NordDesign 2012
August 22 – 24, 2012
Aalborg, Denmark

Computer Aided Design as an Idea and Concept Generation Tool in the Early Stages of the Design Process

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Abstract
This article claims that in certain circumstances digital visual representations (CAD) can facilitate a better understanding of the form than sketches and drawings, in the early creative idea and concept generation stages of the design process. Hereby, intensive reflective and processual visualization activities, which immediately renders feedback in computer media influences the designer to generate images more frequently and more precisely in his/her mind, compared to conventional media.
The above phenomenon has led to discussions around two factors, which redefine the value of CAD in an educational context. These factors are:

- Type of students admitted according to academic inclination
- Type of Design Program

Results have shown that students, who were admitted based only upon good grades, were generally poor in (manual) sketching and drawing. However, due to their solid academic capabilities, they demonstrated a strong aptitude towards learning different CAD systems. When merging these students' CAD with their analytical and creative thinking skills, it has been observed that communication and interactions among educators and students in the early stages of the idea development and concept generation stages were more descriptive and at crucial stages supported by surprisingly well developed CAD drawings / models. It is also evident that explicit iteration and gradual development of ideas and concepts supported by sketches were less prominent.
Concerning the type of design program, Industrial Design Engineering type of schools, who advocate a structured problem solving design process, based on *Analysis – Synthesis*, tend to also support the early implementation of CAD in their processes.
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Keywords: Digital Design Representation, CAD Tools, Conventional Representation, Design Education.

Introduction

One of the most powerful skills the designer possesses is the ability to facilitate decision making by communicating visually, through sketches, drawings, CAD representations and physical models. Designers also place great emphasis on sketches, because they are thought to be associated with creativity [1]. They also allow new ways of seeing and reinterpreting, that could provide new forms and abstract concepts [1, 2, 3].
Computer Aided Design (CAD) tools are currently widely used as a generative and communicative tool in design and engineering practice. However, because of the inherent parts definition, geometric specification and level of precision, it may limit the designer's

creativity and ability to make lateral interpretations. In other words, current computer systems demand too much precision too soon in the design process [4], and create a discrepancy between the creative impulse and the input needed to activate digital commands [4]. Therefore, when it comes to using CAD as a generation tool in the early conceptualisation stages of the design process, it is often used as a planning or pre-designing media to avoid troublesome changes later on in the product definition.

However, with the recent advancements in (digital) sketching, more and more designers use complementary 2-D and 3-D CAD programs in the preparation, conceptualisation and materialisation stages of the designing process. Moreover, when today's generation of Industrial design graduates apply for their first professional positions, the ability to use digital design tools has become a key feature of the selection process [6]. This is supported by findings from Yang et al. [7], stating that 55,1% of design job openings required applicants to possess 3-D CAD modelling capabilities.

In this article, the author will elaborate on the characteristics and differences of using conventional visualisation and representation versus CAD tools in the early stages of the designing process. Furthermore an educational reflection will be made to what extent CAD tools can replace conventional representation tools, such as drawing and sketching, without affecting the creative and problem solving capabilities of the designer. This reflection will be substantiated by results from interviews with 2nd year Industrial design students at NTNU, Department of Product Design. Finally a reflection will be made on the qualities of student intake as well as on the types of design programs.

Conventional 2-D product representation and communication

Sketches can provide insight into and trace the designer's mode of thinking at any particular point in the design process [8]. One of the most detailed studies of the act of sketching was conducted by Goel [9]. He identified two types of operation occurring between successive sketches in the early stages of design, namely *lateral* transformations and *vertical* transformations. In a *lateral* transformation, movement is from one idea to a slightly different idea. In a *vertical* transformation, movement is from one idea to a more detailed and exacting version of the same idea. Goel concludes that freehand sketches, by virtue of being syntactically and/or semantically dense and/or ambiguous, play an important role in the creative, explorative, open-ended phase of problem solving. He believes that the properties of the freehand sketch facilitate lateral transformations and prevent early fixations.

Olofssen et al. identified 4 types of sketches, each with its purpose, strengths and weaknesses. These are "Investigative Sketches", "Explorative Sketches", "Explanatory sketches" and "Persuasive sketches (renderings)" [10].

Concerning creative development and communication, 'explorative sketches' and 'explanatory sketches' are most relevant. Explorative sketches promote the dialectical process between a sufficiently specified and coherent physical form, and abstract, conceptual, propositional knowledge in terms of human cognition [11, 12]. According to Suwa and Tversky [13], sketching does not only aid to memory, but also in perceiving visuo-spatial relationships and reasoning about functional issues and goal-setting. It is one of the most influential modes for a dialogue between the designer and what the drawings suggest [11, 14]. Sketches are representations of the results of thinking processes, decreasing the cognitive load of designers, while provoking creativity during designing [15]. Some studies proposed that ambiguity is one of the key factors, because it allows the seeing of new possibilities in the representations, in other words re-interpretations [9, 14, 15]. Sketches also seem to be essential for revising and refining ideas, generating concepts and facilitating problem solving [16]. The convenience and speed of using sketches enable designers to generate and represent ideas easily and quickly [17].

