TOWARDS A TOOL FOR SCAFFOLDING DESIGN SYNTHESIS

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ABSTRACT
Many design tools support ideation and other divergent design activities. Design synthesis is a core design activity that is often under-supported. Students find it particularly challenging to integrate disparate design insights into coherent design concepts. This paper presents the ongoing development and testing of a guided synthesis tool that intends to support this type of thinking. The tool aims to help students make explicit connections among different kinds of design knowledge and to structure their reasoning in the early stages of concept generation, laying the groundwork for later phases of detailed design and design justification.
The paper discusses several versions of the tools and their evaluation with students from diverse disciplinary backgrounds. Although the prototypes received positive feedback, we are still improving our understanding of how teachers can support students in coherently developing design synthesis, design argumentation, and design rationale. Early feedback suggests that our approach of combining different types of knowledge and design reasoning is promising, but supporting the actual moment of synthesis remains a challenge.

Keywords: Design synthesis, design reasoning, concept generation

1 INTRODUCTION
The study reported in this paper is part of a larger project to develop several design tools for converging phases of design. This paper reports on a tool that focuses on the phase in which initial insights, ideas, and requirements are combined into an initial concept. We see design tools as a way to scaffold certain types of design reasoning. The idea is that the tool supports students in organising information in a certain way or taking certain steps in their reasoning process. The tools are designed to guide design students and non-design students who work on designing new solutions through a synthesis process. The tool is meant to encourage students to make their motivation explicit and to provide a structure for them to act in a particular way towards a design challenge. Over time, it is expected that students will internalise these thinking patterns and adapt this way of thinking flexibly to novel situations [1,2].
Synthesis is a vital design reasoning skill that is challenging, in particular for students with little design experience [3,4]. While divergent thinking is well supported by a wide range of brainstorming and ideation tools, synthetic (or convergent) thinking is hardly supported. Students find it hard to formulate ideas that elegantly address a wide range of demands. This plays out at different stages of the design: formulating a problem statement based on divergent needs, formulating a concept from bits and pieces collected at the beginning of a project, or creating a detailed design that meets all the implicit promises embedded in the concept. Strangely enough, there seem to be few concrete tools and techniques available to support these synthesis steps. To give an impression: [5] feature 27 diverging techniques and only 6 converging techniques. Furthermore, most convergent techniques are decision-making tools, such as multi-criteria decision-making, rather than tools for combining ideas into novel ones. An exception is [6], which offers methods such as 'double down', in which designers are challenged to add 'one' element of an alternative design to their solution; or 'hidden gem', in which designers are invited to combine elements of existing solutions into novel ones.

In this paper, we report on the development of a guided synthesis tool for concept development. Our quest has been to investigate how we could scaffold integrative thinking in the concept generation step. We wanted students to do this in a way that would make integrative thinking a stepping stone towards articulating a design rationale in subsequent stages of the design process. The first step toward achieving this was to review materials on design argumentation and use them as the basis for a concept-creation tool. In this paper, we discuss the iterative development of the tool across several versions, report on student and expert evaluations, and reflect on the potential and limitations of our approach so far.

2 RELATED WORKS

We consider design synthesis to be the creative process of integrating research insights, constraints, ideas, and other information into coherent design directions or solutions. In contrast to analysis, synthesis brings elements together rather than breaking them apart. Different authors emphasise different elements of design synthesis, such as abductive reasoning [7], reframing problems [8], combining disparate inputs [9], and generating structured concepts that guide design decisions [7].

Most writers agree that synthesis is hard to teach [3,4,7]. Therefore, a core question is how to scaffold it. Several suggestions have been made in the literature, such as using concrete scenarios [11] or supporting students in structuring information to benefit synthesis [7,9,10]. Our approach aligns with these writings. We can encourage synthetic thinking by helping students to organise information in ways that lower the threshold for synthesis and by combining this with an explicit invitation to piece things together (like in [6]).

To answer the question of what type of generic structure might help, we examined work on articulating design decisions [12], design rationale [13], and design knowledge [14,15]. The idea was that the type of arguments one uses to convince stakeholders of a design might also form a good basis for design synthesis. The side effect, apart from supporting synthesis, could be that the tool would prepare students to argue for their designs. In the end, a taxonomy of theory functions in design appeared to be the most promising venture point [14,15]. Bringing together many sources on design reasoning and knowledge, such as [16][17], the authors suggest that there are three types of knowledge involved in design, each involving its own type of reasoning: a) an analysis of the current situation in terms of cause and effects, |is|, b) an examination of the desired situation defined in terms of ends and means, |could|, and c) an examination of the desired situation defined in terms of mechanisms, effects and outcomes, |will|. All three types of knowledge are generated or mobilised during the design process and used for developing the final solution. Table 1 provides an overview of the three types of knowledge, their corresponding argumentation patterns, and their knowledge functions.

