Benchmarking of 3D Modelling in Virtual Reality

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Abstract. Virtual reality is getting more and more interest for supporting engineering activities in industry 4.0, especially for reviewing candidate design solutions. Nevertheless, the modelling of the geometry is still based on traditional CAD software before being transformed into polyhedral objects that can be visualized with a virtual reality device. However, in the future, we may expect engineers to directly sculpt 3D shapes in virtual reality. In this paper, we conduct a systematic literature review of existing proposals that aim at modelling 3D shapes in virtual reality. Then, we compare them in a benchmark that helps us to draw conclusions on the current limits and future research perspectives. The benchmarking of existing academic and commercial solutions revealed two conclusions: 1) there is no environment that supports all requirements of the benchmark, and 2) most of the commercial 3D modelling environments in virtual reality only address polyhedral meshes whereas engineers need to manipulate CAD B-REP geometry to edit and refine geometry and make kinematic assemblies

Keywords: Virtual Reality, Computer-Aided Design, 3D Modelling, Conceptual Design, Systems Architecture.
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1 INTRODUCTION

Virtual reality (VR) is getting more and more interest for supporting engineering activities in industry 4.0, especially for reviewing candidate design solutions. Nevertheless, the modelling of the geometry is still based on traditional CAD software before being transformed into polyhedral objects for VR. However, in the future, we may expect engineers to parsimoniously sculpt 3D shapes in VR. Indeed, immersive modelling has three main advantages: 1) designers directly interact with the 3D modelling environment in near-real time, 2) designers can manipulate a full-scale model in the VR environment, and 3) VR provides an intuitive environment which can be used for early product development [1]. In this paper, we address the question: What are the current state-of-the art CAD capabilities and limits in virtual reality?

To answer the question, we have conducted a systematic literature review of existing proposals that aim at modelling 3D shapes in virtual reality. Then, we compare them in a benchmark that helps us to draw conclusions on the current limits and future research perspectives.

2 METHOD

2.1 Literature Review

The literature review followed a systematic process:

- [Identification] A manual web-based search in the Google Scholar database with keywords such as “Virtual Reality”, “Computer-Aided Design”, “3D modelling” and “Geometric modelling” leaded to a collection of 16 conference proceedings and journals since 2010. In parallel, the same keywords served as Google queries for searching commercial and open source CAD solutions in VR.
- [INITIAL SCREENING] Journal articles and conference proceedings were reviewed by two different researchers. After reading the abstracts, both reviewers excluded 13 irrelevant papers from the literature review because they were too old or out of scope.
- [REFERENCE LIST SEARCHES] Inclusion of 6 articles identified through the list of references provided by the papers previously selected.
- [FOLLOW-UP SEARCHES] Inclusion of 4 articles identified through follow-up searches based on an extended list of keywords collected in the papers previously selected.
- [FINAL SCREENING] After reading the abstracts of newly selected articles, reviewers excluded irrelevant papers from the literature review.

2.2 Benchmarking

[Define criteria] We propose categories (e.g., geometric entities, dimensional constraints, geometrical constraints, volume operators etc.) to organise criteria (e.g., geometrical constraints = {coincident, perpendicular, parallel, concentric, tangent, etc.}). The list of CAD criteria results from the extensive experience in CAD of the authors. A manual review of two widely used commercial CAD software including (3DExperience and PTC Creo) enabled to crosscheck the required capabilities too.

[Collect existing solutions] Then, we compiled existing academic, commercial and open-source CAD solutions in virtual reality.

[Evaluate existing solutions] We evaluated each candidate solution with respect to the criteria. The evaluation was carried out by software testing, literature review, or demonstration (webinar, tutorial and marketing videos, etc.).

[Compare existing solutions] Finally, we provide assessment of results with a score that enables us to compare existing candidate solutions for CAD in virtual reality.

3 LITERATURE REVIEW

Accessing and editing CAD features (names, sketch constraints, feature parameters) into a VR environment is difficult [2]. Bourdot et al. [2] proposed a tool enabling implicit edition of the CAD construction history graph (CHG) inside a VR environment. This approach consists in 1) selecting B-Rep entities through 3 DOF VR pointing devices 2) identifying its parameters and parent sketch or B-Rep entities, and 3) editing parameters using VR pointing devices such as location and length. The underlying algorithm relies on the naming of B-Rep entities that enables the retrieval of their parent CAD operations and B-Rep geometry. The demonstrator, which relies on the OpenCASCADE CAD kernel, implements the implicit editing of sketch extrusions: dragging a face, moving an edge, dragging a sketch curve. However, they found that the hand gesture tracking method had a poor precision, making the extrusion distance and orientation inaccurate and leading to an uncomfortable usage. Limitations also include a high computational cost and the long learning curve on tested VR interactions. This tool enables only geometry modification, and would be complex to extend to geometry creation functions. In 2017, an extended work was presented in [3], enabling the modification of sketch constraints parameters. However, editing sketch parameters in VR was not intuitive, even for experienced CAD users.

