INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

Physual Designing - Approaching Design through the Interaction Space

K. Kristensen, H. P. Hildre, O. I. Sivertsen, H. Fyhn and K. Storler

Contextual factors in product development, Virtual tools, Giving the physical domain virtual characteristics, Research methods suitable for understanding the design process, Foundations of design environment, Studies of the designers in the work place.

1. Introduction

During a typical engineering designer's working day, they find themselves busy doing individual design activities on their workstation, searching for information using the web and other resources, receiving and making several phone calls, sending and receiving a number of emails, meeting with visitors in their office landscape, and interacting informally with peers and customers in project meetings. In addition, they make informal sketches on a whiteboard or a piece of paper to clarify certain design aspects, perhaps as they meet colleagues by the coffee maker. They also make presentations and collaborate with others using chat, data conferences, and then save their work in virtual workspaces in order to make their latest updates available to others that are working on the same projects. As described above, the design process is indeed very complex, and it is often difficult to categorize the different sub processes that are taking place in the overall product development process.

Engineering designers utilize and depend on both their physical surroundings and different technology-based generic and engineering-specific tools in order to be effective, in other words they "orchestrate" their design process using the wide array of tools and contextual factors that are available at their disposal. While it is still possible to identify and categorize the various contextual factors and tools in use and place these in the physical or virtual domain respectively, it is no longer possible to categorize the *process of designing* in such a manner that it can be placed solely in one category or the other. This is due to the fact that the physical and virtual domains are approaching each other, and that they are becoming increasingly interdependent.

Where it previously had been suitable to distinguish between the two domains, this is in many situations no longer the case. There are several reasons for this. One of the main reasons is that distinct categorization is getting increasingly difficult as new technologies with attractive characteristics position themselves outside traditional categories. Another reason is that whereas earlier attempts to bridge the physical and virtual domains have happened within the framework of the virtual domain, an approach that has been unsuccessful as the virtual representations of most attractive features of the physical domain have suffered from limited usability in real situations. This is especially true when it comes to trying to recreate a "physical" feeling within the boundaries the typical computer screen represents.

Product development is, to an increasing extent, taking place in dispersed teams collaborating globally across time and space. Keeping this in mind, as both domains have some key characteristics that are identified as essential to successful product development, there is a need to identify new approaches to handling modern design processes that combine key characteristics from both the physical and the virtual domain, particularly in the early phases of product development.

2. Background

2.1 Historical Overview

Engineering design has evolved greatly over the 100 years or so. From the early beginning where the chief engineer dictated solutions in drafting board environments where designers and draftsmen worked together in large rooms, via more specialized techniques like the Blackboard Engineering or "Panoramic Design Technique (PDT)" (Ferguson, 1992), to the highly computerized designer environments of today, with their high flexibility. The rate of change over the last 25 years has been very rapid, and this has led to a shift in the power structure due to the fact that the designs have become more complex, and that the computerization of the design process has led to a less transparent design process. The design process has in many ways become more personalized, increasing the need for coordination. In particular, CAD drawings are not as easily retrievable due to a the fact that they are stored in digital files, often with names that have little meaning to others than the designer him or herself. In addition, the introduction of the computer screen, with its limited size, as the drawing interface, has made the daily design process even more hidden to others than the designer, which has increased the need for specific design reviews, as daily monitoring has become more difficult for the chief engineer. The main advantages of the physical and virtual domains respectively are shown in Figure 1.

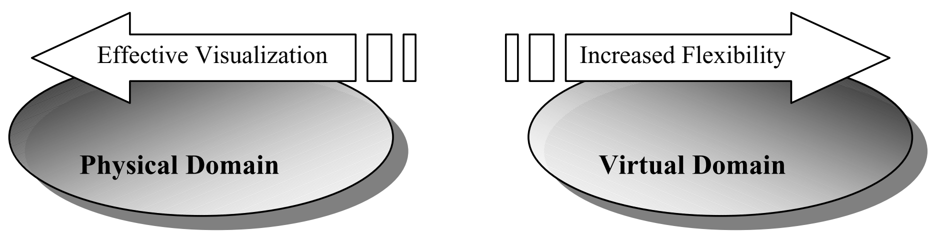

Figure 1. Overview of the physical and virtual domains

There has been an evolution from shared design work to work of a more individual character, from relatively simple products involving few professions in the design process to more complex products, and from integrated working and presentation documents to separate working and presentation formats. In addition, whereas the typical early methodology separated the designers from the draftsmen, the engineers involved in the detailed design today are much more autonomous than their predecessors, as they fulfill the function of both the early designer and the early draftsman.

