Title:
Conceptual Modeling in Product Design within Virtual Reality Environments: Interaction and Geometry Representation

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Keywords:
Virtual Reality, Conceptual Design

DOI: 10.14733/cadconfP.2020.162-166

Introduction:

For a few decades, CAD has become a widely established tool that serves a great variety of activities taking place across the product development process. Regardless of any specific category of product, the idea of generating its digital representation is essential to achieve a properly integrated workflow in relation to several tasks, such as performance evaluations, simulations (e.g. finite element analysis or computational fluid dynamics simulation) or manufacturing related aspects. With reference to the conceptual design stage though, most designers make still use of analog tools like pencils and paper, or their digital counterparts, to sketch their ideas on 2D supports, despite the fact that more enticing alternatives, based on immersive experiences enabled by Virtual Reality, have become widely available.

In this research work, the reasons of this mismatch are investigated. Firstly a description of the state of the art that gathers the most significant works in this domain has been provided. In the attempt to draw a sensible classification, a number of categories have been considered as the main metrics to organize the studies that have been mentioned. Specifically, they define the geometry representation on one hand, which varies between parametric and mesh based methods, and the interaction methods on the other. At the current state, a few issues became apparent in most cases, from weak connections between the modeling paradigm and the interaction systems, to ergonomic problems and, most importantly, the lack of a reliable protocol to assess in an objective way the differences across the studies that have been considered when reading the results of testing sessions.

To get concrete evidence of this criticalities, an experimental session has been organized, involving users with different educational backgrounds ranging from Product Design to Mechanical Engineering. They were asked to produce conceptual sketches of an existing product, a computer mouse, by exploiting three different methodologies: firstly they used a traditional setup based on pencils and paper, then two off-the-shelf Virtual Reality applications were tested, one based on immersive sketching, the other on simulated sculpting. From a preliminary comparison of the sketches made by each user, the results indicate that VR systems don't have a huge impact on the quality of the outcomes, regardless of their preexisting skills. Often though, VR systems tended to cause high levels of fatigue after prolonged use. At the moment, the size of the analyzed sample doesn't provide any statistical evidence, though preliminary outcomes are already good indicators of the maturity of this technology when exploited as a conceptual design tool, paving the way for future research directions.

		INPUT METHODS			
		STANDALONE DEVICES		HAND TRACKING	
		Sticks	Joysticks	Gloves/Rings	Bare hands
GEOMETRY REPRESENTATION	Parametric	[1], [12], [15], [17]	[8], GravitySketch	[7], [9]	[4], [11], [14]
	Mesh	[18]	[19], Kodon		[2], [6], [10]

Table 1: Classification of immersive systems for conceptual design.

Classification:

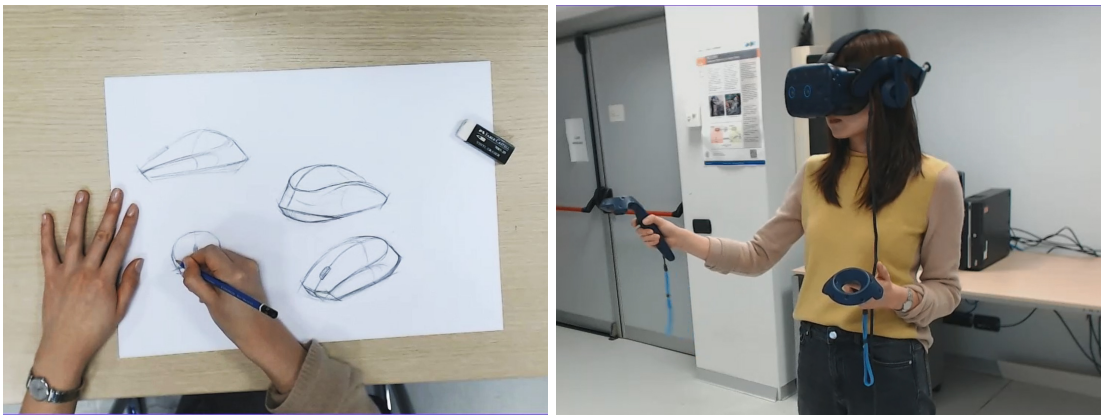
Modeling paradigms and input methods are the categories chosen for the classification (Table 1) . Paradigms describe the way according to which the digital structure of the data is translated into the resulting geometry. As a result, CAD-inspired workflows retain the underlying semantic (features, history trees, etc.) of a parametric approach even with reference to immersive user experiences. On the other hand, mesh-based representations are better suited to manage organic geometries based on free forms at the expense of rigid, parametric representations. Regarding input methods, a first level distinction is made according to the nature of the tracked objects to be used as input devices. They can either be stand-alone controllers, often resembling pens, wands or remotes, or hand tracking systems, such as data gloves or optical sensors allowing bare hands recognition. Moreover, considerations involving the implementation of voice commands have been ignored, since they are not considered strictly relevant in the context of an analysis of the interactions that is inherently related to their spatial deployment. Grounding on this set of terminologies, a new classification is proposed (Table 1)

In the VirDe system [12] and in the work by Kwon et al. [15], prompts are provided through a wand device to operate solid and surface generation features in the former, and more complex NURBS based geometries in the latter. Mine et al. [17] and Feeman et al. [8] have been working on transferring the core features of popular modeling applications (SketchUp and Fusion 360 respectively) in a VR environment, while providing inputs through a custom-built controller to be integrated with a smartphone in the first case, and through commercial VR controllers in the second. Air-Modelling [1] focuses on the generation of simple solid geometries to be displayed in the context of a real environment through an Augmented Reality system, so that the dimensions, proportions and positions of the 3D shapes can be verified in real time.

