INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

EXPLORATORY DERIVATION OF INTERACTION MECHANISMS AND FUNCTIONS FOR DESIGNING IN 3D SPACE BY USING 3D VISUALIZATION SYSTEMS

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ABSTRACT
Designing by using Computer Aided Design (CAD) systems normally involves sitting in front of a two-dimensional (2D) computer screen, thinking about an imagined reality, creating virtual prototypes of artifacts by selecting and executing commands from menus of a CAD system, and simulating their behavior in an imaginary three-dimensional (3D) modeling space while viewing images on flat 2D displays. It is understood that this way of designing is to some extent limiting. There is a need of departing from this norm and instead use imaging means and input methods that fit better to the way designers think and work. There has been a growing interest in the investigation of the possibility of using 3D visualization and interaction technologies for creation, visualization and manipulation of virtual objects, mimicking the designers' way-of-life of using physical objects or prototypes. One of the problems, however, is the lack of formal human-computer dialogue methods for designing in 3D space that could sufficiently support creation, visualization, and manipulation of 3D virtual artifacts and enable users express spatial information and intents directly in 3D space. We report on a preliminary exploratory research we carried out as an attempt to come up with appropriate human-computer dialogue methods for designing in 3D space by using interactive 3D displays. Specifically, this research focused on the analysis of the appropriateness of the traditional CAD systems' interaction mechanisms and functions, as well as of the dialogue mechanisms proposed by various researchers and developers of 3D displays for designing in 3D space.

Keywords: Functions for designing in 3D space; spatial design commands, emerging 3D visualization systems, computer aided design.

1 INTRODUCTION
Despite the advancements in computing and computer graphics research, the visualization and interaction infrastructure of Computer Aided Design (CAD) systems has remained almost the same, as it has been for many years. Even the basic paradigm of designing with the aid of computer-based graphical systems in which designers sit in front of a computer screen, think about an imagined reality in mind, select modeling commands from menus of CAD system, create virtual prototypes of artifacts, and simulate their behavior in an imaginary three-dimensional (3D) modeling space while viewing images on flat screen cathode ray tube (CRT) displays or liquid crystal displays (LCDs) has hardly changed over the years. Design methodologists and CAD researchers recognize this ironic situation. As a result, there has been a growing research interest in recent years of exploring the possibility of using the emerging spatial visualization and interaction technologies for creation, visualization and manipulation of virtual objects, mimicking the industrial practice of using physical objects or prototypes [1], [2], [3]. However, creation of a visualization system suitable for designing in 3D space is a huge and complex research undertaking in which various research issues need to be dealt with simultaneously, including laying out suitable interaction mechanisms and functions that smoothly fit into the natural working environment of designers, namely, interaction mechanisms and functions that support 3D creation, 3D visualization, and 3D manipulation of virtual artifacts; and allow designers to express spatial information and intent directly in space.
In this paper, we report on the preliminary exploratory research we carried out as part of our attempt to come up with appropriate interaction mechanisms and functions for designing in 3D space by using the emerging 3D displays. The term function in this article means an abstract entity of a mechanism or

system of mechanisms that allow execution of specific tasks. It associates an input to a corresponding output on an imaging device. It differs from the term command, which refers to an order, directive or communicated information to a computer program, acting as an instruction or explanation for how an action or method is to be executed or conducted in order to perform a specific task. We first describe the background of this research and clarify problem in the following section. In Section 3, we analyze the interaction mechanisms and functions available on the existing CAD systems [traditionally equipped with 2D displays and WIMP (Window-Icon-Menu-Pointing device) style graphical user interfaces (GUIs)] as well as those proposed by various researchers and developers of 3D displays, and short-list those which could be adopted and used in the envisioned spatial CAD systems [i.e. CAD system equipped with 3D displays and 3D input means]. Section 4 presents and discusses the results. This is followed by conclusions and brief description of future work in Section 5.

