

# In search of lost materiality; the case for physical modelling in Industrial Design Engineering education

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## **Abstract**

Over the recent years, Industrial Design Engineering students at Linköping University have frequently been observed to go directly from sketches into CAD, without making simple sketch models for evaluation in the early stages of their design process. This workflow gives them less information in their decision-making process and they lose the materiality of physical models, which is an aspect that many designers and researchers consider crucial for the development of form. This discussion paper explores whether this is an increasing trend and if so how it affects the breadth of design space exploration. In total, 25 master theses, covering a period of nine years, on Design and Product Development from Linköping University have been analysed. The design representations used and the diversity of the ideas across the product development process were visualized in graphs. This mapping supports our preliminary observation that the use of physical models is declining and suggests this decline correlates to a narrower exploration of the design space.

***Keywords: Education, ideation, materiality, low fidelity prototypes, creativity***

## **1 Introduction**

“You are missing the materiality!” That was the general argument at a recent conference with Nordic designers, artists and design teachers, where the main author discussed the idea of sketching and ideating in 3D space as an alternative way of ideation. They were, as you may have gathered, rather sceptical and argued that the materiality of physical models is essential to design and that the feeling of touching and interacting with an object is irreplaceable. Since we live in a physical world, we therefore require physical interaction when developing new products. However, at Linköping University, we have observed that our students frequently use simple sketches on paper as the sole basis for their concept selection, after which they directly model it in CAD. Thus, they are not getting the physical interaction that the designers and artists deem so important. As most designs being created by Industrial Design Engineers

are three-dimensional, only using two dimensional sketches for evaluating the concepts might affect both the ideation and the subsequent result.

## 1.1 Design representations

The externalisation of thoughts (Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998) is a key feature in design practice. The use of design representations is essential as they can aid processes that cannot be done in the mind's eye alone. The choice of representation comes down to tradition within a field, personal preference and efficiency, that is the time and effort it takes to create the representation. The use of physical models has a long history in design and has been used to communicate between the designer and the client or construction workers hundreds of years before CAD models. Examples are the building of the dome of the Florence cathedral in 1418 or the moving of the Vatican obelisk in 1585 (Ferguson, 1994). Apart from communicating the design idea, physical models can be used to validate ideas (Huizinga, Van Ostaijen, & Van Oosten Slingeland, 2002; Lemons, Carberry, Swan, Jarvin, & Rogers, 2010; Viswanathan & Linsey, 2012) and inspire new ideas (Kelley, 2001).

The introduction gives anecdotal support for the importance of materiality, to have something tangible to interact with to get a feel for the product, which serves both as a validation that the design corresponds to the intended vision as well as a way of triggering new ideas. Just like sketching, model making can be thought of as a design language, in the sense that it represents and embodies design thought (Yang, 2005). This opens up the possibilities for reflective conversation (Schön, 1995) with the material. Kelley (2001) provides anecdotal evidence for the notion that the process of making models can lead to “accidental discoveries”, creating new possibilities and unlocking new ideas. In agreement with this, Viswanathan & Linsey (2012) found significantly more functional ideas when allowing engineering students to build and test their ideas compared to only sketching. Further, Häggman et al (2015) found that designs made with physical models were perceived as having higher novelty than designs created using sketching or CAD, which they link to rough models allowing a broader exploration of the design space. In the same study, they found that foam models were rated top for creativity and aesthetics while CAD correlated with low creativity. Low-fi physical models have also been shown to support a sense of forward progress and strengthens beliefs about creative ability (Gerber, Carroll, Sass, & Oxman, 2012).

The use of physical models to find errors in ideas has been reported by several authors (Huizinga et al., 2002; Lemons et al., 2010; Viswanathan & Linsey, 2012). When exploring virtual testing in the automotive industry, Huizinga et al (Huizinga et al., 2002) warns that relying solely on computer aided engineering tools in the design process can result in flaws that are not discovered until much later in the process. Further, Yang (Yang, 2005) argues that the design information gained in process of creating physical models often cannot be obtained by any alternative design representation, using the different design information gained from a CAD model and physically cutting metal as an example.

