Exploring the Potential of Virtual Reality for Model-Based Systems Architecting

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1 Introduction

Model-Based Systems Engineering (MBSE) software editors, consultants, engineers and architects, particularly those moving from software to systems engineering, claim that SysML-like visual modelling notations, which are symbolic two-dimensional box-and-arrow diagrams, are domain-independent and, thus, very convenient to support the cross-functional definition of a system architecture (Walden et al., 2015). However, the abstract diagramming syntax of MBSE notations makes their adoption difficult (Henderson, 2024), especially by notational nonexperts, and using iconic graphics is one way of improvement (Masri et al., 2008). Few studies attempted to replace 2D diagrams with immersive 3D visuals without providing objective evidence that it improves any aspect of conceptual modelling and design activities. We assume it is due to very limited software demonstrators and a lack of quality criteria for evaluating the impacts of 2D diagrams VS. 3D visuals on conceptual modelling and design activities. The scope of the thesis is limited to a subset of MBSE, that is, Model-Based Systems Architecting activities from needs elicitation to subsystems definition. The interest in proposing immersive 3D user interfaces for MBSA is increasing (Lufti et al., 2023; Yigitbas et al., 2023; Barosan et al., 2022; Oberhausser, 2022; Fuchs et al., 2022; Deshmukh et al. 2015; Mahboob et al., 2017; Corns and Kande, 2011). However, with the rapid disclosure of research results, most papers fall into the category of papers of marginal quality that do not contribute much to the human body of knowledge. Indeed, most articles do not include any evaluation of the proposed virtual modelling environments or just analytic evaluation for qualitative analysis without end-users involved in the tasks. It is more like a few amateurs having fun developing immersive environments than scientific research. Moreover, most articles propose to visualise model elements without new metaphors and authoring capabilities. This thesis will argue that human-centric interactive 3D visuals should replace MBSA diagrams - where appropriate - to facilitate communication and participation in multidisciplinary co-design activities from mission to architecture definition. An interactive and visually rich 3D user interface is proposed to evaluate the value of iconic representations compared with symbolic ones. Unlike previous studies, the proposed solution provides a tight integration of MBSA and virtual reality in a functional demonstrator to conduct empirical studies.

2 Methods

This thesis seeks evidence to show that Virtual Reality (VR) technology can improve the acceptability and acceptance of MBSE by offering the opportunity:

- to encode domain knowledge in rich 3D representations that require fewer decoding efforts for notational nonexperts in conceptual modelling and
- to combine viewpoints in an immersive, unbounded 3D virtual world, reducing the visual momentum, that is, "*the extent to which an interface supports a practitioner in transitioning between various information-seeking activities that are required for understanding and exploring work domains*" (Bennett et Flach, 2012).

In response to the need for new human-model interaction in MBSA, the initial broad research question was: **What is the potential of using VR technology to co-design system architectures, compared with conventional model-based systems architecting notations, software and devices?** However, to be scientific, this research question needs to be more focused and testable. Thus, the previous generic research question leads to the statement of several better-defined research questions focused on 5 criteria: User satisfaction, Quality of the visual notation, Presence, Cognitive load, and Group dynamics. We use a blend of research methods, including online surveys, controlled experiments and formative studies, to evaluate the potential of using immersive 3D visuals to co-design a system architecture. This is of particular interest since the weight of evidence is strengthened when a combination of multiple – quantitative and qualitative – research methods are used to collect and analyse data.

3 Results

The global results of user satisfaction, visual notation, and cognitive load with the students in single-person controlled experiments were significantly better with the 3D user interface. The difference between the novices and experts is detected in the evaluation of User Satisfaction in the meta-analysis. Still, we can't tell if this difference is significant since conducting a statistical test with only 6 professional systems engineers is impossible. For other criteria, there is no significant difference between novices and experts, including the results from the meta-analysis or the statistical test from the survey. Based on the literature, we postulated that there will be a difference between the novices and experts on the cognitive load. However, the previous domain knowledge did not significantly influence the results between novices and experts. VR sickness is another essential factor to consider in individual cases. For instance, users with a low tolerance to VR sickness who rated the 3D immersive MBSA interface with shallow scores may experience a significant impact on their performance in the VR environment.