Feeman et al. proposed to integrate VR and CAD by building a platform that integrates the commercial Autodesk's Fusion 360 CAD geometric kernel with the Autodesk's Stingray game engine for immersive interactions [4]. The VR demonstrator features add and subtract Boolean operations with sphere and axis-aligned box primitives, parameterized by the coordinates of a pair of 3-DOF VR pointing devices. The resulting solid B-Rep model and its visualization triangulation was computed in real-time by Fusion 360. Although these are only primitive shapes, the results show that this approach improves efficiency, creativity and realistic scale perception compared to traditional CAD software. The limitations of this approach are the lack of geometry editing tools, and the limited number of primitives. This basic sketching tool is only usable for the conceptual design stage.

The comparison between 2D and VR sketching tools in [5] aimed at investigating the reasons behind the mismatch between the rapid growth of immersive technologies and their scarce adoption in the conceptual design activities. Traditional 2D sketching activities using paper, pencil and eraser were compared to Kodon [6] and GravitySketch [7] to create 3D sketches with HTC Vive HMD and 6DOF pointing devices. Results showed that the background of the tester has an influence on task time as well as design quality (for example, a person whose background is product design will have more sketching skills than one's having a mechanical engineering background). Another result is that traditional 2D sketching tools are faster than studied immersive 3D sketching VR tools. Authors identified the physical fatigue after a short period of time as the main limitation in immersive sketching systems.

Recent works showed that 3D Modelling in VR has some limitations such as the accuracy of the user's gesture [3], the lack of the geometry editing tool, the headset weight and the eyes forced focus.

4 BENCHMARK

4.1 Criteria

Criteria for comparing candidate solutions come from our extensive experience in CAD, the literature review, as well as two widely used CAD software: 3DExperience [8] and PTC Creo [9]. To facilitate the presentation of our results, we provide categories in Fig. 1 and Tab 1. Comparison criteria were the implementation of basic part design tools found in 3D CAD environments.

4.2 Candidate Solutions

Several proprietary and open-source software were tested (Tab 1). Mindesk [10] is a commercial 3D design platform built on top of Rhino 5. SkyrealVR [11] is another commercial VR software to visualize and modify CAD products and collaborate with teams. VRSketch [12] is an extension of Google SketchUp to edit and view 3D models in VR. Gravity Sketch [7] is a tool for communication, enabling the creation of 3D shapes and images in virtual reality environment. Blender [13] OpenXR features VR is an editing tool based on the OpenXR standard. ProBuilderVR [14] is an experimental geometry design tool for Unity3D, featuring a VR editing mode. FlyingShapes [15] is an immersive 3D sculpturing tool. The open source solution FreeCAD [16] was not considered in the benchmarking as VR CAD editing environment, although its OpenXR support may be used to develop easily VR shape editing tools. All tested software [10]-[15] generate a mesh model, excepted Mindesk and SkyReal that enable the export of the B-Rep of each shape separately, but lacks Add/Substract Boolean operators. The benchmarking includes also the academic VR-CAD demonstrators as presented by their authors.

4.3 Benchmarking

The bar chart (see Figure 1) is a visual overview of the benchmarking (see Tabble 1) showing that the candidate solutions Mindesk and VRSketch are the most advanced CAD solutions in VR that are accessible for testing.

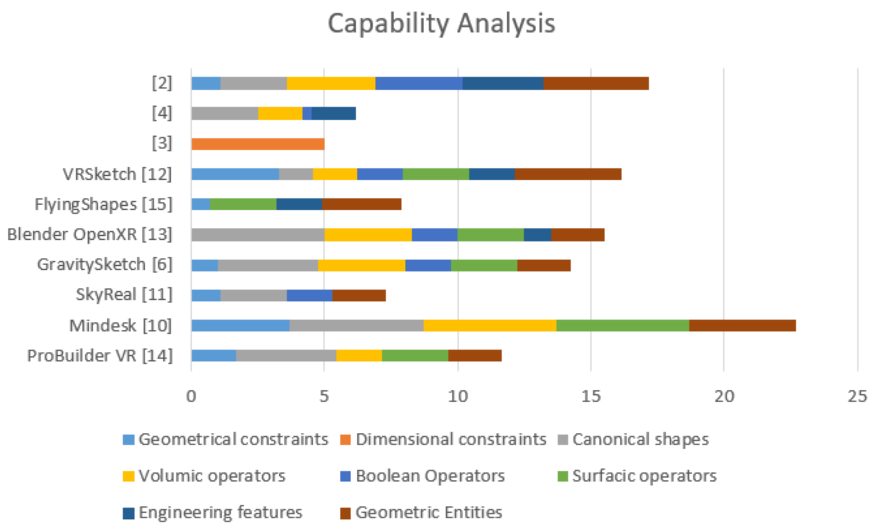

Figure 1: Bar chart of all candidate solutions.