2 RESEARCH BACKGROUND AND PROBLEM CLARIFICATION

The 3D display technology scene is currently characterized by a large variety of competing display concepts offering a wide variety of visualization options. Some of the emerging 3D display technologies have been applied successfully in the entertainment and advertisement industry. These technologies are also gaining acceptance in other fields, including medical, military training and engineering. In engineering, attempts are being made to use them e.g. to improve product design and development processes. The problem, however, is that most of these technologies are still infant and therefore need further research and development. Numerous research aiming at making them better support the intended activities have been reported. For instance, some research and development projects have recently focused on improving interactivity of 3D displays. For example, Darken and Durost [4] describe a method to identify the dimensional characteristics of a task to ensure appropriate interaction in virtual environments. Raskar and Low [5] describe the notion of spatially augmented reality, in which users can interact naturally with images in virtual environments. Balakrishnan et al. [6] explore the user interface design challenges for volumetric 3D displays in which physical 3D enclosure separate user and image. There has also been parallel research in the past two decades that focuses on studying the possibility of application of natural input methods such as gestures, speech and hand motions. For instance, Dani and Gadh [3] report on a new type of interaction method for shape modeling in which combinations of spoken commands and hand motions are used to model shapes in a virtual reality environment. Bloomenthal et al. [7] present a prototype system named 'Sketch-N-Make' which employs a gesture interface that mimics the familiar pencil sketching practice to enable the user to create rough digital sketches. Eggli et al. [8] describe Quicksketch: a system on which solid objects can be created by using gestural commands. Zeleznik et al. [9] describe a gesture-based interface for sketching in 3D scenes. Kuczogi and Horváth [10] describe a communication model for the user interface of speech based shape conceptualization system.

Several dedicated research focusing on specific related research problems, including on the creation of appropriate mechanisms and functions for interacting with the 3D images displayed by the emerging 3D visualization systems have also been reported. For instance, Peng [11] created a set of tools for users to instantiate and edit 3D graphic elements that can be positioned directly onto the virtual model during 3D concept design modeling, allowing early concept designs be developed as if they are worked out by designers working directly on the site. Foley et al. [12] present a classification of interaction tasks that can be performed on VR systems. Kurtenbach et al. [13] present a system that allows 3D volumetric displays to interact with a number of different input configurations. The user interacts via the input configurations, for example, by moving a digitizing stylus on the sensing grid formed on the dome enclosure surface. This interaction affects the content of the volumetric display by mapping positions and corresponding vectors of the stylus to a moving cursor within the 3D display space of the volumetric display.

Although numerous research aiming at improving the emerging 3D display technologies and enabling them sufficiently support different user groups, including designers, have been reported, further research and development is still needed. For design applications, several issues still need to be explored or understood well, including setting up the suitable ways of using the emerging interactive 3D display technologies and systems. The question of what mechanisms and functions are needed in interacting with 3D images when designing in 3D space by using interactive 3D displays also needs to be dealt with. It is said that the emerging 3D visualization technologies and systems will remain inferior to equivalent two-dimensional (2D) visualization technologies and systems as serious design support tools until the users of 3D displays can interact sufficiently with images in 3D space and access the same data as currently possible on the conventional 2D systems.

3 INTERACTION MECHANISMS AND FUNCTIONS FOR DESIGNING IN THREE-DIMENSIONAL SPACE

We partly dealt with the above-described research questions in the work reported in this paper. The activities involved were twofold, namely: (i) identification of interaction mechanisms and functions in the existing CAD systems that could be adopted and used in spatial design systems, and (ii) identification and characterization of extra mechanisms and functions that might be needed. These objectives have been achieved as follows. We analyzed the mechanisms and functions widely available in CAD systems and short-listed those which could be used in spatial design. We also analyzed the interaction mechanisms and functions presently available on some of the emerging 3D visualization systems and also those proposed in the literature; for instance in [1], [6], [14], [20] and [21] and short-listed those which could be included in interactive 3D display systems, choosing them based on their merits, and also by taking into the consideration the findings of the needs analysis we previously carried out – see [15], [16]. We specifically focused on the identification of interaction mechanisms and functions that could be used to accomplish the conceptual design tasks mentioned in [17]. We first in the following section examine the mechanisms and functions commonly available on the traditional CAD systems equipped with 2D displays, 2D input devices and WIMP style GUIs. We then examine the interaction mechanisms and functions proposed by the developers of 3D displays and various researchers in Sections 3.2 and 3.3 respectively.