Creating physical models requires considerably more knowledge of materials and techniques than a simple sketch on paper, which is why it is often claimed to take more time compared to sketching (Yang, 2005). However, Häggman et al (2015) found that foam prototyping resulted in faster generation of ideas than sketching or CAD. While the latter should not come to any surprise, models being faster than sketches is a quite interesting result. However, in their experiment, the sketchers created detailed sketches while the physical modellers created fast low fidelity models which could explain the surprising results.

## 2 Method

The purpose of this paper is to explore if the use of physical models affects design space exploration. To this end, a document research method was chosen and finished master theses were selected for analysis. This allows a wider sample of works as opposed to following a single master thesis work and documenting their work process. However, the drawbacks are that the theses might not be a true account of their process and it requires the researchers to interpret the written material.

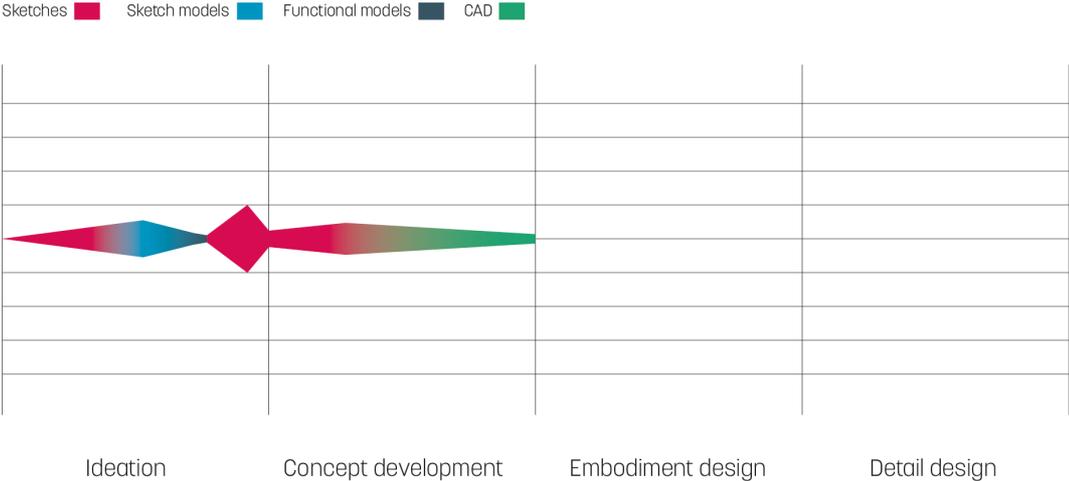
Theses with a focus on design and product development were selected from the pool of master theses that were supervised at the department of Machine Design at Linköping University between 2008 and 2017. Out of these, 25 theses with a clear focus on developing a product were selected for the study. The theses were read through several times and the design representations used before settling on a final design for the product were sorted into five different categories. The framework used for the categorization was ID cards, a taxonomy of design representations developed by Eujin Pei (2009). The categories used in this study and the corresponding card from the ID cards are listed in Table 1 below. As the focus of the study was to investigate the use of different design representations, the many different kinds of sketches were grouped together into *Sketches*. This category includes all kinds of two dimensional sketches, regardless of media used to produce them. The ID cards taxonomy only includes manual design representations, which is why there are no corresponding cards for the CAD category. However, the *CAD* category in this study includes all kinds of 3D CAD software used for ideation. The category *Other* included all design representations that could not be sorted in any other of the categories.

