REALIZING A TRULY 3D PRODUCT VISUALIZATION ENVIRONMENT – A CASE FOR USING HOLOGRAPHIC DISPLAYS

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ABSTRACT
Recent advancements in the areas of visualization have led to realization of a large variety of three-dimensional (3D) visualization technologies. Conceptual design and prototyping are among the product development activities that can benefit from the capabilities provided by the emerging 3D visualization technologies. As adopting a new technology can sometimes result into unexpected adverse consequences, a structured approach to visualization technology selection and planned utilization is naturally indispensable. Some general-purpose guidelines and methods for selection of technologies are available and could probably be adapted and used, but none of them square precisely with the challenge of selecting visualization technology for product visualization. This paper describes the systematic method we put together and followed, the actions we took, and factors we considered; which lead to categorization of holographic display as a viable truly 3D product visualization technology. Such a systematic approach, factors and actions, when appropriately considered, could help industrial organizations aspiring to invest in new visualization technologies to make measured selection, and could also guide them towards better utilization and maintenance, which would ultimately justify investing in the selected technology.

Keywords: Product design, product visualization, computer-aided design.

1 INTRODUCTION
The definition of three-dimensional (3D) visualization systems when addressed to general support of product visualization has a considerable breadth. The widest definition covers any visualization technology capable of displaying 3D images. Today, manufacturers of 3D visualization technologies have developed many different types of commercial and experimental visualization systems, which can be categorized variously as: (i) stereoscopic displays, (ii) auto-stereoscopic displays; and (iii) volumetric displays. Stereoscopic displays use various methods to convey separate image to each eye, and in this way allow perception of depth [1]. Autostereoscopic displays generate 3D images that appear 3D without the need of any special eyewear or head tracking gear [2], [3]. In contrast with stereoscopic and auto-stereoscopic displays, volumetric displays generate volume-filling images in a variety of ways. Multiple displays stacked-up planes and rotating panels (which sweep out a volume) are examples of the methods employed in volumetric displays [4], [5], [6]. Holographic displays are also classified as volumetric displays in many publications - see e.g. [7], [8]. They generate 3D images by reproducing light fields that are identical to that emanated from the original scenes, giving perfect volume-filling 3D images [8].
Most of the existing 3D visualization technologies are general-purpose technologies used in various areas of application. It is important, however, to divorce the application of 3D visualization technologies from an exclusive traditional view of supporting passive visualization - a typical kind of visualization support needed in the application areas such as advertisement and entertainment - because these technologies are increasingly being embraced and used in many other professional activities such as engineering design, architecture and manufacturing. For example, nowadays in the manufacturing industry, 3D visualization systems are increasingly becoming popular, and various manufacturers are more and more using these technologies in product development processes, not only to speed up and improve product design, but also for other purposes – including, for instance, to train workers and to configure factories and stores.
For the organizations intending to start using 3D visualization technologies, selecting a suitable technology is the first major challenge they are more likely to face. Such organizations often find

themselves amidst many choices because the 3D visualization technology scene is presently characterized by a large variety of competing display concepts, each having some specific strengths and weaknesses. In this paper, a systematic method we put together and used in selecting a 3D visualization technology for product visualization is presented. The paper describes the basic elements of this method and explains how we applied it and how it led us to select holographic display as a viable truly 3D product visualization solution. The main steps we followed; including the necessary preparations made, feasibility and the needs analysis conducted, selection criteria formulated and managerial issues are described in details.

2 PROBLEM ANALYSIS

There are many types of 3D visualization technologies around with various capabilities and specifications, and the list of technologies to choose from is increasingly becoming exhaustive. While the visualization market is currently witnessing significant technological advancements, the role of these technologies in some application areas is also expanding and their significance becoming more and more apparent [9]. In particular, engineering design firms, defense industry, and medical firms are increasingly investing in 3D visualization technologies. There is already evidence of increased application of 3D visualization technologies in engineering product development – aimed at improving efficiency and reducing costs. The visualization technology scene is generally in a state of influx and new hardware configurations are continuously being developed – refer to e.g., [10] for a comprehensive review and analysis of existing and emerging visualization technologies. In general terms, since specific guidelines or systematic procedures for selection of 3D visualization technologies are not available, there is a real danger of industrial organizations to embark on using 3D visualization technologies without paying attention to proper selection of hardware or peripheral devices, or even without satisfactory preparations for using these technologies. Proper selection is essential because there is a real chance of making a wrong choice of visualization technology, which can actually compromise rather than improve performance, and therefore result into loss of the actual purchase costs. Choices should be based on realistic criteria and made through thorough examinations of the available technologies. The selection should not be based only on highly visible attributes such as documentations or look and feel, but rather on quality and suitability of the device.