Table 1. Three types of design knowledge and corresponding questions, adapted from [14]

Type of knowledge, knowledge functions	Goal within the design process and argumentation patterns	Questions to gain this type of knowledge
|is| > Diagnostic knowledge (description, explanation)	Analyse the current situation, causes, and effects	What is happening? What are its causes? What are the effects now and later?
|could| > goal-oriented knowledge (generation, aspiration)	Explore and generate goals, design criteria, and solution concepts. Formulate means-ends propositions.	What are the main design aspirations for the solution, according to relevant stakeholders or external aesthetic or ethical frameworks? What are possible and desirable solution concepts?
|will| > result-oriented knowledge (prediction, prescription)	Enhancing and improving the solution concept into a final design	How can we improve our design? What works, and why?

Not all types of knowledge are equally important in each phase of the design process, but in the concept development phase, designers typically iterate quickly across all types of design knowledge. An innovative solution concept includes knowledge of a) what is the case now, and why; b) what kind of solution concepts could be desirable in terms of contributing to design goals and criteria of all stakeholders; and c) what effective social and technical mechanisms and design patterns could help realise the proposed solution. We consider these types of knowledge and argumentation as intrinsically complementary. Our idea was that if we used the taxonomy of knowledge functions in design [14,15] as the basis for a new design tool, it could provide both a structure for synthesis and preparation for design argumentation. The guiding questions in Table 1 can serve both ends.

3 TOWARDS A SYNTHESIS TOOL

The tool was developed in a series of seven design iterations. In each iteration, the tool was a) refined based on the feedback on the last version, b) tested in a class of students or by a panel of experts in design education, and c) evaluated in a standardised manner. Four iterations followed tests with students; three were done based on teacher and expert feedback. Students in the test group were typically from different backgrounds, such as economics or the humanities, and used the tool in their design thinking class. We used convenience sampling, meaning the tool was tested in classes that we happened to teach at the time of the test. In both expert and student evaluation the respondents were asked to fill out a form with five questions based on the E2R evaluation approach [18]: a) what worked for you in using this tool?, b) what would you want more from the tool?, c) what can be improved?, d) if you could choose why would you use this tool rather than a different one?, e) if you would grade this tool on a scale from 1-10, what would it be?. The researcher who administered the test summarised the answers to these questions, leading to changes in the next version.

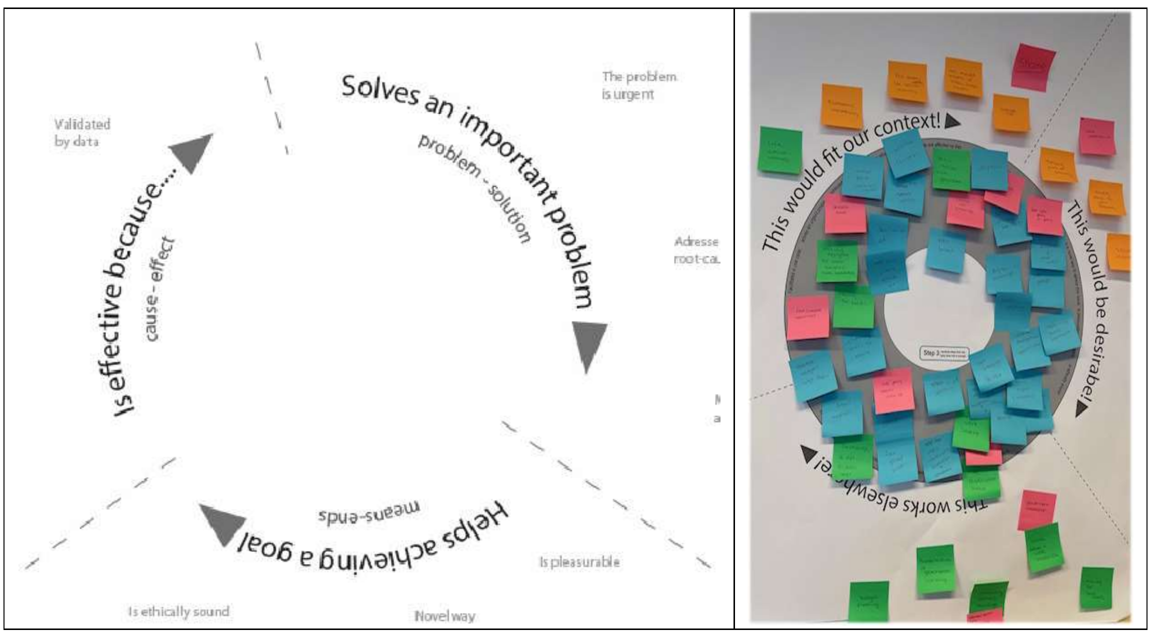

Figure 1. Depiction of the first version of the tool (left) and the 7th version in use (right)