Table 1: Category and corresponding ID card

Category	ID card(s)
Sketches	Idea sketch, study sketch, referential sketch, memory sketch, coded sketch, information sketch, sketch rendering and prescriptive sketch.
Sketch models	Sketch model, Design development model
Functional model	Functional model
CAD	No corresponding card
Other	No corresponding card

Many models of the design process contain three or more phases (British Design Council, 2005) where the first one is clarification and/or ideation, followed by development, and detail design. This study uses the concept of four phases. For the purpose of this paper, the first phase is called *ideation* and is defined as the activities before a number of concept are being chosen as the main ideas to proceed with. In most cases the students have made this distinction themselves by naming the chapters accordingly. The second phase, *concept development*, is defined as the activities after ideation and before one final concept has been chosen. These two phases are chosen for study as all theses, regardless of the aim and the expected final result, have selected one concept as the final one and thus completed the two first phases. The two latter phases, *embodiment* and *detail design*, are included in the graphs but not studied as almost half of the theses in this study had the goal of developing a concept, which only takes them through the two first phases.

For comparison, the design representations used in the two phases and the diversity of the visualized ideas and concepts was mapped into graphs with different colors for the design representations and the height of the graph depicting the approximal diversity of the ideas. An example is shown in Figure 1 below. The diversity was collected by counting every unique idea visualized in each thesis. The width of the colored sections in the graphs is an arbitrary measurement, made by the main author, of the focus this design representation got in the thesis and does not indicate the time spent on each design representation. In theses where there are several parts that are being developed separately, only the ideation and concept development of the main part is presented in the graphs.



**Figure 1: Example of a graph showing design representations used (color) and diversity of ideas (height of graph).**

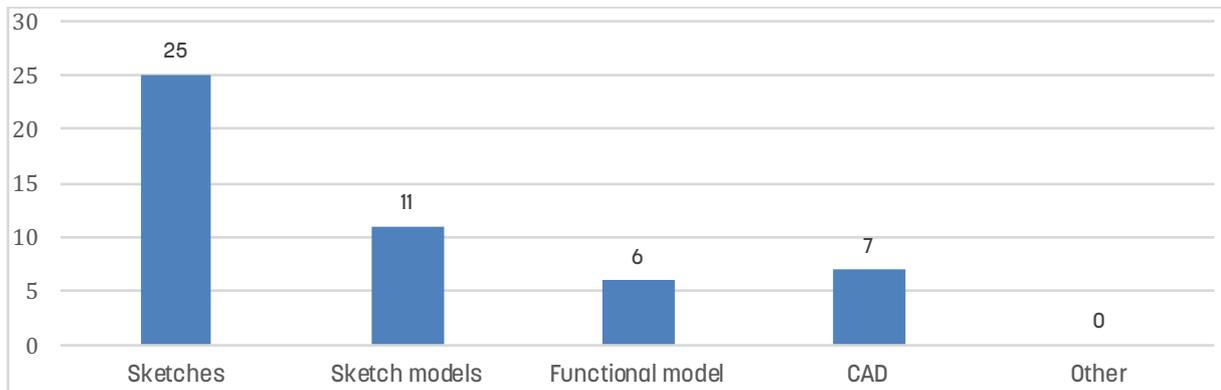
The graphs were also put on top of each other and the opacity was lowered to produce a graphical representation of the mean value of the diversity and design representation usage. This is shown in Figure 7.

### 3 Results

A total of 25 theses were used in the study. The theses all follow a similar pattern where they begin ideation using simple sketches or sketch models, which is not surprising as they were all working according to the design processes of Ulrich & Eppinger (2008) and Delft Design Guide (Van Boeijen, A., Daalhuizen, J., Zijlstra, J., & Van der Schoor, 2014). When enough ideas have been created, a selection takes place where a smaller number of ideas are chosen to go into the concept development phase. Here, the ideas are developed into actual concepts using sketches, models and/or CAD. The final concept is then selected using either concept screening or concept scoring (Ulrich & Eppinger, 2008), or both, often inviting the company to help decide which concept is going to be the final one.

All of them (100%) used sketching for ideation. Sketch models were used in 11 theses (44%), functional models in 6 (24%) and CAD in 7 (28%). No other design representations were found. Further, in 10 theses (40%) sketches were the only design representation used to decide on the final concept.