4 Discussion

The results confirmed the interest in using VR to co-design system architectures as it offers semantically more transparent representations, motivating users to get involved in the tasks. The modelling interface decreases learning time and effort with simple, efficient, intuitive, and ludic interactions. Some threats to validity include the limited recruitment of experienced participants to evaluate the influence of representations on experts and novices. Numerous variables were uncontrolled in the experiments because we wanted to investigate too many dependent variables as it was the first empirical study. Another limitation is that all measures are subjective, acquired using indirect techniques, mainly questionnaires, so all scores reflect perceived evidence (e.g., perceived cognitive load) rather than objective (e.g., cognitive load measured by brain activity monitoring). Still, the study belongs to exploratory and formative research to gain insight, discover opportunities, and derive more focused research questions. The objective of this work is not to fully replace conventional 2D interfaces, but to better understand what MBSE tasks are more appropriate to iconic *vs.* symbolic visual metaphors or monoscopic *vs.* stereoscopic visualisation devices, with the final goal to provide recommendations to improve the MBSE modelling environment by facilitating the transition between 2D and 3D, for instance.

Reference

Barosan, I., Van Der Heijden, J. (2022). Integration of SysML models in a 3D environment for Virtual Testing and Validation, in: Federated Africa and Middle East Conference on Software Engineering. Presented at the FAMECSE '22: Federated Africa and Middle East Conference on Software Engineering, ACM, Cairo-Kampala Egypt, pp. 39–45. https://doi.org/10.1145/3531056.3542784

Bennett, K.B., Flach, J.M. (2012). Visual momentum redux. International Journal of Human-Computer Studies 70, 399–414. https://doi.org/10.1016/j.ijhcs.2012.01.003

Corns, S., Kande, A. (2011). Applying virtual engineering to model-based systems engineering. Systems Research Forum 05, 163–180. https://doi.org/10.1142/S1793966611000321

Deshmukh, M., Wolff, Robin, Fischer M., Philipp, Flatken, Markus, Gerndt, Andreas, 2015. Interactive 3D visualisation to support concurrent Engineering in the early space mission design phase. Presented at the 5th CEAS Air & Space Conference.

Fuchs, M., Ghanjaoui, Y., Abulawi, J., Biedermann, J., Nagel, B. (2022). Enhancement of the virtual design platform for modeling a functional system architecture of complex cabin systems. CEAS Aeronautical Journal. https://doi.org/10.1007/s13272-022-00608-z

Henderson, K., McDermott, T., Salado, A. (2024). MBSE adoption experiences in organizations: Lessons learned. Systems Engineering 27, 214–239. https://doi.org/10.1002/sys.21717

Lutfi, M., Valerdi, R. (2023). Integration of SysML and Virtual Reality Environment: A Ground Based Telescope System Example. Systems 11, 189. https://doi.org/10.3390/systems11040189

Mahboob, A., Weber, C., Husung, S., Liebal, A., & Krömker, H. (2017). Model-based systems engineering (mbse) approach for configurable product use-case scenarios in virtual environments. *21st international conference on engineering design*.

Masri, K., Parker, D., Gemino, A. (2008). Using Iconic Graphics in Entity-Relationship Diagrams. Journal of Database Management 19, 22–41. https://doi.org/10.4018/jdm.2008070102

Oberhauser, R. (2022). *VR-SysML : SysML Model Visualization and Immersion in Virtual Reality*. *c*, 61-66.

Walden, D. D., Roedler, G. J., Forsberg, K., Hamelin, R. D., Shortell, T. M. (2015) *Systems engineering handbook: A guide for system life cycle processes and activities*. International Council on Systems Engineering., & INCOSE

Yigitbas, E., Gorissen, S., Weidmann, N., Engels, G. (2023). Design and evaluation of a collaborative UML modeling environment in virtual reality. Softw Syst Model 22, 1397–1425. https://doi.org/10.1007/s10270-022-01065-2