Several decision-making models and selection methods are available. These include, for instance, decision-making models for selection of advanced technology - see e.g. [11]; for selection of machines or equipment - see e.g. [12]; for selection of system components – see e.g., [13], and so forth. Most of the existing approaches involve using techniques such as modeling a problem into multiple criteria scenario targeting specific applications or technologies; multi-objective integer programming algorithms [14]; subjective ranking schemes; or comparing the interdependence between two or more technologies [15]. These methods can be adapted and used in many selection tasks but none of them precisely square with the challenge of selecting visualization technologies for product visualization. It is also important to note that despite the availability of formal models or methods, some literature suggest that most of the selection and acquisition decisions are often ultimately made by the decision makers, who normally rely largely on their knowledge, experiences, biases they have, and personal judgments – see e.g., [13].

In the light of the above discussion, the problem dealt with in this paper can be summarized as follows. Due to the state of influx of 3D visualization technologies, picking one visualization technology in preference to the others, without carrying out an in-depth systematic technology and needs analysis or using suitable guidelines can sometimes be risky. A 3D visualization technology can be a major investment with considerably high degree of uncertainty in some companies. Therefore, there is a real need for a systematic method and guidelines, especially at the strategic level, for ensuring that a suitable visualization technology is selected. Such a method should be sufficiently objective and based on specific formal or tailor-made criteria, and should guide organizations or individuals to carry out thorough examination of available visualization technologies rather than making hasty choices based only on highly visible attributes such as documentations or look and feel.

The following section describes the systematic approach for selection and planned utilization of new technologies we put together and applied in the work presented in this paper.

3 A SYSTEMATIC SELECTION AND PLANNED UTILIZATION APPROACH

A systematic approach we put together and applied in the selection and planned utilization of 3D visualization technology for product visualization is presented in this section. This approach is partly a result of the hybridization of various formal approaches and de facto systematic procedures used in the selection of new technologies. It takes into account various factors affecting the selection, which we broadly categorized as, technological factors (functionality, usability, reliability, maintainability, flexibility, etc.), strategic factors (e.g. financial, infrastructural, and market positions of the organization, etc.), and social factors (environmental factors, personnel policies, etc.) – see Figure 1. With regard to technological factors, there are several published guidelines that can guide industrial organizations intending to invest in new technologies to expansively explore existing and emerging technologies - see for instance [16]. Some of such guidelines can be adopted and applied in the framework of the proposed systematic approach. Figure 1 shows in detail the scheme we created and the activities involved in the selection of visualization technology. In principle, this scheme first guides users to conduct feasibility study and needs analysis, and then to formulate selection criteria and use them as the basis for evaluation when selecting a 3D visualization technology to invest in.

Under the approach we put together and applied in this work, feasibility study must be conducted at the onset of the actual process in order to ascertain the success of investing in 3D visualization technology. Feasibility study must include a multi-dimensional review and analysis of existing alternative technologies; and should extend to studying various aspects of the new investment and of the technology itself such as the economics of the new investment (i.e. whether the firm can afford to invest in new technology), technical capability (i.e. whether a technology that can fulfill requirements exists, whether the firm has enough experience in using that technology, etc.), schedule (e.g. whether the new investment interferes with normal business operations, etc.), organizational (e.g. whether the new technology has enough support of the firm's management, whether it brings an excessive change, whether the organization is changing too rapidly to absorb it, etc.), cultural and societal (i.e., impact on the local and general culture in the firm, environmental factors), market (i.e., analysis of market forces that could affect success of investment) and legal (i.e. making thorough legal scrutiny). In order to win the management's confidence, if the organization's financial situation permits, it would be more persuasive and credible if a third party team or individual (preferably from outside the company, who is neutral and also expert) would carry out feasibility study.