**Table 2: Design representation use in all theses**



Below are graphical visualization (graphs) of the design representations used. The colour shows what the design representation was used and the diversity of ideas is indicated by the height of the graph. The first image shows them all sorted chronologically from top left to bottom right. The subsequent four images, Figures Figure 2-Figure 6 shows the graphs sorted by how many different design representations were used. Following that, Figure 7 shows the graphs stacked with lowered opacity to produce a graphical mean value. All graphs have four phases, but as only the two first phases are of interest for this study, the two last are blank.

Sketches ■ Sketch models ■ Functional models ■ CAD ■

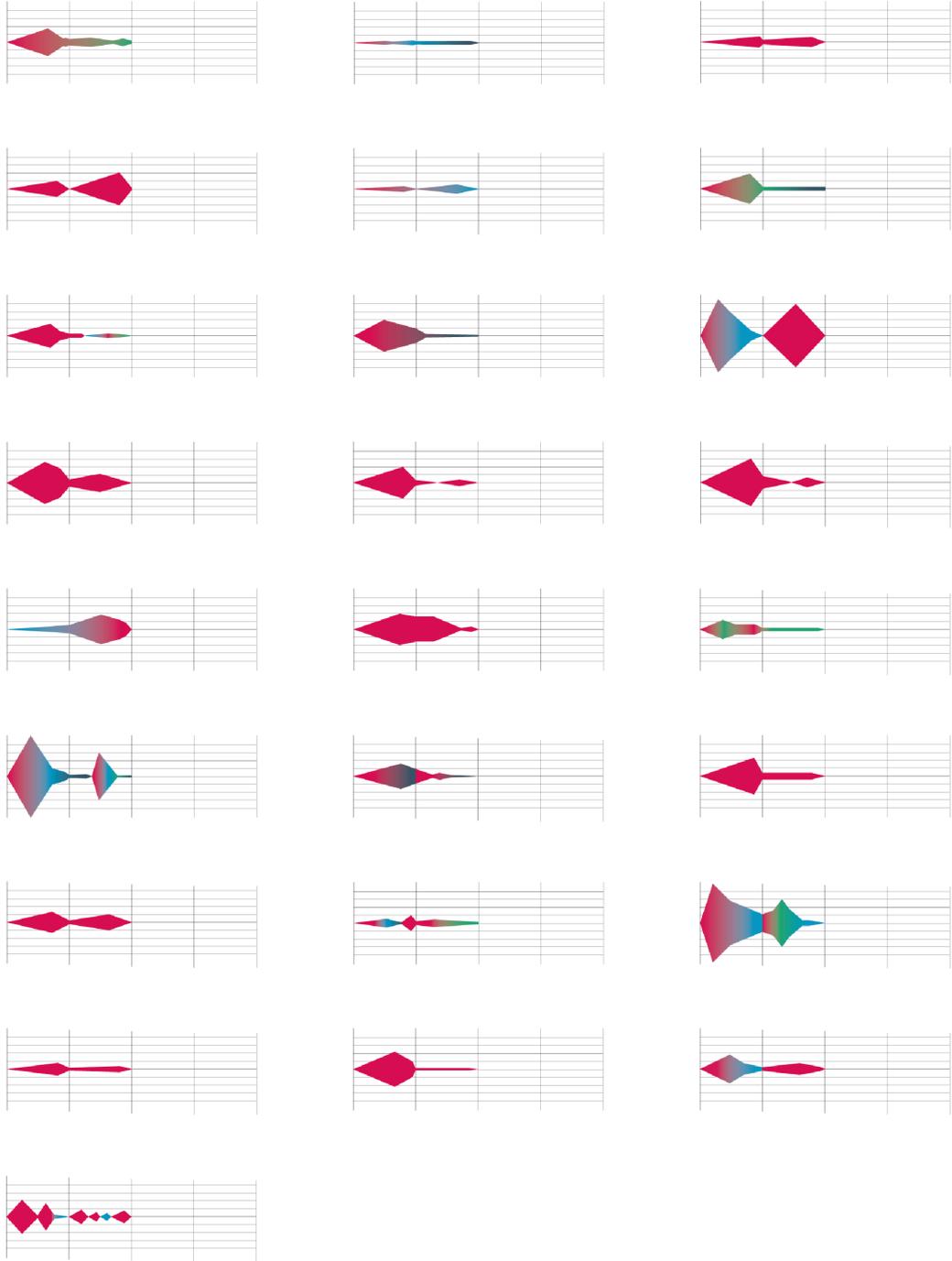
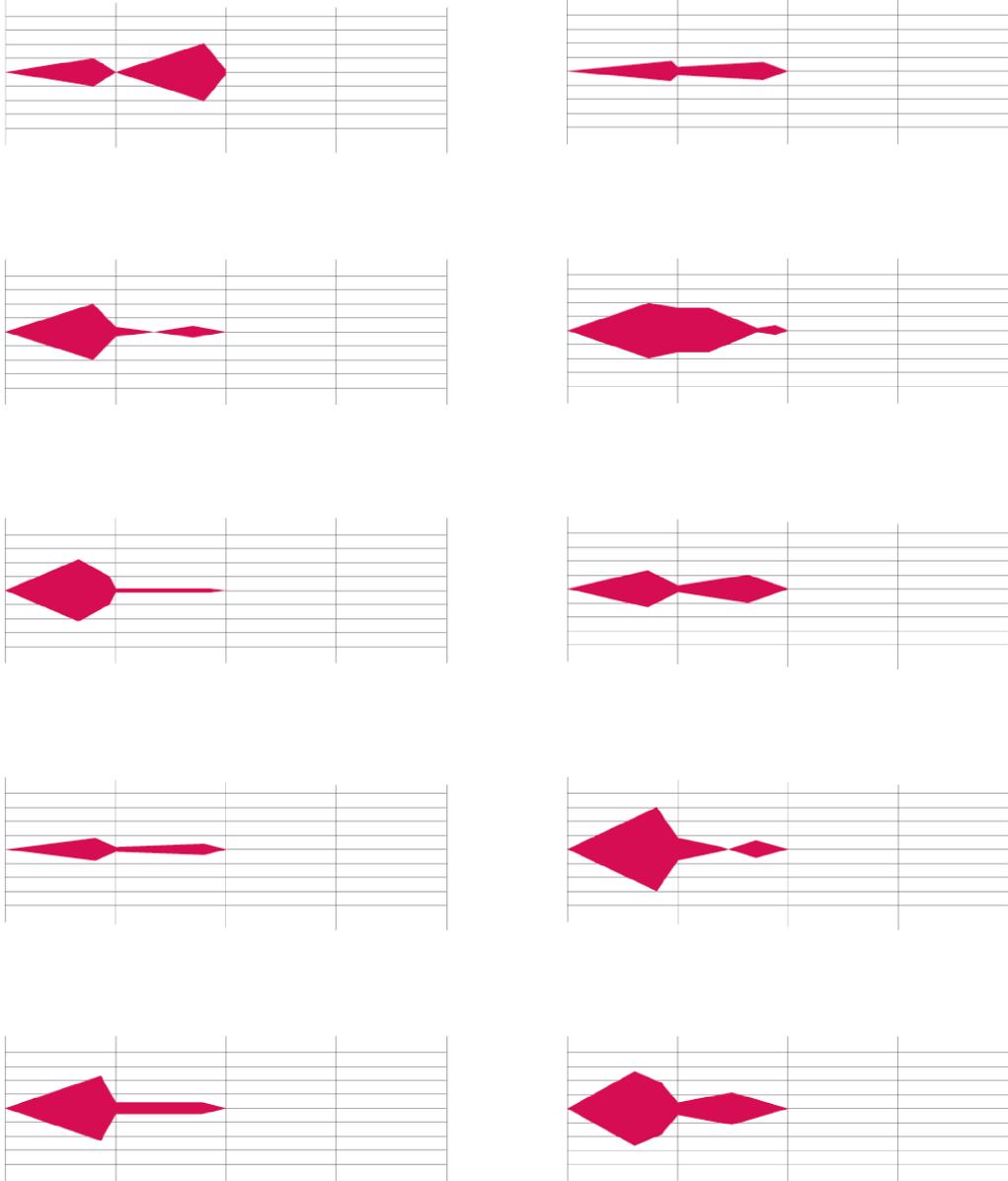