Explanatory sketches have to be understood within the context of communication, whereby these sketches play a most decisive, but also most challenging role in terms of task clarification, either with colleagues or clients [18].

However, persuasive renderings might not always communicate adequately to all external partakers of a project. For example they may appeal to someone in marketing because of its appearance and artistic flair, but will probably fail when shown to product engineers as they seek different and more accurate information. According to Lawson, an additional problem with sketches is their propagandistic intention to convince the client that the design is at least satisfactory or excellent, while concealing weakness as much as conveying strengths in the design [19]. Things that would not work in real life can be tweaked in a drawing, misleading the client to accept a flawed design, which again can prove to be a very costly mistake. This is underlined by Errington-Evans's opinion that drawing is such a powerful means of communication that it can become an end in itself. This can trap the designer into the designing the drawing rather than the product." [20].

Designers, who strongly support the use of digital design tools, may find that hand drawings are not accurate enough and need to be complemented by CAD models, even for the final representation and realisation stages.

Computer Aided Design representation and Communication

The use of Computer Aided Design (CAD) tools has significantly penetrated the practice of designing throughout almost all stages of the design process. It has also moved from a peripheral component of design education to a central tool in the designing activity [20]. This is due to the wide variety and affordability of CAD software. Examples of popular and user-friendly software are: SolidWorks, Rhino and 3-D Studio Max.

The temptation of using digital models rather early in the design process is because of their ability to extract either perfectly machined models, or even stunningly realistic illustrations, at a pace and precision that not even the best illustrator or model maker could ever achieve. This brings along certain implications for designers who adopt a more result oriented approach towards the use of CAD. They find that it does not allow making lateral interpretations, because of the inherent parts definition, geometric specification and level of precision. Therefore, when it comes to using CAD as a sketching tool in the early stages of the design process, such as task clarification and conceptual design, interaction with non-digital representation media, such as sketches are the most common. With respect to the simultaneous use of these tools, it has been shown that most of the designers used sketches to prepare and support CAD-work, whereas the CAD is probably used as a media to avoid troublesome changes to the product definition [18].

However, when designers adopt a more explorative mindset when using digital design tools, some CAD or Computer Aided Conceptual Design (CACD) can be used as a product design structurisation tool, based upon how the designer decides to structure the designing activities manage the properties of the product, as well as its quantified structure [22].

Research Focus

This research attempts to redefine the value of CAD in an educational context by find out to what extent and how CAD tools should substitute and / or complement conventional representations tools, such as sketching and rendering. The reference point in this research is not to comprehend CAD from its dualistic character as explained in the previous sections, but to appreciate CAD as a design tool, which is more substitutional then complementary to conventional methods of representation, especially in the early stages of the design process.

Therefore, a study was undertaken to better understand the distributed use of conventional versus CAD tools in undergraduate design education and to identify opportunities for curriculum development. The aims of this research project were to:

- Confirm that undergraduate students, who demonstrated strong academic performance in science subjects at secondary school and A-levels, were more inclined to learning CAD tools and using them in their design projects
- Support the rhetoric that CAD design tools are to be used more prolific in the early stages of the design process, substituting conventional representations to a certain extent.
- Confirm that an engineering driven design education program supports and provide the right environment for training and using CAD tools early in the design process.

Empirical data gathering

In the 2nd year, 2nd semester design project of the NTNU Industrial Design course, 30 students were tasked to participate in the Electrolux Design Lab 2012 competition. An iterative process of exploration, contextualisation, analysis and ideation took place in the fall 2012 semester, which lasted for 15 project weeks. During the ideation activities, students were different kinds of 2-D and 3-D representations. However, it has been observed that a majority represented their ideas and concept using manual sketching and drawing and / or CAD visualisations.

Different research materials were used to analyse 30 students' aptitudes towards conventional sketching and drawing, versus CAD. These materials comprised of the following:

- A "main design submission", according to the Electrolux design lab competition format. More concretely, the submission format comprises of 6 – 9 poster format slides, explaining the final product, background history, motivation and client's insight. This is complemented by representations, demonstrating the product's use in context as well as technical functionality.
- A sketchbook illustrating the ideation and conceptualisation process
- A questionnaire comprising of 10 short questions.