Furthermore, the proposed approach requires that the need for 3D visualization should be thoroughly analyzed. This must involves scrutinizing the major objectives of investing in 3D visualization

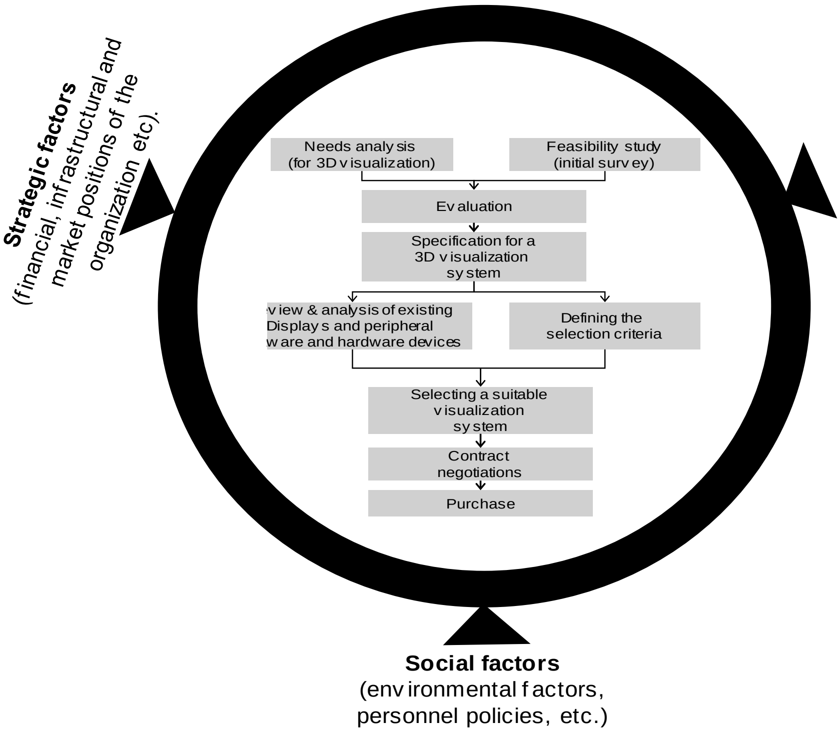


Figure 1. A general scheme for selection of 3D visualization technologies

technology and exploring potential problems and possible future changes. The common and easiest way of obtaining needs is by interviewing people. Also, approaches such as focus group research and questionnaire survey method can be used to gather information. It is advised that if personnel and financial resources permit, two or three methods should be used in tandem to gather information and/or collect data. There are many factors and issues to consider when selecting a 3D visualization technology. Of paramount importance is the relevance of each factor to particular needs and to the budget of investment. During needs analysis, it is also important to draw up appropriate functional requirement specifications, including those for operating software and peripheral hardware devices. In addition, it is imperative to consider ongoing advances in technologies (i.e. both emerging technologies and new technological advances), financial resources of the organization and the experiences of other organizations. Once the functional requirements are clear, the organizations can then look more closely at the market and devise some general selection criteria.

These selection criteria serve different purposes. For instance, they can be used as benchmarks to ensure, e.g., that cost criterion is met; the device is flexible enough to accommodate the particular ways in which the organization or company likes to work, the device is easy to learn and use, the device has clear documentation, the device has required capabilities (e.g. display/workspace) and so forth. Moreover, it is important to consider issues such as: Can the manufacturer or supplier maintain or modify the visualization device when needed (e.g., can the underlying software or associate peripheral devices be changed for the latest upgrades)? Is the visualization device adaptable to possible changing needs? Is the visualization device unique? (i.e., is there a visualization device around from which the company can gain experience?) Can the visualization technology be housed within the existing company facilities? (e.g. with existing lighting, room temperature, humidity, power supply and so forth), Can the visualization technology offset the costs of introducing it by e.g. speeding up the product development process? Will the visualization device improve productivity? Is free training offered and what training fees are payable on later enhancements? Can the employees gain hands on experience before the visualization technology is finally selected?