2.2 Drafting-based Methodology

Drafting-based, or early product development methods, were based on the use of large drafting boards, and were deeply rooted in the physical domain. The advantages included a layout that gave the chief engineer an easy overview of the process, and quick, instant response as a logical outcome of this. The large drafting boards were excellent for capturing information and for large-scale visualization, they made it easy to comment on the proposed solutions, and the technical skills necessary to make drawings were limited. The fast response characteristics of manual sketching made it easy to pay attention to the totality of concept (Ottoson, 1998), to quickly gain a good overview of the overall situation, and to make excerpts of the totality by highlighting important concepts that had not yet been finalized. This made it easier to communicate early phase concepts and ideas. In terms of document and drawing format, the working media at the same time served as presentation media. This suggested a strong sharing mentality; any drawing was ready for presentation and discussion at any point in time. It should be mentioned that this mechanism was further supported by the relatively low complexity of the design of the products, compared to most industrial products being developed today. The drafting-based methodology was developed for and supported group productivity. Summarized, these advantages are all a function of the belonging in the physical domain.

The disadvantages of early product development methods are mostly related to limited flexibility. Because of the manual character of the design work, it is difficult to make changes in a well-developed design. In addition, it is difficult to modularize and incorporate previous designs easily. As fewer minds were actively engaged in making the main design solutions, this called for skillful, strong design leadership by the chief engineer. Finally, it is nearly impossible to effectively collaborate over distance using paper-based media.

2.3 ICT-based Methodology

ICT-based, or late product development methodology, differs from previous methods by being much more rooted in the virtual domain. Many of the key characteristics are different, and among the many advantages the aspects mentioned below are considered the most important. First of all, computer tools traditionally have been developed to support increased individual productivity, making design modifications and modularization a lot easier. Second, they have increased design flexibility in terms of allowing the proposed designs to be shared over distance, making it easier to outsource development of components and modules. Whereas the drafting-based methods are excellent for capturing information, the ICT-based methods are superior in terms of storing information, and they are very flexible in terms of manipulating and displaying this information over distance, in a variety of formats and contexts. The advances in information and communication technology have been one of the most powerful forces behind the trend global engineering represents. ICT-based methodology is powerful in terms of making rapid changes and modifications, which is a logical outcome of the fact that the typical ICT-based methodology is well rooted in the virtual domain.

There are also disadvantages, although these have not been emphasized because the advantages have outnumbered the disadvantages. Among the most prevalent disadvantages is the fact that the design process to a great respect has become invisible for others than the designer. The designers have “disappeared into the computer” using personal workstations with a small user interface that is adapted to the individual designer’s need, but that is less suitable for presentation purposes. In particular, the typical screen is too small for effective visualization, as required for design reviews and for effective communication. The *virtual interaction space* therefore has limited communication functionality in open, co-located settings. The input devices are also adapted to individual needs, compared to a large, open surface available to many designers to draw, write, point, and make comments.

3. Current Situation

The progress in product development methodology is a result of external requirements and technological development, which has removed obstacles for efficient collaboration over distance. However, some of the benefits of the earlier approach got lost in the transition from the typical drafting-based approach to the late ICT-based approach.

Throughout the last decade one has seen several attempts to merge the physical and virtual domains through recreating “physical” spaces in the virtual domain, by the use of physical metaphors, and in particular through the use of room analogies. Perhaps the best example of this is Teamwave by Teamwave Software Ltd. This and other virtual workspaces that borrow room metaphors make virtual workspaces easier to navigate and use, through the use of familiar expressions and concepts. One can say that the virtual domain has been brought closer to the physical domain, or that there have been attempts to give virtual workspaces imposed physical characteristics. Whereas is might be a good solution to improve the ease of navigating through introducing familiar expressions and terms, the most powerful aspects of the physical domain cannot be recreated easily in the virtual domain (Fyhn et al, 2001). These aspects include a sense of presence and flow, in particular during creative sessions as a brainstorming event, and a feeling of operating in real time, where one can receive momentary feedback, often based on body language.