3.1 Analysis of the Appropriateness of the Traditional CAD Systems' Interaction Mechanisms and Functions

The prevailing CAD systems offer a wide range of menu items (i.e. collections of functions) that provide the user with the capability to create and interact with graphical images displayed by the graphical output devices of these systems, which traditionally are 2D screens. Figure 1 illustrates the way menus are commonly organized in CAD systems. Typical menu items in these systems include, for instance, *draw* (i.e. creating basic geometric elements such as points, lines, circles, fillets and chamfer corners, hatches, etc. automatically); *modify* (deleting, rubbing out or erasing any part of drawing, re-scaling drawings, adding lines or features to existing drawings, inserting and editing text, copying, rotating and dragging (i.e. move) any part of a drawing); *zoom* (expanding or contracting an area of the visual image of the drawing on the screen); *rotate* (achieving geometric transformation to enable the user to view geometric models from different angles), and *extend* (extending or truncating curves, lines or surfaces). Others include *translate* (transforming the model so that every entity of a geometric model remains parallel to its initial position); *trim* (extending or truncating curves, lines or surfaces); *mirror* (a function for construction of symmetric models); *stretch* (stretching the undersized end-point to the desired location); and *scaling* (changing the size of an entity).

These sorts of menu items are used in the construction of both 2D profiles and 3D models (i.e., wire frame, surface and solid models). The starting point in the process of generation of 3D models in some 3D modelers are 2D profiles; which can then either be '*swept*' along a line, '*spinned*' about an axis, '*copied*' and '*moved*' backward or forward and the two surfaces joined or the depth of the 2D profile defined to create 3D object. Some systems also allow users to create objects using primitives, i.e., using basic solid objects like cones, spheres, blocks, and cylinders, which can then be combined in several ways using Boolean operators - see e.g. [18] and [19]. The available menu items allow CAD systems to communicate with users in one of the three ways, namely: by producing graphical outputs on a flat 2D screen or printer, by text outputs on a 2D screen or printer, or by audible outputs through an audio speaker. Menu selection is the common interaction style for CAD systems. The user typically make a selection from a predefined set of menu items by e.g. controlling cursor position with a mouse, hitting a function key, typing a menu item label on a keyboard, pointing with a light pen, touching a sensitive panel, or by selecting thorough a tablet. The user can in this way input geometric information items such as locations of geometric elements, lengths or basic solid objects as the building blocks for creating graphical representations or images of the product on a 2D display. The user can subsequently work with the graphical representations by using the control functions such as scale, stretch, modify, etc. The graphical outputs on flat 2D screens are essentially the 2D or 3D images that viewers would have drawn on a piece of paper.

It can be said that some of these menu items (i.e. functions) could be adapted and applied for designing in 3D space by using interactive 3D displays. These include, for instance, Boolean functions (BF), which allows uniting, intersecting and subtracting primitives; editing functions (EF), which could be used to perform operations such as erase, undo, redo, copy, paste, cut and trim; primitive creation functions (PCF), which could be used for creation of basic solid object elements such as spheres, cubes, cylinders, cones, etc. Others are browsing and retrieval functions (BRF), which could be used for browsing and retrieving information in the form of text, images, etc.; engineering analysis functions (EAF), which could be used in stress analysis, etc.; object visualization functions (OVF), which could be used for rotating, turning, and zooming in/out images; and system management functions (SMF), which could provide tools for, e.g., opening existing/new document, saving/saving as files, and importing or exporting files. Apparently it is widely perceived that these functions are insufficient for designing in 3D space; see e.g. [3], [10], [21] and [23]. Many additional functions are needed to adequately support creation and manipulation of 3D images in 3D space. In the following sections, some human-computer dialogue mechanisms recently proposed for interaction with 3D models displayed by 3D displays are presented.