Analysis of results

Results were classified and discussed according to the following three sources:

- A heuristic analysis of the "main design submission"
- A heuristic analysis of the sketchbook. In this analysis, ideation and concept sketches were categorised according to whether they were *designerly* represented or not
- An analysis of the completed questionnaires

Main design submission

In total, all 30 students submitted their "main design submission". Most of the students demonstrated a good understanding of the contextual problem, which have been well translated into valuable customer insights. In terms of representation and presentation, a strong emphasis has been placed upon CAD and Computer Aided Conceptual Design. Given their current level of education as well as previous exposure to CAD tools, a significant majority submitted an *"above expected"* level of representation.

Sketchbook illustrating the ideation and conceptualisation process

27 Out of the 30 students submitted an accompanying "Sketchbook". 17 Out of the 27 students showed rather poor sketches and drawings. The output can be characterised as "child-like" and did not reveal any signs of *designerly* flair. However, 10 out of the 27

students demonstrated some *designerly* flair in the representations of their ideas, concepts, or both.

When cross-comparing conventional sketches and drawings with CAD representations, students who were *designerly* proficient in sketching and drawing also performed well in their CAD representations *(Example: see figure 1)*. Besides that, some students (9 out of 17), who did not do so well in terms of sketching and drawing, showed surprisingly good CAD visualisations *(Example: see figure 2)*. Only 2 out of the 10 students, who were proficient in manual sketching and drawing, demonstrated limited CAD capabilities.

Figure 1 Example of a design submission, where the student demonstrated *designerly* manual representation as well as CAD modelling skills

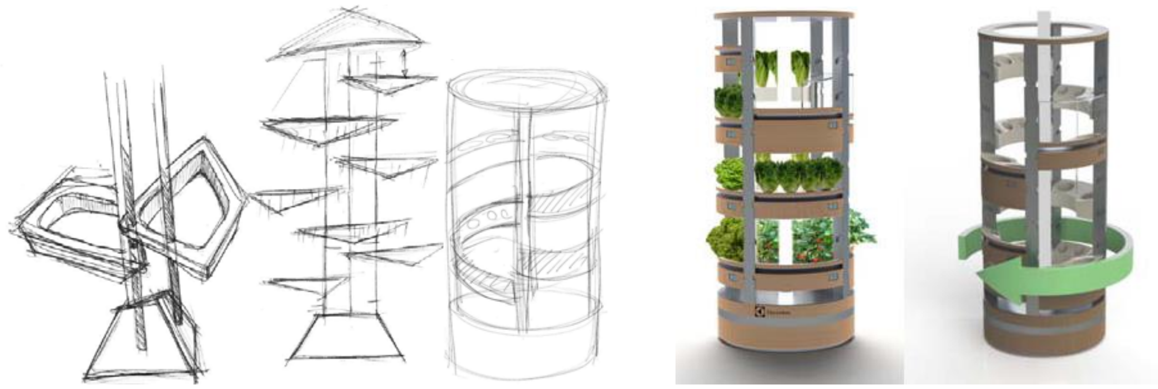

Figure 2 Example of a design submission, where the student demonstrated poor manual representation, but good CAD modelling skills

Questionnaire

Reference to the student's science-based academic background, only 25% (5 out of the 20) of the respondents had training in sketching and drawing prior to their commencement at NTNU Department of Product Design. They received their training through electives during their A-level (upper secondary school) education, completed a module in sketching and drawing at another design school before starting with the Industrial design course at NTNU, or taught themselves through video games and You Tube.

In this 2nd year design project, 75% of the respondents emphasised more on the use of CAD compared to sketching and drawing, because they had difficulties in sketching and drawing in a *designerly* way. A majority only use 2D sketches to visualise roughly for themselves, resulting in low quality "thumbnail Sketches", whereas others do not see the advantages of developing clearer and well developed sketches and drawings. However, a deeper underlying reason was that they felt incapable of developing professional and *designerly* looking sketches

and drawings in a short period of time. Their lack of training and practice may also limit their creativity if they were to emphasise designerly sketching. Therefore, this group prefers to design back and forth using quick rough sketches to facilitate their creativity and explore the more concrete forms and concepts by directly using CAD software.
On the part of design communication and confidence, only 20 % of the respondents felt insecure, because they were not able to sketch convincingly, which may affect how they communicate their design intentions. The majority did not have any communication problems, because they were able to communicate well using CAD, physical 3D models, as well as verbal and written descriptions.