During the last decade one could also observe emerging technologies that could bring some of the attractive characteristics of the virtual domain out in a wider physical context. These technologies represent both input and output devices that aid large scale visualization. Examples of such technologies include, but are not limited to LCD projectors, plasma screens, e-beam and other active surface tools for improved visualization, drawing tablets, et cetera.

In the early days of computers, they were mostly tools for improved personal productivity, hence the name *Personal Computer*. However, the emergence of the Internet, email, collaborative workspaces, data conferencing tools and new input/output devices has greatly improved the collaborative potential of computers. By bringing advanced information and communication technology out in the physical context, a new form of design process emerges. This is the process that can be labeled *physual design* – a process that is making the most use of the advantages of both the physical and the virtual domains, and at the same time, limiting the drawbacks of these two when considered separately, by actively orchestrating available virtual tools and contextual factors in such a way that the drawbacks in one domain are compensated for by appropriate opposing forces in the alternative domain.

3.1 Contextual Factors in Product Development

The physical domain is defined by the surroundings and other aspects of the physical context that encompass engineering designers. These are placed in the physical domain because of their distinct physical characteristics, by representing physical artifacts. Interactive surfaces in the *physical interaction space*, such as drawing surfaces (blackboards, whiteboards, paper, etc.) are of special interest, since these represent the points where engineering designers interact with their surroundings using pre-described, accepted methods. The physical domain is strong in terms of supporting a feeling of presence and real time collaboration, and for communicating through effective, large-scale visualization and the use of body language, which can trigger many senses simultaneously. These physical characteristics are not easily recreated in other media, as they require high bandwidth and expensive, cutting edge technology. High-end virtual reality systems share some of the same characteristics, but these are still inferior in terms of cost/value in most situations. One of the most prevalent advantages of interactive surfaces in the physical domain is that the input and output surfaces are the same, and this is well adapted to the favorable process that takes place during engineering design, where the designer actively reflects on his or her own design process (Schön, 1982).

3.2 Tools for Virtual Collaboration

The virtual domain is made up by tools, mostly electronic or computer-based, with distinct virtual characteristics. Among the most important of there are virtual workspaces, telephone, email, CAD/ CAE systems, PDM systems, data conferences, chat applications, and mobile telephony. One of the advantages of these tools is that many processes can be automated, which saves valuable time. They are also very flexible in terms of making information available to people that are not present. Digital files can be made available for download to recipients around the world in seconds, which is a considerable improvement over previous solutions. Virtual tools hence opens up the design process for potential contributors worldwide, which for instance dramatically increases the number of available experts, since these now can work from their home base rather than traveling around to meet with different clients. Among the drawbacks of such tools is their low ability to support a feeling of presence and real time collaboration, and by having input devices that are separate from their output devices (for instance mouse and keyboard versus computer screen). In addition, the input devices are often inferior to their physical counterparts for certain important engineering activities such as sketching.

3.3 New "Physual Tools"

The new "Physual Tools" that suggest a new approach to designing, can be described as tools capable of enriching the physical domain by introducing distinct virtual or digital characteristics. More so than the earlier attempts to recreate a physical reality in the virtual domain, they can be described as tools

"Where physical meets virtual." Examples of input technology in the "Physual tools" category include e-beam, digital sketching boards, large interaction surfaces as large touch screens and other WYSIWYG (what you see is what you get) interfaces. Examples of output technology include LCD projectors and virtual reality equipment. It should be mentioned that most of these tools are adapted, either alone or with accompanying technology, to work as both input and output devices, and that this is one of the most attractive characteristics of these tools.

4. Physual Designing

The approach suggested here, physual designing, combines the advantages of the physical and virtual domains respectively, and at the same time, avoids most of the disadvantages by orchestrating the various contextual factors, active surfaces, and virtual and physual technologies at disposal in such a way that appropriate physical elements counteract shortcomings in the characteristics of the virtual elements and vice versa. By following this approach systematically, it is possible to combine effective, large-scale visualization with the increased flexibility that is made possible through the use of virtual and physual tools. The physical surroundings of the designer then become a flexible interaction space with physual characteristics, which are well adapted to the need for close communication and collaboration, both co-located and distributed.