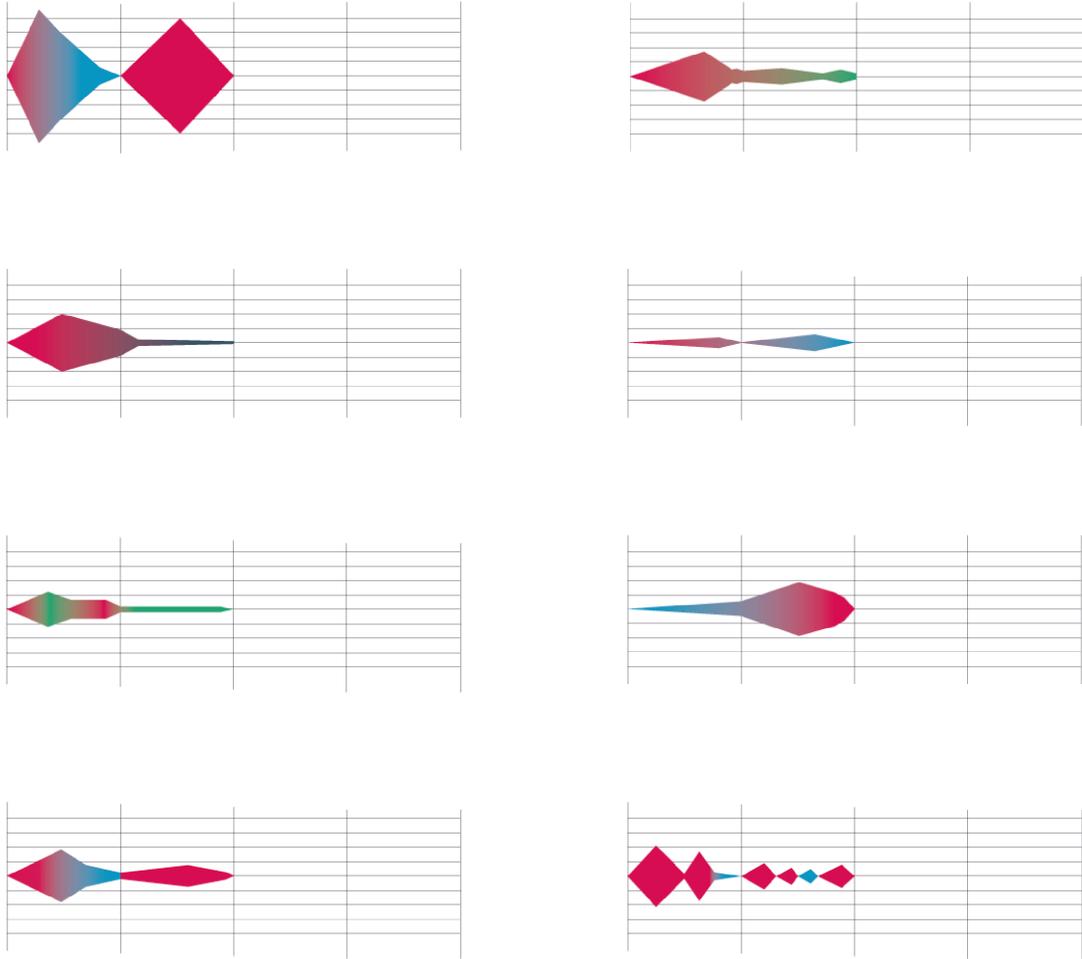
Figure 2: Collection of all graphs. The graphs are sorted chronologically from top left to bottom right