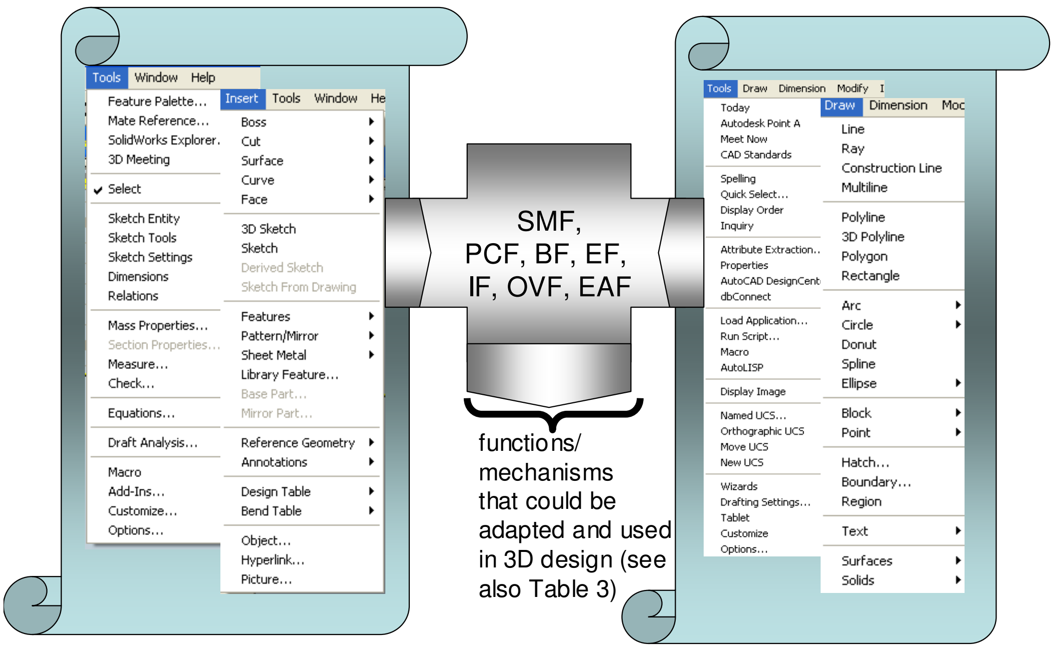

Figure 1: Typical organization of menus in CAD systems. Menus items usually represent a collection of functions offered to the user at a specific dialogue step.

3.2 Human-Computer Dialogue Mechanisms Proposed by the Developers of the Emerging 3D Imaging Devices

Research and development in computing and computer graphics fields have lead to creation of various means and methods for interacting with the images displayed by some of the prevailing 3D imaging devices. Table 1 lists some of the 3D human-computer object creation, visualization and manipulation instructions that have been proposed by some computing and computer graphics researchers. The execution of these instructions will require specific techniques, mechanisms and functions, which will allow the user to get through the intermediate steps needed in accomplishing specific tasks and also to manage the placement of data and graphical information on a 3D display. Several mechanisms that could be used in the development of 3D human-computer instructions have been proposed and tested by some researchers – see e.g. [4], [6], [12], [20], [21]. It should, however, be noted that most of the 3D display technologies and devices are quite novel. Thus, most of these mechanisms have only been tested using high fidelity mockups and props, which have enable the developers glimpse the future with minimal prototyping efforts. It can be said that some of the mechanisms related to the instructions listed in Table 1 can be adapted and used in the execution of spatial design tasks.

Table 1: Some of the 3D human-computer instructions proposed by some computing and computer graphics researchers

Instructions	Type of 3D display	Description	Reference/ Further Readings
Execution	Volumetric 3D display	Execute commands via menu-item selection or text entry	[6]
View	Volumetric 3D display	Using techniques such as magic lens or projection shadow to adjust scene contents to better view or interpret all 3D information	[6]
Move	Volumetric 3D display	Place an object in the 3D scene or drag it through one to three dimensions	[6]
Navigation	Volumetric 3D display; VR system	Pan, tilt or zoom the 3D scene	[6], [21], [22]
Path generation	VR System	Generate a series of positions and orientations over time	[4], [12]
Positioning	VR System	Indicate a position on the display or in the workspace	[4], [12]
Quantification	VR System	Specify a value to quantify a measure	[4], [12]
Rotate/ Orientation	VR System, Volumetric 3D display	Orient an object in the 3D space/Alter the orientation of an object in the workspace	[4], [6], [12], [21]
Emailing	VR system	Quick way to show/email 3D sketch to others	[20]
Printing	VR system	Printing views as 2D images	[20]
Animation	VR system	Animated technical presentations	[20]
Illustration	VR system	Authoring tool for 4D illustrations of documentations, books, etc.	[20]
Export/Import	VR system	Exporting/importing geometry to/from other packages	[20], [22]
3D Sketching	VR system	Quick 3D sketching for a single user	[20]
Scale	VR System	Shrink or enlarge an object	[6], [21]
Selecting	Volumetric 3D display, VR System	Make a selection from a number of alternatives or move object within a scene and provide feedback such as highlight or vibration	[4], [6], [12], [21]
Text input	VR System	Input or output of a text string	[4], [12], [20]

