodynamics, acoustics or thermal factors. The design approach of primary generators is therefore not intuitively used in non-expert creative (design) processes, but arrives from either substantial experiences, as observed in the literature, or potentially through strategic training and didactics, as attempted in the three projects presented in this paper.

Accordingly, while the numbers from the survey clearly illustrate a measured positive impact on the students' work, merging problem- and solution-oriented creative processes, it was possible to identify through observations that students often struggled to adapt to a process in which they only were to focus on a few aspects at a time. Invariable, students occasionally lost focus and started considering many aspects irrelevant to the design task, leaving the design method, which reduced the ability to follow the design conjecture towards solutions, which in turn are used as a platform to identify new problems. As the numbers show, students grew accustomed to focusing on a few primary drivers, and with training increased the iterative design procedure towards better design propositions.

Also, the use of multi-method techniques (sketching, physical models, digital models, digital simulations, physical simulations, diagramming) appears to enable a better basis for creative exploration and design iterations. The identification of both solutions and problems appears to be more tangible when a design is assessed and generated. However, it also requires a focus on the development of different techniques that complement each other, as the lack of experience reduces the usefulness of a method that would enable new design insight for further design progression.

When evaluating the design schemas of the students, it became evident that visual aspects were dominant from the outset. A large majority of the first design iteration was based on the construct of multiple subelements that had little or no acoustic effect and were near impossible to build. However, as students started to study and apply acoustic and construction aspects based on the prescribed three-phase design method, the number of iterations grew and the quality of their design increased with respect to the subject studied.

While the greater number of iterations, compared with common, less-structured creative processes, raised the quality of the design, it was also noted that the focus on increased iterations induced a lack of thorough and critical design thinking during iterations. With respect to this observation, a focus on increased iteration processes must ensure an adequate time frame for assessment in the sketch-analyse-synthesise process, while maintaining focus on the progressive and relatively fast looping process between creative activities.

CONCLUSION

The context of the study and the results produced should be considered and ideally be applied and tested elsewhere to promote further conclusions on the design method. It speaks to the support of the studies conducted that the design method has been applied across several singularly defined projects, with different scientific thematic aspects, such as structural, acoustical, manufacturing and aerodynamic parameters, integrated into the creative design process model. The number of students, between 90 and 100 for each project, working from the method proposed is also considered high; moreover, the group of students comprises both local and international visiting students with prior educational training in architecture, design and engineering, representing a versatile population of students.

The research presented suggests a design method for creative integrated design processes and argues for its qualities and capacities additionally as a pedagogical method. Questions that may be addressed in future work include, but are not limited to, the following: Is there a conceptual limit to how many evidence-based aspects should (and could) be integrated in the early creative design process towards a design proposal? Are aspects/parameters ideally integrated in parallel or as serial-influencing generators? Is formal (visual) language always bi-primary to other primary integrated aspects? How instrumental are secondary and tertiary generators? What other creative methods could be sought to balance between artistic clarity in a design proposal and the increasing parameters that must be part of the design process?

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APPENDIX

Survey Questions

Parametric Modelling:
Q1: How many times have you used parametric modelling, such as Grasshopper, for a design task?
Q2: How difficult is it to use parametric modelling for a design task compared with hand sketching?
Q3: How difficult is it to use parametric modelling for a design task compared with physical model making?
Q4: Why do you find it is difficult to work with parametric modelling, such as Grasshopper?
Q5: How relevant is parametric modelling to the architectural-engineering design processes?
Q6: How much does parametric design support creative architectural-engineering design processes?

Design Process:
Q7: How many design aspects did you consider during the design process?
Q8: Did you consider one aspect more important than other aspects during the design process?
Q9: Did the number of design aspects increase during the design process?
Q10: Did you shift aspects as the primary design driver during the design process?
Q11: How many design iterations (modelling-analysis-synthesis loops) were made during the design process?
Q12: Did the use of primary design drivers help to increase the number of design iterations, compared with working without primary design drivers?
Q13: How closely did you follow the Element, System, Formation design process?
Q14: How much did the Element, System, Formation design process support the iterative design process?

Design Knowledge:
Q15: How much has your knowledge of architectural acoustics increased during the project?
Q16: How much have your skills in acoustic simulation increased during the project?
Q17: How much has your knowledge of parametric modelling increased during the project?
Q18: How much have your skills in parametric modelling increased during the project?
Q19: How much has your knowledge of experimental design processes increased during the project?
Q20: How much have your skills in architectural detailing increased during the project?