Sketches ■ Sketch models ■ Functional models ■ CAD ■



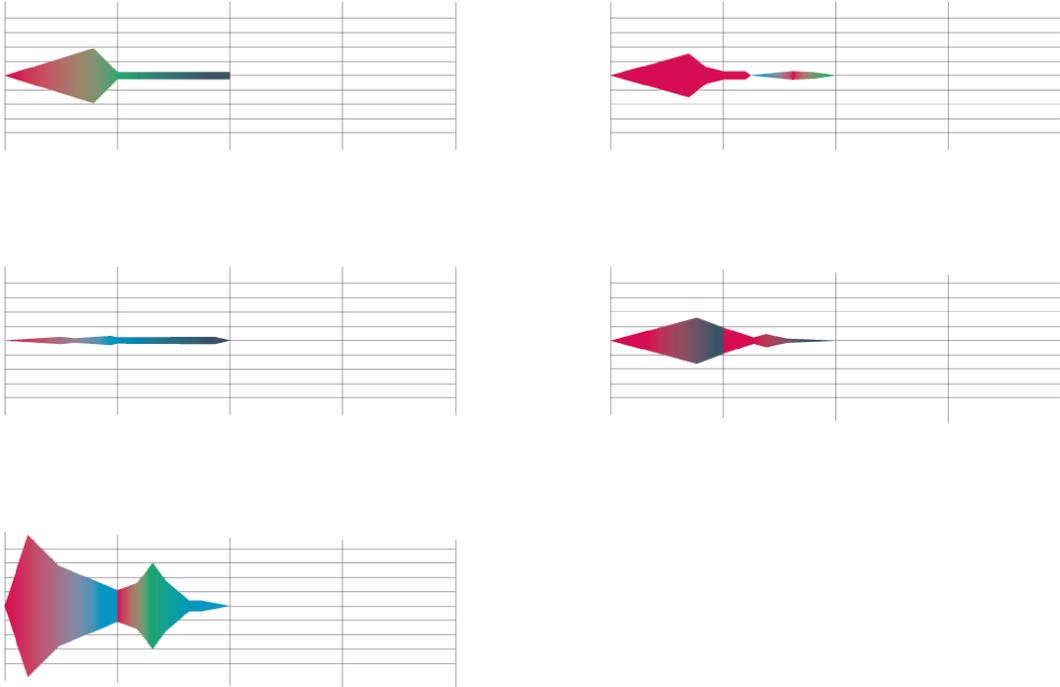
**Figure 3: Graphs showing theses using sketches only**

Sketches ■ Sketch models ■ Functional models ■ CAD ■



**Figure 4: Graphs showing theses using two design representations**

Sketches ■ Sketch models ■ Functional models ■ CAD ■

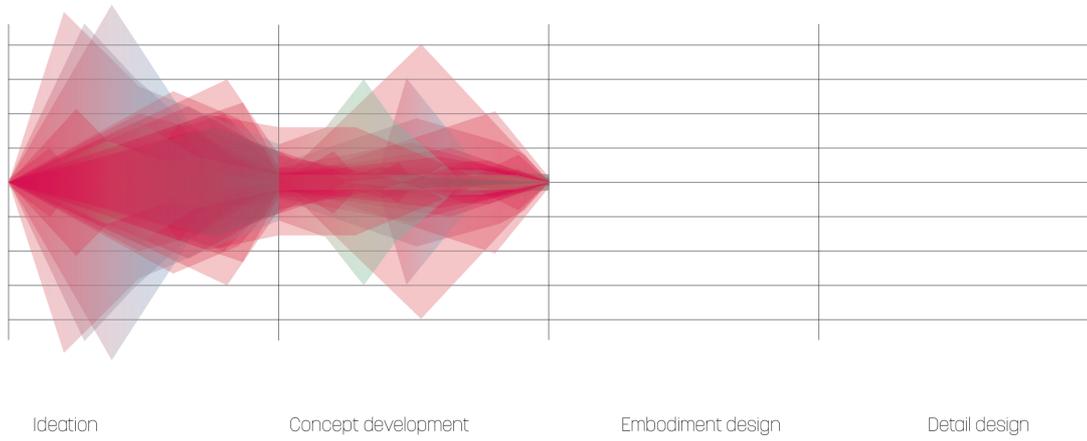


**Figure 5: Graphs showing theses using three design representations**

Sketches ■ Sketch models ■ Functional models ■ CAD ■



**Figure 6: Graphs showing theses using four design representations**



**Figure 7: Overlay of all the graphs**

## 4 Discussion and proposals

This study explores if there is a decline in the use of physical models and, if so, how it affects the breadth of design space exploration, using 25 master theses on Design and Product Development from Linköping University. It further explores whether this is a fruitful approach to be repeated with multiple accessors and potentially in real time. The results and proposals for further studies are discussed below.