	Geometric entities						Dim,		Geometrical constraints									Canonical Shapes				Volumic Op,			Boolean Op.			Surf Op.		Eng. Op.	
	Spline	*Circle*	*Rectangle*	*Point*	*Plane*	*Line*	*Length*	*Angle*	*Horiz.& Vertical*	*Fix/UnFix*	*End point*	*Mid-Point*	*Perp. & Parralel*	*Concentric*	*Coincident*	*Tangent*	*Symmetry*	*Cone*	*Cylinder*	*Box*	*Sphere*	*Extrude*	*Sweep*	*Revolve*	*Union*	*Intersect*	*Subtract*	*Offset*	*Patch*	*Hole*	*Chamfer*
[2]	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
[1]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	1	0
[3]	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VR Sketch [11]	0	1	1	0	1	1	0	0	1	0	1	1	1	1	1	0	1	0	0	1	0	1	0	0	1	0	0	1	0	1	0
Flying Sh, [13]	1	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Blender [12]	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	0	0	1	0	0	1
Gravity Sk. [6]	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	1	1	0	0	1	0	0	0
SkyReal [10]	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	0	1	0	0	0	0	0	0
Mindesk[9]	1	1	1	0	0	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
Fillet and rib features are not in this table, as all tested VR-CAD software lack this feature.																															

Table 1: VR-CAD software benchmarking.

To go further in the benchmarking of Mindesk and VRSketch, we reuse [17] a use case that belongs to the domain of systems architecture (see Figure 2).

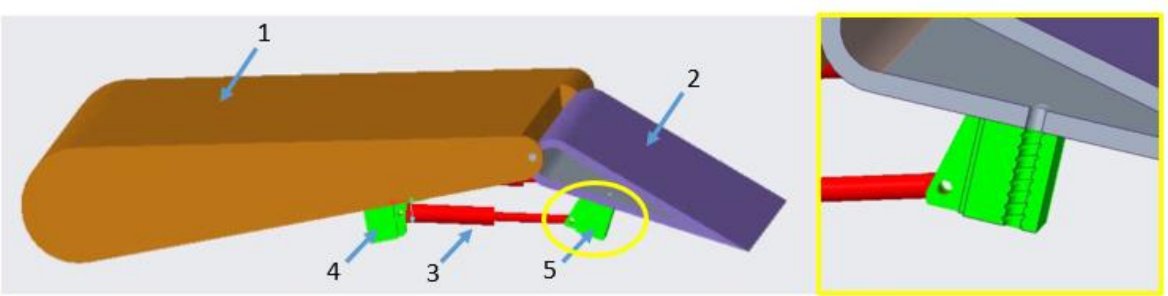

Figure 2: Architecture of a 3-bar EMA use case (1: Wing, 2: Aileron, 3: cylinder, 4 and 5: frame).

While designing the architecture of an engineered system, architects need CAD features to create preliminary shapes as well as to resize and position the main parts. In this use case, we evaluated the CAD capabilities of Mindesk and VRSketch for the preliminary design use case of an Electro-Mechanical Actuator (EMA). Figure 2 shows the B-Rep model corresponding to the expected preliminary design of the EMA created with a commercial CAD software.

To compare the leading VR-based CAD software Mindesk and VRSketch, we have used the same HTC Valve Index head mounted device and 6DOF pointing devices. Figure 3 and 4 show the resulting models.

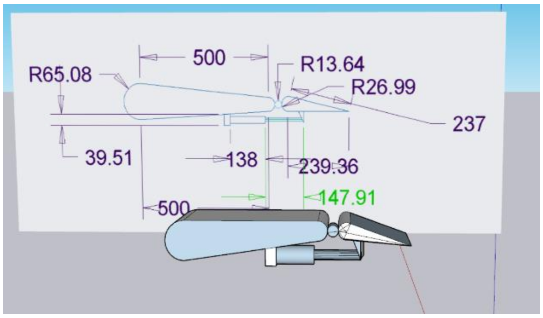

Figure 3: EMA in VR Sketch.

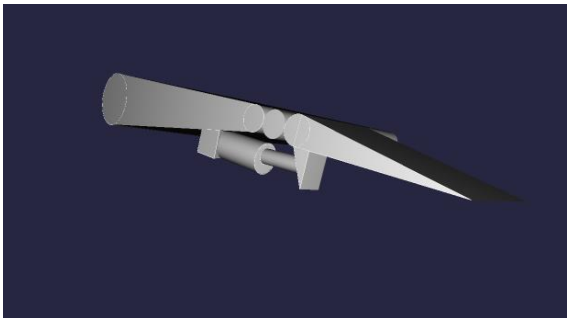

Figure 4: EMA in Mindesk.