When focussing more into the use of CAD, all students had some prior basic knowledge about using SolidWorks CAD in the design project (2^{nd} year / 1^{st} semester) prior to this one. However, much of the detailing and rendering activities in CAD has been learned and practiced in this project. 80% of the respondents have invested more than 40 hours in learning CAD in the previous 2^{nd} year / 1^{st} semester design project. This generally led to an atmosphere of great self-confidence among 2^{nd} year students in using CAD for this project. 80% of the respondents felt that they need not to use much time (less than 10 hours) to revise what they have learned previously in CAD and were able to focus on learning other complementary CAD programs, which provide better rendering capabilities. They also use more actively CAD programs in the idea generation or concept development stages of the design process. According to 80 % of the respondents CAD facilitated exploration, testing, and the generation of variations more systematically and quicker than sketches. They also found it more accurate in terms of concept detailing, dimensioning and exploration of possible materials. The proficiency among this generation of 2^{nd} year design students in using CAD is demonstrated in how fast they are able to generate reasonably professional digital representations, given their level of completed design education. 60% of the respondents took less than 20 hours to complete and present their final design in CAD. 20% spent between 20 – 40 hours, whereas only 10% took longer than 40 hours.

Discussion

The existing tension field on *When, Where,* and *How* to use conventional design representations versus CAD is becoming more and more prevalent. In this section, the results will be further discussed and reflected against the background of the students and limitations of the study.
In general, students, who were admitted to the NTNU Industrial Design program, demonstrated strong academic performance in science subjects at secondary school and A-levels. Their average A-level examination score was 57, which was far above the national average and the average of students entering engineering programs at the Norwegian University of Science and Technology (NTNU).
As these students entered the Industrial design program based only upon good grades, it was expected that their manual sketching and drawing capabilities were generally poor. Therefore, they were given formal training in drawing and rendering during the first three semesters of the program. However, due to their solid academic capabilities and attitudes towards *"what designing is about"*, many of them did not have the interest to improve and practice their manual sketching and drawing skills. Instead, they demonstrated a strong aptitude towards learning different CAD systems.
Once the students have entered the industrial design program and been exposed to the studio environment, they were also able to benefit from social learning practices, which are embodied in project-based learning and master/apprentice relationships. Social learning

theory focuses on the learning that occurs within a social context. It considers that people learn from one another, including such concepts as observational learning, imitation, and modelling [23]. According to Wenger, learning is defined as an inter-play between social competence and personal experience. It is a dynamic, two-way relationship between people and the social learning systems in which they participate [24]. Concerning CAD training, social learning plays a significant role, where 2nd year design students learn from and imitate their seniors. This interdependent and facilitative learning structure gives another explanation why NTNU Industrial Design students are more inclined towards using CAD tools.

In taking an adaptive versus a creative behavioural perspective, the author has observed that these 2nd year industrial design students were more structured and adaptive in their thinking patterns and the way they practice design. This is shown by how these students communicate and interact in the early stages of the design process.

In the research and analysis stage, all of the students adopted a problem solving approach, where they argued for the existence of a problem and attempted to solve it from a contextual viewpoint, based upon the Electrolux Design Lab 2012 theme, which is "Experience". In conjunction with the theme, a specific context was explored, researched and analysed from Social, Technological, Economic, Environmental and Political (STEEP) perspectives. Most of the students did this exercise well and were able to formulate clear consumer insights. However, this adaptive, structured and problem solving approach has also perpetuated in the idea development and concept generation stages. Instead of a comprehensive and explicit representation of ideas and concepts, students tend to inwardly develop low quality thumbnail sketches, but rather verbally describe and explain potential design solutions thoroughly. As a kind of compensation for the overall inability to represent in a designerly manner, partly argued from the viewpoint that CAD facilitated exploration, testing, and the generation of variations more systematically, accurately and quicker than sketches, these 2nd year design students emphasised the use of digital design tools in the designing processes, which they managed surprisingly well.

The earlier mentioned tension fields between the use of conventional sketching and drawing versus CAD in the design process, challenges the Industrial / Product design education community to act upon opportunities for curriculum development that will equip design students with relevant skills and knowledge. Although this study is still preliminary, one can already assume that the type of design program actively promotes the use of conventional or digital ways of representation in the designing process. Industrial Design Engineering type of schools, who advocate a structured problem solving design process, based on *Analysis – Synthesis,* tend to also support and earlier and more comprehensive implementation of CAD in their processes.

Conclusion

Visual representations are omnipresent throughout the New Product Development (NPD) process, from early sketches to CAD-rendered general arrangement drawings. Usually, as the design progresses, the representations illustrate increasing degrees of concretization and detailing [25]. In other words, as the project evolves from abstract to concrete, the degree of realism also increases.

Given this practice context and outcome of this preliminary study, it can be concluded that students with a strong academic science background are more inclined to towards a structured and problem solving approach to design. The fact that they have these strong analytical skills and ability to learn CAD tools fast and independently encourages them less to explicitly communicate through *designerly* sketches and drawings, especially in the early stages of the design process.

This observation should encourages design programs to rethink and re-evaluate their educational objectives, in conjunction with which design tools are to be emphasised or not in terms of design knowledge and skills transfer.

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