Looking at the all graphs, we notice that most of the graphs have similar shapes, with the exception of three graphs with a considerable higher diversity of ideas. These three have all used two or more design representations. Meanwhile, almost half of the theses in the study used only sketching to support their choice of concept. This suggests that our initial observation was correct. Moreover, the graphs suggest that these have an overall lower diversity of ideas. Consequently, this would suggest that using more than one design representation, particularly using physical models, leads to a broader exploration of the design space. It could however also be that students who used more design representations in this study are naturally more prone to explore the design space.

The overlay image provide an interesting pattern, resembling the double diamond model by The British design council (2005). However, the double diamond is a model of the whole development process, from inception to final product. The two phases in this study correspond to the phase “develop” in the Double Diamond model, where one or more concepts are being refined (British Design Council, 2005). In the Double Diamond model this is visualized as a divergent phase but, as the model very simplistic, there is potential that there could be smaller diamonds (divergent and convergent phases) inside the two big diamonds. A model like this, coined the Double Diamond revamped, has been proposed by Dan Nessler (2016).

While the setup of the study did not allow the communicative part of design representations to be investigated in this study, it raised the question if the need for communication is greater in pairs, as they would need to show each other their proposed concept. This might be done efficiently with a physical model, as it could capture the three-dimensional nature of the product while not taking as much time as a CAD model would. There are no results in this study to support this notion, but it is worth exploring in future studies.

A finding that was not originally intended was that many of the ideation processes in the in the study began with words in the form of brainstorming and morphological matrices, before sketching. This corroborates the findings of Jonson (2005), who asked design students and designers from different fields to note their activities in a design project and found that verbalisation was the primary tool when getting started in a design project. This is an interesting notion which could be explored further, for example comparing design space exploration using only words versus using design representations.

Further, an interesting observation was that there were no corresponding ID cards (Pei, 2009) for the CAD category, meaning that there were no cards describing the use of computer aided tools for development and validation, such as using 3D CAD models to fit internal components or FEM-models. The only ID card showing a 3D model is the card service model (Pei, 2009) which is used for communication. Several of the design representations listed in the ID card taxonomy could also be created using computer aided toolsm, eg. a functional model in CAD showing a complex mechanical movement. It seems that the ID-cards taxonomy could be expanded upon by adding virtual sketches, drawings, models and prototypes.

One major drawback in this study is that the measure of diversity in the solutions relies on what the students have displayed in their thesis. This is no direct measure of the actual quantity and diversity. But given that they probably only show the best work in the thesis, the number of ideas shown should be an indication of the overall quantity. Further limitations with this method is that we cannot be sure of the point where the final concept is decided on in all theses.

In the theses that only reach visualisation of the chosen concept, this is simple. However, in the theses that continue with embodiment and detail design, the final concept does not necessarily have to be the same as the concept chosen after concept development.

It would have been interesting to map the use of design representations to some measure of quality, for example the final grade. However, the master theses are not graded at Linköping university and as this study was done long after the thesis were completed, there was no reliable way to assess the quality. Thus, to study the correlation between design representations and quality, this study could be repeated on projects that are graded.

## **5 Future studies**

The efficiency of using physical models could not be assessed in this study. However, as Häggman et al (2015) found that foam models resulted in faster generation of ideas than sketching or CAD, which is contrary to the belief that sketches are the quickest, there seem to be opportunities for more studies on the efficiency of prototyping compared to other design representations.

As this study only cover the two first phases there is an opportunity to expand the study to also include the embodiment and detail design phases. However, this would require another dataset as almost half of the theses in this study has the goal of developing a concept and not a finished product.

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