As shown in Figure 1, a comprehensive evaluation must also be carried out before purchase. The consequences of investing in new technology must be investigated and the benefits and drawbacks of the envisaged investment must also be assessed thoroughly. Human aspects such as possible effects on established work arrangements and other possible social implications of the change must also be investigated. It is also imperative to, for instance, evaluate and consider installing a new visualization system alongside the existing system to promote cohesion with on-going practices, installing suitable furniture for the new working environment, and so on.

After feasibility study, needs analysis and evaluation; the downstream activities shown in Figure 1 can be carried out. Specification requirements must then be compiled based on the results of feasibility study and needs analysis, and formal and more specific selection criteria must be formulated as well. After that, a thorough review and analysis of affordances of competing technologies must be carried out and the appropriate visualization system ultimately selected by using the selection criteria as benchmarks. The following section presents a case study that recounts how the above systematic approach for selection, and planned utilization of new technologies was applied in selecting a truly 3D visualization technology for product visualization.

4 CASE STUDY

The systematic approach presented in the previous section was used in the real world to select a truly 3D visualization device. Our research group is presently involved in the development of an experimental spatial product visualization environment [17]. One of the key desirable features of this environment is that it should be equipped with a visualization technology capable of displaying truly 3D images. By truly 3D images we refer to geometrically volumetric images that occupy actual volume of space. As mentioned earlier, there are various different types of 3D visualization technologies that can display 3D images (- see also [10]). One of the main exploratory research issues was therefore to indentify a suitable 3D visualization device and to adapt it to suit the envisioned visualization device. We first reviewed and analyzed various competing display technologies in order to properly understand them. In this preliminary exploratory work, we started by exploring users' expectations, identifying the needs and consequently formulating requirements. We then evaluated the adequacy of various types of 3D visualization technologies by using these requirements as benchmarks (refer to [18] for more details). This was intended to ensure that the visualization device of the truly 3D visualization environment is selected based on formal criteria and through thorough examination of the existing and emerging 3D visualization technologies rather than making decisions based on highly visible attributes such as documentation or look and feel. In the following sub sections, we describe how we conducted needs analysis, evaluated candidate technologies, selected the suitable category of visualization device, and how we chose a particular visualization device for our spatial product visualization environment.