On the other hand, Proto-TAI++ [18] proposes a mesh-based representation of bidimensional simple thin shapes to be drawn on a tablet and assembled in the 3D space by means of a physical proxy which reflects their position and orientation.

SurfaceBrush [19] presents a modeling interface derived from the more popular TiltBrush application, and is supported by a specialized surfacing algorithm that converts raw artistic strokes into a manifold, meshed surfaces.

Regarding those application based on hand tracking methods, Mockup builder [7] is a system that recognizes the position of the user's fingers through special devices to be worn as rings, in order to draw simple flat shapes on a multitouch, stereoscopic panel so that they can be later extruded in the third dimension. Another approach is the one proposed by Fuge et al. [9], where custom built data gloves are used to draw point clouds in space that are later converted into surface geometries. In the works by Cohen et al. [4], Cui et al. [6] and Bordegoni et al. [2] a bare hand recognition system has been implemented by means of a Leap Motion device. In the first study, the system allows to virtually pick and move in the



(a) (b)

Fig. 1: (a) Tester involved in the 2D sketching activity and (b) tester wearing an HTC Vive Pro device and holding controllers while operating in the VR environments

3D space the control points of NURBS curves and surfaces by means of a natural gestures interface. The second one aims to apply the same kind of interactions within the workflow of traditional mesh-based modeling applications (e.g. Maya). In the third one, the goal is to virtually edit 3D geometries that have been previously extracted by scanning physical products, while reproducing through a mechanized metallic strip the curvature of the target surface along a given cross-section. Huang et al. [10] present an application in which user generated 3D sketches are digitally beautified and converted into simple shapes to be later assembled together. Older, similarly implemented applications are the ones proposed by Kang et al. [14] and Hummels et al. [11].

Also software houses have recently started to commit to the development of digital tools in this domain. This can be intended as a clear signal that there is an actual interest from a marketing point of view, meaning that such applications are mature enough to be be made commercially available even outside the branch of academic research. Relevant examples are (see Table 1), that has been implemented as a EU funded project, and Kodon (see Table 1), that are also the two systems that have been later adopted for the testing session. Gravity Sketch is based on a VR environment where the user can produce curves and surfaces in the form of virtual strokes, by means of standard VR controllers (e.g. HTC, Oculus). Kodon implements is a digital sculpting platform that is operated with similar hardware.

Discussion:

A crucial problem in relation to the analysis of prior research work is the lack of an established protocol to assess the significance of the tests, when they have been performed.

At this point, the goal of this study is to tackle this very problem, in the attempt to compare more traditional 2D sketching techniques 1a with VR based methodologies 1b. For this purpose, two commercial applications have been investigated: Gravity Sketch and Kodon. The former is an immersive 3D sketching tool that simulates virtual strokes, while the latter is a clay modeling simulator based on voxel models.

3D sketching within a digital environments represents one of the most interesting methodologies among state of the art proposals. The user in this case is able to draw 3D curves and surfaces by means of natural gestures interfaces. As described, a system like this is the most natural evolution of traditional 2D sketching, since the third dimension can be "unlocked" with reference to the available workspace,

empowering the designer with a larger set of possibilities.

Sculpting applications are enticing alternatives to 3D sketching. Despite being targeted to the digital artists community, they may prove their utility even in an industrial design context, since their working principle basically consists of a digital simulation of the physical clay modeling activity, which often occupies a very relevant spot within the general product development process for validation purposes in many domains. In this case, the user is provided with a set of tools to add, subtract or smooth material.

A testing protocol has been devised by involving three people with Product Design and Mechanical Engineering backgrounds and asking them to reproduce the shape of a computer mouse by means of the aforementioned tools. From preliminary results, VR systems don't have a dramatic impact compared to 2D sketching tools with reference to the quality of the outcomes: in other words, users did not come up with better representation with VR tools, meaning that the users' skills kept consistent across each methodology, and predictably, the only designer taking part to the experiment produced the best representations. Furthermore, VR systems were reportedly causing fatigue issues in most cases, a problem that clearly does not affect 2D sketching.

Establishing metrics in a rigorous way is among the most critical aspects in this research field. Quantifying the quality of the outcomes in a reliable way is a goal that needs a larger sample of user to be accomplish, in order to indicate what are the main parameters that are worth to be considered. From this preliminary session, it seems quite clear the necessity to normalize the results for each tester, because the range of skills tends to be very wide, so it's quite pointless to rank the outcomes on an absolute scale.

Further testing then is necessary to define more rigorously the research direction in this domain, while achieving a sufficient level of statistical significance to provide more meaningful insights.

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