3.3 Interaction Mechanisms Proposed by Design and HCI Researchers for Creating and Manipulating 3D Virtual Objects in 3D Space

Design and human computer interaction (HCI) researchers have also keenly been striving to devise appropriate mechanisms and functions for interacting with 3D images in 3D space by using natural modes of communication such as hand motions, verbal utterance and gestures. Some of the words that could be used in the execution of some interaction tasks, e.g. during construction of conceptual shapes in

3D space have been created [Table 2]. Overall, the claim that the emerging input means could be used alongside the emerging 3D visualization systems in spatial design holds promising theoretical considerations, though there are important unanswered questions as well. In general terms, apart from the fact that the available technologies still need further development to make them better support designing in 3D space, there is also a need to conduct further design research and HCI studies. This includes, for instance, studying the effects of the emerging input and output technologies on the performance and on workload distributions in CAD processes and developing suitable methods for designing in 3D space by using natural input means.

Table 2: Some of the hand-motion 3D sculpting words proposed for human-computer dialogue in 3D space by some design researchers [14], [23]

Type of 3D sculpting word	Description
Procedural	Include words such as start, stop, share, obtain, neutral, end, resume, undo and redo. Used to define the starting and end of postures that enclose hand motion
Geometric	User in the construction of shape model. Include commands such as plane, cylinder, cone, sphere, ellipsoid, and free form – which are used to specify respective half spaces (i.e. planar, cylindrical, etc.)
Identification	Used to indicate and to select basic shape elements such as points, curves, etc. Include the following commands: Identify point, curve, surface and object.
Connectivity	Connect shape elements in various ways, e.g. surface-to-surface, surface to curve or vice versa, surface to point or vice versa, curve to curve, curve to point or vice versa, and point to point
Positioning	Used to orient object in 3D space and to quantify/indicate dimensions or measurements
Scaling	Used to shrink or enlarge a virtual object by indicating the distances between two surfaces, curves, or points. Also to shrink or enlarge angles by indicating the orientation of two surfaces or degrees; as well as for zooming in/out to increase shape proportionally.
Assembly	Used to put/separate/compose/assemble/ disassemble/put aside/bring in/cut through/ cut out entities. Include mechanism for constructing, deconstructing, composing, decomposing, assembling, disassembling, putting aside, bringing in, cutting through, and cutting out.

4 RESULTS AND DISCUSSION

Figure 2 illustrates our approach and shows categories of interaction mechanisms and functions that have been short-listed for designing in 3D space by using interactive 3D displays. There are many different configurations of 3D display devices [15], [16]; and images may be displayed differently on various devices. Interaction with the images displayed on these devices would definitely depend on the configuration of the 3D device in question and the way images are displayed. In our work, we focused on the identification of mechanisms and functions that could be used for designing in 3D space by using 3D displays that generate volume-filling 3D images, namely, enclosed volume 3D displays [such as *Felix 3D display* (http://www.felix3d.com) and *Perspecta display* (http://www.actuality-systems.com/)] and airborne 3D displays [such as *Heliodisplay* (http://www.io2technology.com/) and *Vizoo's FreeFormat*^{TM} (http://www.digitalexperience.dk/)]. In enclosed volume 3D displays, 3D images are generated in various ways, including by using *swept-volume* technique and *static-volume* technique, and are displayed in enclosed spherical, cylindrical or curved volume. Airborne displays are screen-less imaging devices, in which the visualization of images do not require any specific viewing space or a physical screen. Viewers typically see the 3D images suspended in mid-air. Several