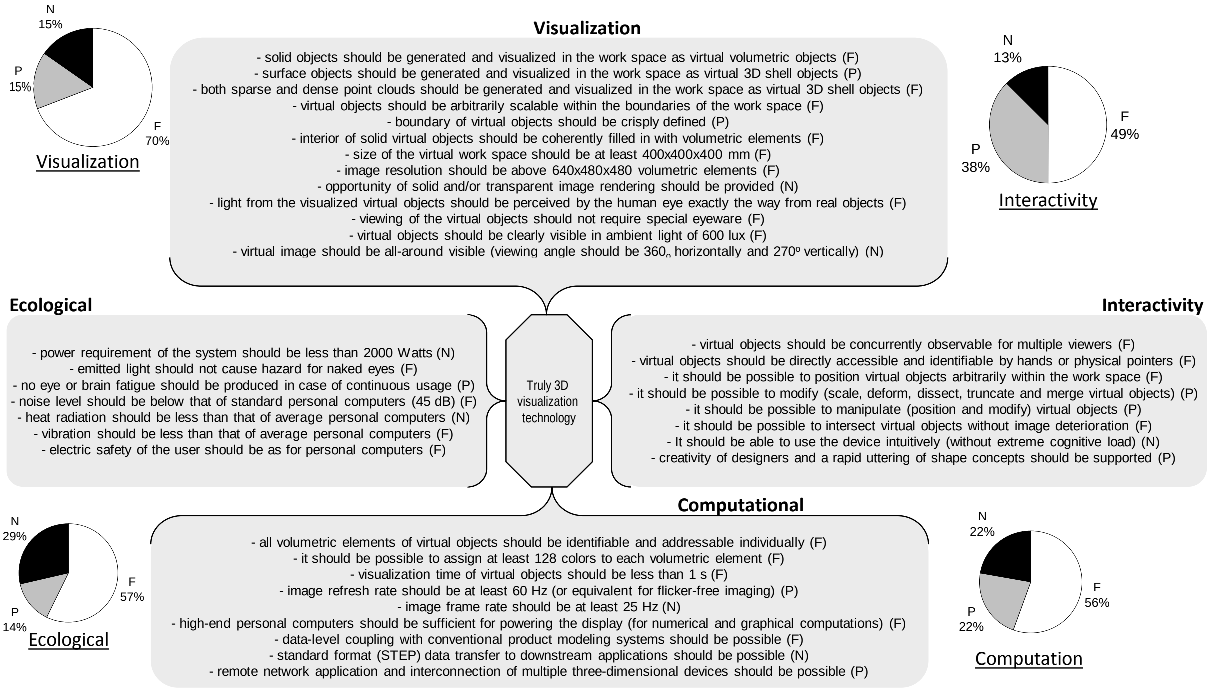
4.1 Feasibility and Needs Analysis

Product development is a complex and multi task process. Some of the activities in this process such as ergonomics review and assembly verification require space imagination and can therefore be dealt with more aptly by using 3D virtual representation of products. Some desirable characteristic features and functionalities of truly 3D product visualization environment have been mentioned in some design research as well as computing and computer graphics publications, and some researchers have recently directed their efforts towards achieving these desirable features and functionalities. In summary, much of the recent research efforts have focused on the development of: (i) hardware and software technologies for supporting 3D creation, visualization, and manipulation of virtual objects [19], [20]; (ii) spatial interaction techniques that allow product developers to express spatial information and intent directly in space [21]; (iii) methods and tools for supporting collaboration in virtual environments [22]; and (iv) visualization devices that combine both input and display functionalities in a single device [23]. [24]. Overall, the general consensus is that in order to comprehensively support spatial product visualization, it is imperative that the visualization device used should be sufficiently interactive, and should also provide visual cues, including stereopsis, relative size, light and shadows, perspective, occlusion, and interposition cues. The displayed 3D virtual models should occupy physical volume of space and should be represented volumetrically (i.e. with 3D data). The visualization devices presently used in design and other product development activities provide only some of the above-mentioned capabilities. Apart from visualization, other sensory inputs such as 'touching' are also vital, and can, for instance, enable viewers feel the presence of virtual objects. "Touching" a virtual object would probably require a special display system with, e.g., a "haptic interface" to transmit forces back to the hands or fingers of a viewer in a way that mimics the sensation of touching a real object [25]. The expectation is that using natural modes of communication such as hand-motions, gestures and speech in interacting with the images generated by 3D visualization devices would enable the product developers to explore their designs more aptly.

In the light of the above technological needs analysis, we concluded that apart from the need to consider classical usability requirements, specific requirements such as visualization requirements (including e.g., resolution, realism of images, etc.) and interactivity requirements (including e.g., direct accessibility of images in a 3D space, intuitiveness, etc.) – see Figure 2 - should also be considered in the selection of a truly 3D product visualization device. As for visualization, apart from the obvious needs such as providing the capability to display 3D images with sufficient resolution and proper lighting, the visualization system should also, for instance, generate images in physical volume of space, it should provide wide field of view to allow multiple viewers to view images from different perspectives, it should permit viewers to walk around the 3D virtual object, and so forth. These requirements (see Figure 2) were used as benchmarks in the selection. A two-stage analysis and selection process was followed: first, the suitable type of visualization technology was selected and after that a specific visualization device was selected as described in the following sections.

4.2 Technology Type Selection

The requirements for a spatial product visualization device introduced in the previous section and shown in Figure 2 served as the basis for assessing the appropriateness of various types of competing 3D visualization technologies (refer to [10], [18] for further details). The process involved (i) reviewing and analyzing the capabilities of the existing types of 3D display technologies (alternative visualization technologies considered included stereoscopic visualization devices such as head/helmet mounted displays (HMDs) and 3D glasses commonly used for visualization in CAVE systems and other virtual reality (VR) systems; autostereoscopic display technologies; swept volume displays such as Felix 3D display (http://www.felix3d.com) and Perspecta display (http://www.actuality-systems.com); aerial projection display technologies such as Heliodisplay (http://www.io2technology.com) and the FogScreen™ display (www.FogScreen.com); and aerial



Summary of fulfillment rates

Requirements type	% fulfilled	% partially fulfilled	% not fulfilled
Visualization	70	5	15
Interactivity	49	38	13
Computational	56	22	22
Ecological	57	14	29

Figure 2. Criteria used as benchmarks for 3D visualization technology selection: Key: (F) = fulfilled; (P) = partly fulfilled; (N) = not fulfilled.

volume filling displays such as holographic displays), (ii) identification of the possible kinds of support that could be provided by each type of 3D visualization technology, and (iii) selection of the appropriate category of 3D visualization device based on formal criteria. Aerial volume-filling visualization technology was eventually identified as the appropriate category of visualization technology for our experimental spatial product visualization system. Although most of the existing aerial volume-filling 3D visualization technologies comply with only a subset of the selection criteria, they can still more aptly support the desired form of product visualization.