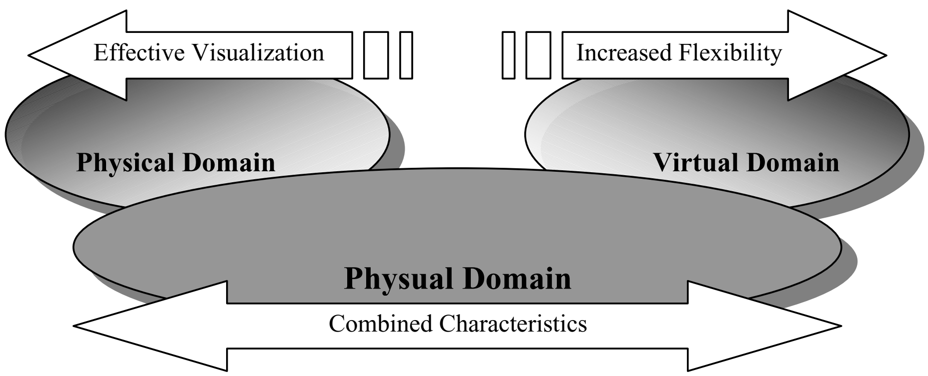

Figure 2. The physual domain, combining the physical and virtual domains

Figure 2 describes how physual designing in the *physual domain* combine the favorable characteristics of both the physical and the virtual domain, making it possible to obtain effective visualization across time and space, which in turn will increase the ability to carry out product development in globally dispersed teams, and to effectively and continuously monitor the early phases of product development.

5. Data Collection

Besides literature studies, qualitative pilot studies have been carried out in various classes and among the employees at Department of Machine Design and Materials Technology at the Norwegian University and Science and Technology. In addition, lecturers have shared their classroom experiences when using various technologies along the entire spectrum from physical to virtual, with emphasis on the impact of physual tools for visualization and increased flexibility.

6. Conclusions

Physual designing represents a new approach that have some distinct advantages over earlier categorization between physical and virtual working environments and tools. By emphasizing the need to give physical workspaces, as defined by a set of contextual factors, distinct virtual characteristics (such as the ability to work directly in digital media), it is possible to obtain some very favorable combined characteristics. In particular, the combination of large-scale visualization in a shared physical context, with the feeling of presence and real time collaboration this gives, with the increased flexibility offered in terms of ability to communicate and share information over distance, is very powerful.

The findings in this paper should be verified, and additional experiments should be conducted, in order to gain a better understanding of how the relations between the physical and virtual domains evolve as new tools with distinct physual characteristics are developed.

Acknowledgements

I would like to thank Thomas R. Svinåmo for his valuable comments and assistance during early stage observations in the class SIO2043 Machine Design and Mechatronics.

References

Lerdahl, E., "Staging for Creative Collaboration in Design Teams", Doctoral Thesis, NTNU, Trondheim, 2001.

Kristensen, K., "Developing Methods for Developing New Methods of Improving Design Productivity by Focusing on Transitions Between Working Situations," Conference Proceedings, ASME IMEC&E, New York, 2001.

Fyhn, H., Kristensen, K., Hildre, H. P., et al., "Produktutvikling i det virtuelle rom," Department of Machine Design and Materials Technology, NTNU, Trondheim, 2001.

Maher, M. l., "Designing the Virtual Campus as a Virtual World," Conference Proceedings, CSCL 99, Stanford University, Stanford, 1999.

Ottoson, S., "Qualified Product Concept Design Needs a Proper Combination of Pencil-aided Design and Model-aided Design Before Product Data Management", Journal of Engineering Design, Vol.9, No.2., 1998, pp 107-119.

Hildre, H. P., "Corporate universities and new opportunities for academic institutions," Workshop on Learning, Stanford University, Stanford, 1998, pp. 27.

Hildre, H. P., "Challenges and new roles for engineering universities," Workshop on Learning, Stanford University, Stanford, 1998, pp.8.

Levin, M., "Technology transfer is organizational development: an Investigation into the relationship between technology transfer and organizational change," International Journal of Technology Management, Vol.14, 1997, pp 297-308.

Ferguson, E., "Engineering and the Mind's Eye", The MIT Press, Cambridge, 1992.

Schön, D., "The Reflective Practicioner", Basic Books, New York, 1982.

Kjetil Kristensen, Research Fellow
Norwegian University of Science and Technology, Department of Machine Design and Materials Technology
Richard Birkelandsvei 2B, N-7491 Trondheim, Norway
+47 73593816, +47 73594129, kjetil.kristensen@immtek.ntnu.no