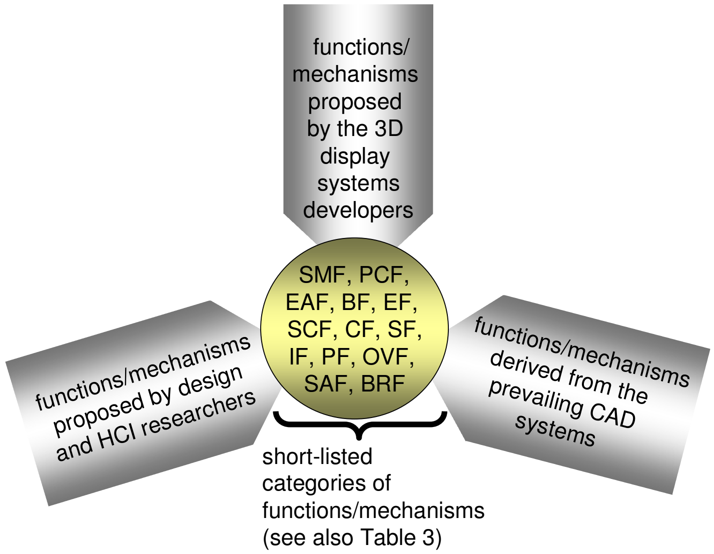

Figure 2: Short-listed categories of 3D interaction mechanisms and functions. These could be adapted to provide designers with means to create and manipulate 3D virtual objects in 3D space

techniques are used in these displays, including holographic techniques. Airborne and enclosed volume 3D displays are among the 3D imaging devices that seem to have the largest potential to support designers, especially in the early stages of the design process. Thirteen categories of mechanisms and functions have been short-listed [Figure 2]. Some of these are novel, some of them have been derived from the existing CAD systems, and others have been created by the developers of 3D display systems. These mechanisms and functions could be adapted and used to support various 3D design tasks including e.g. creation of and assembling of free-form shapes, tracking locations in space, and for navigation in 3D space. Utilization of interactive 3D displays with these sorts of interaction mechanisms and functions in design will mimic the natural work environments of designers. It should be noted that the emerging 3D visualization systems can be used either much like a printer, providing a peripheral device to display 3D images, with interaction done via standard 2D PC-based input devices, or as a primary display and interaction platform. This research targeted the later application scenario, which obviously in unconventional, and therefore call for development of suitable interaction mechanisms and functions, user interfaces and input devices for designing in space.

Many developers of 3D display systems see engineering design a clear future beneficiary of their products. The greatest potential is in shape sculpting, where there is often the need to expressively and quickly create and modify shapes, especially in the early stages of the design process. If flanked with appropriate 3D sculpting tools, these technologies would enable users to more conveniently sculpture various forms of shapes. Industrial designers are likely to be among the main users, and could possibly use interactive 3D displays in the early stages of the design process to construct and modify 3D concept models. There is also a great potential of using these displays for virtual prototyping, e.g. in shipbuilding firms, aerospace industry and in automobile industry. In particular, interactive airborne 3D displays would provide accessible virtual environments, in which, e.g., assembly and disassembly, and even the ergonomics of the designs could be experimented. This would mean a reduction of the dependency on the expensive physical mockups, and a shift to digital prototyping practice in these industries. Widespread use and acceptance of the emerging 3D visualization technologies and systems would, however, depend on several factors, including, for instance, availability of suitable methods for designing in 3D space and prices of the display devices and peripheral devices. Overall, the situation is such that 3D visualization tools are increasingly being embraced by design firms nowadays as the falling cost of computer power makes them more affordable. Various manufacturers of products are joining automakers and aircraft manufacturers in using these technologies, not only to speed up and improve product design, but also e.g. to train workers and configure factories and stores.

Table 3 compares the status quo practices (i.e. designing 3D objects using flat 2D displays and 2D input means) vs. designing in 3D space using interactive 3D display devices and natural input means. It is important to emphasize that using 3D displays as primary design and visualization tools would possibly mark a departure from the present practice of designing by sitting in front of a 2D computer screen, thinking about an imagined reality in mind, selecting modeling commands from menus of CAD system, creating virtual prototypes of artifacts and simulating behavior in an imaginary 3D modeling space, while viewing images on flat screen displays.

Table 3: A comparison of the existing way of designing using CAD systems vs. designing using the envisioned spatial design systems [Legend: SMF = System Management Functions such as Open existing/New document, Save/Save as, Import/ Export; Select BF = Boolean functions, i.e. union, intersection and difference; EF = Editing functions e.g. erase, undo, redo, copy, paste, cut, trim, etc. 2DPCT = two-dimensional profile creation functions such as for creating line, circle, chamfer, etc; PCF = Primitives creation functions, e.g. for creation of sphere, cube, cylinder, cones, etc.; SCF = Surface Creation Functions e.g. for creating planes, cylindrical, spherical, ellipsoids, conic surfaces and freeform swept surface; SAF = Surfaces assembly functions such as join, etc; SF = Scaling functions e.g. increase/reduce distance between the surfaces or points, flatten, OVF = Object Visualization Functions such as rotate, turn, zoom in/out); CF = Connectivity Functions such as for connecting surface to surface, surface to curve, surface to point, etc.; IF = Identification functions e.g. for identifying/selecting point, plane, curve, shape etc. PF= Positioning Functions e.g. turn, increase or decrease distance between points, curves, planes etc.; BRF = Browsing and Retrieval Functions, e.g. commands for browsing and retrieval of information in the form of text, images, etc.]; EAF = Commands for preliminary stress, temperature, manufacturability, etc. analyzes]