Figure 1 depicts the first version of our tool. It consists of an idea circle with three segments corresponding to the three types of knowledge: |is|, |could|, and |will|, and the main reasoning styles corresponding to that: problem – solutions, means-ends, and problem-solutions. We also put prompts taken from [12] for each segment to further aid the brainstorms of the students: (a) the design facilitates a use case, (b) the problem the design solves is urgent, (c) the problem addresses a 'root cause', (d) many people may be affected by this, (e) the design is pleasurable, (f) the design addresses the problem in a novel way, (g) the design has positive side-effects, (h) the design is ethically sound, (i) the design addresses a real need, (j) the design is elegant, (k) the design meets a standard, (l) the design is validated by data, (m) the design uses tried and tested means, (n) the design ideas are supported by research. After an open brainstorm, students were invited to (a) organise their ideas on sticky notes into the three segments on the outer circle, (b) synthesise them by picking one from each segment, and (c) combine them into a concept. The idea behind this was that every good idea has a hook in the real world (i.e. solves an important problem), meets aspirations of its users (i.e. helps people to achieve a goal), and uses effective means to do so. Figure 2 depicts the development of the tool so far and students' feedback on different versions. Each line depicts a key feedback point (i.e. organising ideas in the top line). The thickness of the dot suggests how many students gave this feedback (i.e. also in later iterations).

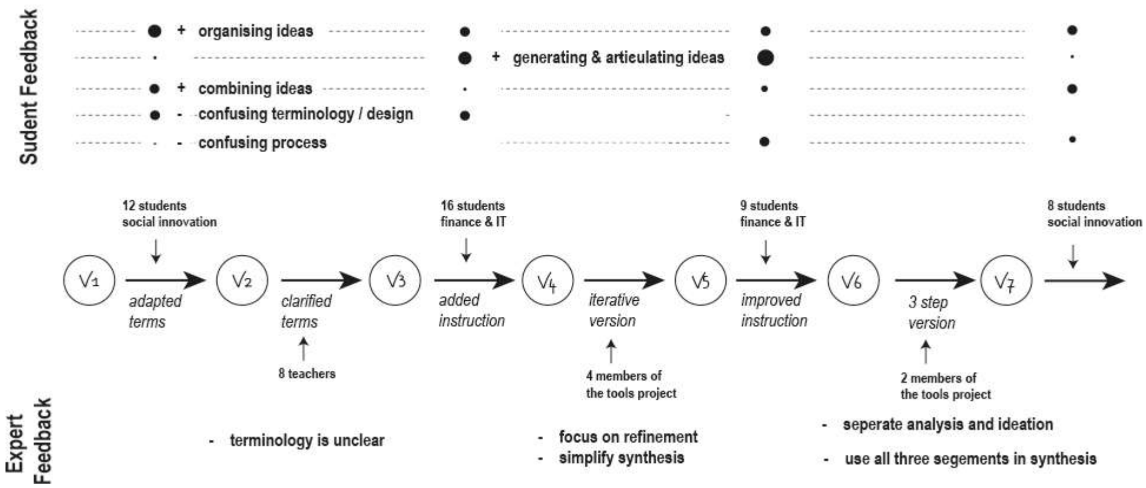

Figure 2. Depiction of the iterative design process and the feedback of experts and students

The *first* version was tested with 12 3rd-year bachelor's students in a social innovation course. The students appreciated the tool for helping them organise, combine, and articulate their ideas. However, they found the terminology confusing and the distinction between the segments unclear. For example, many ideas would solve users' problems by helping them achieve a goal, so they would not necessarily see these segments as different.

In the *second iteration*, we therefore adapted the segment terminology to be more engaging and distinctive: ‘this helps’, ‘we want this’, and ‘this works elsewhere’. The other prompts remained the same. This was evaluated by an expert panel of 8 teachers, who were positive about the tool but suggested adding more instructions and a box outlining boundary conditions or requirements for the design.

In the *third iteration*, the tool was tested with minor adjustments to terminology and improved instructions with 20 3rd-year bachelor students in a design minor in finance and IT. As in the first test, students praised the tool for helping them organise their ideas and for its collaborative nature. They specifically praised the tool's collaborative use and the encouragement to combine best practices with their own ideas. Apparently, the clarification of terminology had put them on this track.

In the *fourth iteration*, a panel of design education experts suggested the tool could be adapted to invite design iterations. The idea was that, rather than a static worksheet, the sheet could be used multiple times, with each version refining the design idea. The ‘we want this’ section was simplified by asking students to write down their main design challenge in this segment. Next, they could write down existing products and practices in the ‘this works elsewhere’ section and ideas for their particular challenge in ‘this helps here’ section. The following step was to synthesise ideas for a new design from an existing product or practice and one of their own ideas. The prompts were replaced with instructions to clarify this new procedure.