4.3 Choice of a Specific Visualization Device

The next step was to choose a visualization device that meets our specific needs. As mentioned in Section 4.2, aerial visualization technology type emerged as the most appropriate type of display solution for our product visualization needs. There are many aerial visualization technologies on ground (such as display technologies based on electro-holographic techniques or optical holographic techniques), each offering different display capabilities (workspace/screen sizes, number of colors, etc.). The question was therefore which specific device should be used as a visualization device for our spatial product visualization environment? Apart from the criteria shown in Figure 2, several other issues needed to be considered as well. These included issues such as: Can the visualization device be integrated with existing devices – such as the hand-motions tracking or speech detection devices available in our lab? Is the visualization device expandable e.g. to suit possible changing needs? Is the visualization system compatible with standard hardware and software platforms? Is the visualization device compatible with the conventional display conventions? Does the visualization device have proper resolution and workspace size? Does the visualization system display realistic and colored images? Can the manufacturer modify the visualization system as and when needed (e.g., can the underlying software be exchanged for the latest version)? Is the visualization system unique (i.e. are there other systems around to glean experience from)? Can the visualization system be housed in our lab environment? Is the operating manual easy to follow? How many personnel are offered free

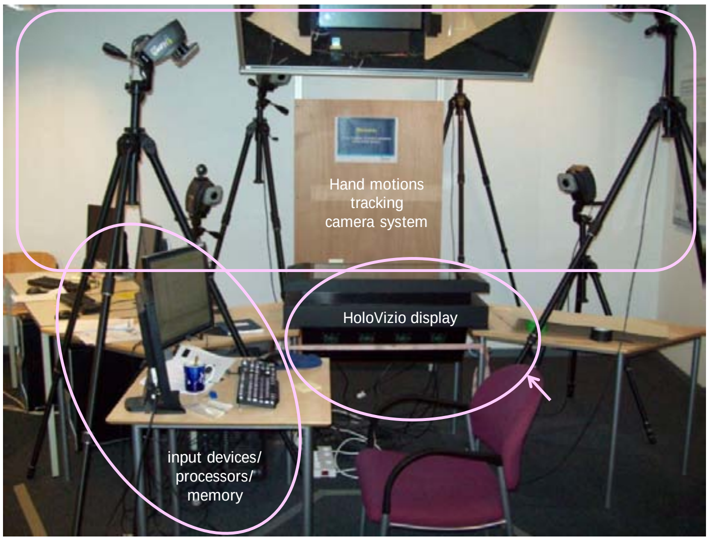


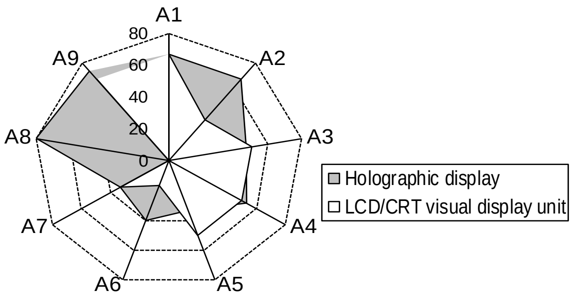
Figure 3. The selected 3D visualization technology (HoloVizio 128WD display) shown as one of the building blocks of an experimental 3D spatial product visualization system (placed like a horizontal panel on a table – it could also be constructed underneath or placed vertically just like a flat panel LCD display).

training? What fees are payable on later enhancements? Can we gain hands-on experience before the visualization system is finally selected?