	PREVAILING CAD SYSTEMS	**USING INTERACTIVE 3D VISUALIZATION SYSTEMS**		
		Mediated stereoscopic displays	**Enclosed volume 3D displays**	**Airborne 3D displays**
Display device	Flat screen monitors, e.g. CRT, LCD, Plasma and DLP displays	Visualization using head/eye-wear devices e.g. HMDs, CAVEs	Spherical/cylindrical/ curved screens. 3D images are formed by sweeping 2D images	Aerial space – i.e. the images displayed in mid-air
Input method	1D/2D input devices e.g. keyboard and mice	Most 3D displays are used primarily for passive visualization. However, some have mechanisms by which viewers can use e.g. rotate, translate or zoom images with bare fingers/hands.		
User interface	WIMP style GUI	No formal user interface		
Field of view	Less than 180-degrees viewing	180 – 360 degrees of viewing	360-degrees all-around viewing	360-degrees, all around-in-and -through viewing
Ways of designing	User sits in front of 2D screen, thinks about an imagined reality, selects commands from a menu, create and simulate images on a 2D display.	Multiple users can walk into and around 3D images and view the images simultaneously. Current research efforts aims at creation of haptics, gestures and hand-motions based natural interaction means which viewers could use to manipulate virtual objects. This will enable them create 3D images, walk directly into and/or around the images, interact with images (i.e. write and draw in the air), walk through the drawn images, and feel the presence of virtual objects.		
Functions/ mechanisms	SMF, 2DPCT, PCF, BF, EF, EAF	CAD Systems' functions/mechanisms that could be adopted: SMF, PCF, BF, EF, EAF Additional functions/mechanisms; SCF, CF, SF, IF, PF, OVF, SAF, BRF. Additional SMF and EF (e.g. start, end, share, obtain, neutral, stop, resume) needed to support collaboration.		

Rather, it should be stressed that we envision a different paradigm of designing in 3D space with the aid of interactive 3D graphical visualization systems in which the designers will use e.g. haptic/tactile, gesture and hand motions commands to create and manipulate virtual 3D objects, and will be able to walk directly into and/or around the images, interact with them, write and draw in the air, walk through the drawn images, and feel presence of virtual object.

5 CONCLUSIONS

The paper has presented part of our research on exploratory analysis of the possibility of using the emerging interactive 3D displays as primary visualization and interaction devices when designing in 3D space. The focus was on the identification of the interaction mechanisms and functions needed for designing 3D objects in 3D space by using the emerging 3D displays. Thirteen categories of interaction mechanisms and functions have been identified. These mechanisms and functions can be adapted and applied to support various 3D design tasks, including e.g. creation and assembling of free-form shapes, tracking locations in space, and for navigation in 3D space. Investigation of the sufficiency and completeness of the short-listed mechanisms and functions was not the subject of exploration in the work reported in this paper. Further research is therefore needed to explore and to come up with additional interaction mechanisms and functions to complement those identified in this work. Overall, the interaction mechanisms and functions for an interactive spatial design system should be consistent with the natural ways of working of designers, in terms of image creation, visualization and manipulation support. It would be necessary, for instance, to use the existing 3D displays as prototypes or physical mock-ups to explore the adequacy of the short-listed mechanisms and functions. There is also a need to conduct further research, development and HCI studies, including, for instance, to study the effects of the short-listed mechanisms and functions on the performance of the users. It is, however, important to mention that shifting from 2D to 3D displays could push design by using computers into a whole new dimension, literally, and the consequences could be enormous. It could, for instance, imply or call for: (i) a different methodological infrastructure for designing 3D objects, (ii) new data exchange and interface formats, and (iii) perhaps even significant restructuring and changes in industrial practices.

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