Based on this, the *fifth version* was tested among 10 students a design minor in finance and IT. The feedback was similar to that in the first and third iterations. Also, the students suggested that the separate steps needed clarification.

In the *sixth iteration*, two experts evaluated the tool and noted that versions 4 and 5 had taken a slightly different direction from the original tool. In particular, the simplifications to support an iterative mode had the side effect of reducing the different needs, wishes, and aspirations that may guide a design to a single, refined design, thus narrowing the design's aspirational space. Put differently, the |could| information was fixed to a specific design goal rather than mapped as an open space for exploration. The experts felt this fixation might be inappropriate in this stage of the design. Therefore, we created a new version of the tool. This version was the same as the tool that was used in the first 3 iterations, but with clarified terminology and a 3-step process: a) analysis according to the 3 segments of the tool, b) a synthetic brainstorm by combining elements from 2 segments, and c) concept creation by combining multiple ideas from the synthetic brainstorm. These steps were visually depicted as 3 concentric circles (Figure 1, right side).

For this *seventh version,* students praised the structured way of working and the geometrical support for that (working from the outer fringes to the centre). However, they needed guiding questions for the analysis phase, asked us to clarify the terminology further, and they requested guidance in the last open synthesis step.

Across these iterations, students consistently suggested that the tool helped them organise, generate, and combine ideas. They felt particularly encouraged to combine existing ideas with their own. In general, students' feedback was consistent but not very specific about how the tool helped combine ideas. Additional work will be needed to determine more precisely how different versions support synthesis. Over iterations, the terminology became less of an issue, suggesting that our clarifications worked, but occasionally students continued to report overlap between the segments. Versions 3-5, in which we simplified the tool into a synthesis of existing ideas, were conceived more as brainstorming tools, whereas versions 1 and 7 were perceived more as organisers. Many of the changes we made were based on the expert feedback, since they focused more specifically on our rationale for supporting synthesis.

4 CONCLUSION AND DISCUSSION

In this paper, we have reported on the ongoing development of a guided synthesis tool. The core idea has been that design synthesis is challenging for students, and concrete tools that support synthesis in design may scaffold the development of synthetic design skills. Our venture point in designing such support has been that students could be helped by deliberately combining elements from different types of design knowledge: (a) relating to the current situation is one is designing for, |is|, (b) the imagined possibilities and aspirations for the design, |could| - or (c) knowledge about what works and why, |will|. The reasoning for this choice was two-fold. First, we believed that synthesis would be easier if the elements being combined were inherently complementary. Second, we believed this structure could be reused in later phases when students need to articulate a rationale for their decisions. Across the four student evaluations and the three experts' evaluations, there was support for this basic venture point of the design. Students claimed that the tool helped them to combine ideas and encouraged them to look at the design from different angles. This was probably reinforced by the tool's geometry: working from the outside towards the middle of the circle signalled that students needed to piece things together. Although we are positive about using |is|, |could|, and |will| as starting points for design synthesis, students did not always immediately grasp the differences among these sections. Simplifying the terminology has helped a lot, but we are still exploring other ways to make this more natural for students.

A second consideration is that the tool places equal emphasis on the three types of knowledge, whereas one could argue that, in different phases of design, these types may not play equally dominant roles. Tools that support synthesis in the detailed design phase might need a structure in which |will| knowledge plays a greater role. Our versions 4, 5, and 6 had such a bias, although we returned to a more even treatment of all three knowledge types in later versions. We are still exploring how the different tools we are developing in our project can be linked to help students place the right emphasis at the right time. During the seven iterations, the tool's focus has shifted back and forth between a concept-creation tool, in which students dream up concepts from the materials they collected, and a concept-development tool, in which students iteratively refine concepts they already have. We see opportunities to split these versions into separate tools with these dedicated goals. In that case, using the same underlying structure might help students who use them in sequence.

So far, the project has delivered valuable insights into how design synthesis can be supported in practice. However, it is worth acknowledging that the actual moment of synthesis remains somewhat elusive. It is an open question whether the different versions of our tool really scaffold synthetic thinking more effectively than existing tools. Such claims would require us to refine our evaluation methodology quite drastically [20]. In the student evaluations in our setup, most information was provided on the tool's usability, but less on its effectiveness. That is a lot to ask from a beginning designer: to learn about synthesis and reflect on a tool's contribution to this activity at the same time. Moreover, the evaluation is quite global. Other methods, like think-aloud protocols, could be more informative. These limitations do not degrade the value of our work. As teachers, we are confident in saying that using our tools in class creates a context in which students feel encouraged and safe to *try* synthesis. For our educational context, this is already quite a leap. To gain more insight into how a synthesis tool can help converge after ideation and make design choices explicit, we plan to conduct additional research. To this end, we will observe students across the various phases of a design project.

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