To model the EMA, VRSketch enables precise dimensional constraints, whereas Mindesk does not (see Fig. 3). The video recordings of our VR-based modelling sessions are available online [18].

We estimated the overall workload of Mindesk and VR Sketch equal to 48 and 40, respectively. The major difference between both alternatives is the modelling time: 15 minutes in VRSketch and 45 minutes in Mindesk. In practice, Mindesk has a long learning curve to create sketches as well as sketch-based features (e.g revolution, extrusion) and often has an unexpected behavior. The reason are the errors due to poorly designed interactions. For example, after creating the reference plane for sketching, the sketch entities are not constrained to the stay on that plane, resulting in poorly oriented 2D entities requiring rotation and translation steps. It also lacks simple operations like "undo-redo", arc creation. Neither VRSketch, nor Mindesk enable threaded hole creation. Mindesk has the capability to save the model in STEP format, representing independent surfaces. Moreover, Mindesk does enable holes whereas VRSketch features face dragging enables holes within certain limitations. Finally, VRSketch lacks revolution features, which has no impact in the EMA use case.

5 CONCLUSION

The benchmarking of existing academic and commercial solutions revealed two conclusions:

1. In the preliminary design scenario on the electro-mechanical actuator, tested VR environments are limited by the poor ergonomic interfaces for modelling sketches and 3D operators compared to traditional CAD,
2. 3D modelling VR environments output mesh files rather than solids B-Rep composed with canonical and NURBS geometry.

Future work will aim at developing a VR-based environment to operate CAD B-Rep kernels editing operations with HMD and controller interfaces. This environment will better support the direct modelling on canonical shapes, for example by using face-dragging with VR-controllers instead of dimensional properties edited with a keyboard and a mouse. Another improvement will concentrate on the VR-metaphors for 2D sketching, like the fitting of planar curves with VR controller trajectories, and the fitting of sketch constraints with VR controller gestures. The construction history graph could be represented by a 3D graph in VR. In this future work, the VR-based interface will also allow the selection of B-Rep geometric entities to define reference planes, and filleting and chamfering surface features.

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REFERENCES

[1] De Araùjo, B. R.; Casiez, G.; Jorge, J. A.: Mockup builder: direct 3D modeling on and above the surface in a continuous interaction space, in Proceedings of Graphics Interface 2012, 2012, 173–180.
[2] Bourdot, P.; Convard, T.; Picon, F.; Ammi, M.; Touraine, D.; J.-M. Vézien, J.-M.; VR–CAD integration: Multimodal immersive interaction and advanced haptic paradigms for implicit edition of CAD models, Comput.-Aided Des., 42(5), 2010, 445–461, https://doi.org/10.1016/j.cad.2008.10.014.
[3] Martin, P.; Masfrand, S.; Okuya, Y.; Bourdot, P.; A VR-CAD Data Model for Immersive Design, in Augmented Reality, Virtual Reality, and Computer Graphics, vol. 10324, L. T. De Paolis, P. Bourdot, and A. Mongelli, Eds. Cham: Springer International Publishing, 2017, 222–241.
[4] Feeman, S. M.; Wright, L. B.; Salmon, J. L.; Exploration and evaluation of CAD modeling in virtual reality, Computer-Aided Design and Applications, 15(6), 2018, 892–904, http://doi.org/ 10.1080/16864360.2018.1462570.
[5] Lorusso, M.; Rossoni, M.; Colombo, G.: Conceptual modeling in product design within virtual reality environments, 2020.
[6] Kodon from Tenk Labs, http://store.steampowered.com/app/479010/.
[7] Gravity Sketch, https://www.gravitysketch.com/.
[8] 3DExperience from Dassault Systèmes, https://www.3ds.com/3dexperience.
[9] PTC Creo, https://www.ptc.com/en/products/creo.
[10] Mindesk, http://www.mindeskvr.com/site/.
[11] SkyReal VR, https://sky-real.com.
[12] VR Sketch from Baroque Software, https://vrsketch.eu/.
[13] Blender, https://wiki.blender.org/wiki/Source/Interface/XR.
[14] ProBuilder VR, http://www.procore3d.com/probuilder-vr/.
[15] Flying Shapes, https://www.flyingshapes.com/.

[16] FreeCAD, https://www.freecadweb.org/.
[17] Mhenni, F.; Choley, J.; Caron, F.; Munck, A.: Collaborative Mechatronic Design and Systems Engineering: an Educational Experiment with KARREN, in 2018 IEEE International Systems Engineering Symposium (ISSE), 2018, 1–7, https://doi.org/10.1109/SysEng.2018.8544405.
[18] EMA design use case Videos, https://pagesperso.g-scop.grenoble-inp.fr/~foucault/VR-CAD-Videos/.