By using the comprehensive list of requirements we formulated (see Figure 2) as selection criteria and considering the issues mentioned above, decision was eventually made to invest in HoloVizio 128WD display (http://www.holografika.com/) - an electro-holographic display capable of displaying aerial volume filling images. As can be seen in Figure 2, most of the requirements were fully or partially fulfilled. In general terms, the global specifications of the selected 3D display (i.e. the HoloVizio 128WD display) roughly square with those of a "truly" aerial 3D display. It creates a virtual workspace of 720 x 520 x D (D = 350 – 400) mm, with a field of view of 50 degrees, and 32-bit true colour image. No 3D glasses or positioning/head tracking devices are needed in order to experience 3D view, several viewers can simultaneously see the same 3D scene in the display workspace, viewers can see colored 3D images in the display workspace as they would see in reality, and viewers can walk around the display workspace within the field of view seeing the objects and shadows moving as in the normal perspective. This visualization device is compatible with current display conventions, and it is therefore possible, for instance, to display CAD models in the workspace or even to replace, say, a standard 2D desktop monitor used as a visual display unit in an existing CAD system with a HoloVizio 128WD display. The HoloVizio 128WD display has been incorporated in our experimental 3D product visualization environment as shown in Figure 3.

5 A STUDY ON THE APPLICATION PROSPECTS AND ACCEPTABILITY OF HOLOGRAPHIC DISPLAYS

We conducted a study to identify product development activities that can be supported by the HoloVizio 128WD display based product visualization environment and how this visualization environment could be applied in practice. A shortlist of product development activities that could possibly be supported was first compiled (see Figure 4) through brainstorming. Fifteen graduate industrial design engineering students participated in this study and were asked to indicate if they would prefer performing the activities listed in Figure 4 by using a standard flat screen display (such as LCD and CRT display), or by using the case study holographic display. They were first allowed to use and to familiarize themselves with the experimental holographic display in advance (for a period of about one to two months). During the study, subjects were asked to imagine that both display devices (i.e. the HoloVizio 128WD display and the LCD/CRT visual display unit) were set approximately under the same lighting condition and have the same resolution. Figure 4 summarizes the views of the subjects on whether the listed activities could appropriately be supported by using a HoloVizio display or a LCD/CRT visual display unit. As can be seen, most subjects preferred using HoloVizio display over LCD/CRT visual display unit in activities that require space imagination such



Legend: A shortlist of activities that could possibly be supported by using the HoloVizio 128WD display

ID	Activity
A1	Shared discussions during teamwork
A2	Visibility and aesthetics studies on exteriors or interiors of product models
A3	Exterior or interior ergonomic assessments
A4	Review of assembly variations
A5	Reach investigations
A6	Prototyping - can the images be used in place of physical prototypes?
A7	Marketing and advertisement
A8	Presentation tool for 3D concepts
A9	Overall satisfaction – degree to which the display satisfies the user

Figure 4: A radar diagram showing the extents to which the experimental holographic display-based 3D visualization environment support some selected early-phase product development activities

as shared discussions in team works, presentation of 3D concepts, visibility and aesthetics reviews on exteriors or interiors of the product models, ergonomics reviews (i.e. exterior or interior ergonomics assessments), reach investigations, and review of assembly variations. However, the general consensus among the subjects was that the HoloVizio display needs further improvements to make it appropriately support activities such as product marketing, advertisement, and prototyping. Among the required improvements mentioned by most subjects is that the resolution of the device should be improved and it also need to be equipped with intuitive interfaces.

Furthermore, focus group interviews (see e.g., [26]) were also held in several occasions to seek opinions, perceptions and attitudes of various selected experts and possible future users towards the idea of using a holographic display-based visualization environment to support product visualization. The objective was also to determine the strengths, weaknesses and opportunities associated with using holographic display based visualization environment and to identify the application potentials of such an environment. The advantage of these focus-group interviews is that they were more dynamic and they generated a wide range of rich and deeper knowledge through interactions with interviewees. Thirty three candidates participated in these interviews in a period of about three and a half years. All subjects were either design researchers (with IT and computer-aided design engineering background) or graduate industrial design engineering students. Subjects were allowed to use and familiarize with the experimental visualization environment before they were interviewed. Their background ensured that they would have something to say about the visualization environment. All interview sessions were held informally and discussions proceeded in an interactive way - and participants were free to

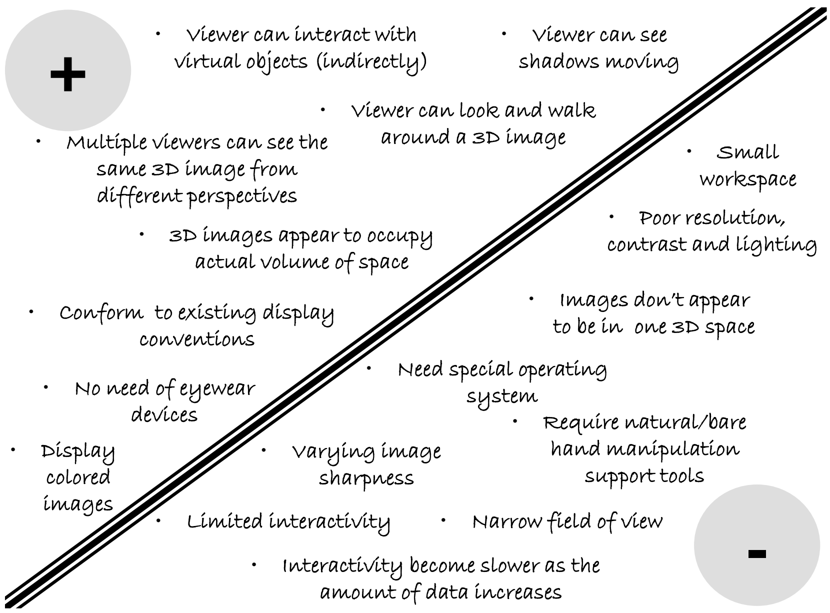


Figure 5. Expressions used most frequently by focused group research participants to describe features of the experimental environment positively or negatively.

discuss various issues related to the case study product visualization environment. The sessions' durations ranged from fifteen minutes to about a half an hour. Notes on what was said in these sessions were taken and after each session we took time to reflect on what transpired, and listed down the keywords and expressions used by focused group interviewees to describe the experimental visualization environments. These focus group discussions continued (for a period of over three years as mentioned earlier) until a clear pattern emerged (- and new interviews seemed to produce no significant new information). Figure 5 shows the keywords and expressions used most frequently to positively or negatively describe the holographic display based visualization environment. Optimistic expressions and phrases such as 'multiple viewers see the same image', 'viewers can look and walk around images', 'can see 3D object from different perspective' and so forth basically describe the characteristic features of the HoloVizio display that can be useful in product development activities that require space imagination such as shared discussion, visibility and aesthetics studies and visualization of 3D concepts. These are in fact the activities that were also identified during the prior study described earlier as activities that can more aptly be supported by the holographic display-based product visualization environment. The negative expressions are essentially suggestions for improving the case study display device to make it better support product visualization.

6 SUMMARY AND CONCLUSIONS

The paper has presented a structured method we put together and used in the selection of a 3D visualization technology. It has also presented and discussed key issues that need to be considered and measures that need to be taken prior to the selection, in particular between the moment a decision is made to invest in a 3D visualization technology and the moment the management approves the implementation of a visualization technology. This structured approach is partly the result of hybridization of some of the existing approaches for selection of new technologies. The application of this approach has led to selection of holographic display as a viable truly 3D product visualization solution. It has been shown that the proposed systematic approach can be of practical use for the organizations planning to invest in advanced visualization technologies. The practical application of the proposed approach has demonstrated that it can systematically guide organizations intending to invest in 3D visualization technologies to make sensible choices by embarking on thorough analysis and evaluation of alternative technologies, thus minimizing the likelihood of clinging to decisions unsubstantiated by the realities on ground. It guides organizations to first carry out comprehensive analyses of existing and emerging visualization technologies, and then to formulate multiple selection criteria and to use these criteria as benchmarks for evaluation and selection of appropriate category of technology and a suitable visualization device. Although this structured approach and the guidelines described in this article are specifically intended for use in the selection of advanced visualization technologies, they can probably be adapted and used in the selection of other technologies as well. It is important to note that the benefits and the impacts of investing in a new 3D visualization technology might be difficult to notice in short term. It sometimes takes a long time until one can notice that investment in a new technology has actually paid off.

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