A Methodological Approach to Model-Driven Software Development for Quality Assurance in Metaverse Environments

E. Enamorado-Díaz[1,*]

[1]University of Seville, Escuela Técnica Superior de Ingeniería Informática, Avda. Reina Mercedes s/n, 41012 Seville, Spain

Abstract

The metaverse has potential applications in many fields, for example, the field of health care. Due to the particularities of the metaverse technology (immersive access due to virtual and augmented reality, combination of people with digital twins, etc.) it is necessary to define software development methodologies that guarantee quality during the development of applications in this context. The thesis project presented in this article aims to identify and analyze existing proposals in the current scientific literature in order to know the state of the art, and then propose a methodological framework to ensure quality in the development of applications for the metaverse. Finally, it is proposed to use the Model Driven Engineering (MDE) paradigm and to validate the proposal with a real case of application in the healthcare field.

Keywords

Metaverse, Health Care, Model-Driven Engineering, Methodological framework, Software quality

1. Introduction

The COVID-19 pandemic has drastically changed social interactions. Social distancing policies, confinements and mandatory quarantines have accelerated the technological mediation of communication on an unprecedented scale [1]. Many face-to-face activities, such as office work, education and conferences, have moved to the online space through cell phones, social networks and even the metaverse.

The concept of metaverse has changed in recent years. The metaverse can be defined as a multiuser environment that merges physical reality with digital virtuality [2]. It is based on the convergence of technologies that enable multisensory interactions with virtual environments, digital objects and people, such as virtual reality (VR) and augmented reality (AR). In other words, the metaverse is an interconnected network of immersive social environments on persistent multiuser platforms. It enables seamless communication between users in real time and dynamic interactions with digital artifacts.

Therefore, one of the goals of the metaverse is to replicate the feeling of connection with the real world by creating immersive virtual environments. Applications can be seen as a tool, meaning that the metaverse can help solve difficulties and problems in the real world. But it

CAiSE 2024 Doctoral Consortium

*Corresponding author.

eenamorado@us.es (E. Enamorado-Díaz)

0009-0002-7467-3382 (E. Enamorado-Díaz)

can also be seen as a goal, which refers to how the metaverse itself can perform actions such as developing the metaverse itself and generating benefits [3].

As such, many companies have begun to move into the metaverse, including healthcare companies. The Metaverse can be beneficial both for helping medical professionals in many aspects of their work, as well as for patients, as it can make the Internet more accessible to many people who struggle to interact with digital content every day due to neurodivergence, disability or other impairments. Machines, systems and procedures will be tested securely through digital twins to detect bugs and vulnerabilities before they are carried out in a physical environment.

The metaverse is being built on many advanced technologies such as VR, AR, artificial intelligence (AI), machine learning (ML) and sensores of various types. These various tools create more complexity. Due to these particularities of metaverse technology, it becomes necessary to define software development methodologies that ensure quality during the development of applications in this context.

The contribution of the paper. The thesis project presented in this article aims to identify and analyze existing proposals in the current scientific literature in order to know the state of the art, and then propose a methodological framework to ensure quality in the development of applications for the metaverse. Finally, it is proposed to use the Model Driven Engineering (MDE) paradigm and to validate the proposal with a real case of application in the health field.

Our starting hypothesis is the use of MDE could eventually facilitate the quality assurance of software development in the metaverse domain. MDE proposes an approach where software development is performed through models, allowing transformations that generate additional code or models with specific characteristics of a given technology. In the complex environment of the metaverse, which is built on advanced technologies such as virtual reality, augmented reality, artificial intelligence, 5G networks, cloud services, machine learning and various sensors, effective resource management becomes a significant challenge for organizations. The hypothesis is based on the premise that MDE can provide a sound methodological framework to address this complexity and thus contribute to quality assurance in software development in the metaverse. Through the application of models that evolve and adapt to the specific technological characteristics of the metaverse environment, it is expected that MDE will facilitate the creation of robust and high quality software in this innovative context.

To obtain the proposed solution, the following objectives and activities have been identified:

- O1. To know the current situation of the metaverse in the healthcare environment and to identify, analyse and discuss methodological proposals that facilitate the quality assurance of software development in the metaverse environment.
- O2. To define a methodological proposal that includes the necessary mechanisms to facilitate quality assurance in software development in the metaverse. Specifically, a definition metamodel will be proposed to model the desired metaverse scenario and, on the other hand, an execution metamodel will be proposed to model the executable characteristics of the scenario defined with the previous metamodel.
- O3. Define the necessary transformation rules to derive the necessary artifacts from the execution model.

- O4. Develop a tool to support the practical use of the proposed solution. This objective entails: (i) defining appropriate domain-specific profiles or languages to make it possible to instantiate both metamodels; and (ii) implementing a CASE tool to support such an environment.

This paper, in addition to this introduction in which a brief summary of the proposed work to be done is presented, is composed of the following sections: the review of related work is addressed in Section 2, providing an overview of the existing context. The formulation of the initial hypothesis is presented in Section 3, followed by the description of the methodology used in Section 4. The proposed solution is detailed in Section 5, specifically addressing the stated objectives. Finally, the general conclusions are found in Section 6, closing the paper with a summary of the findings and possible future research directions.

2. Metodology

This PhD project follows the Design Science Research Methodology [4] which establishes 4 phases (Figure 1):

- **Phase 1: problem identification and motivation.** We carry out a thorough systematic literature review (SLR) to collect existing proposals related to our research question. Systematic Review is a process where related works are examined. For this study, we propose using the method proposed by Kitchenham [5] for conducting systematic reviews in the field of software engineering. This method consists of three phases: planning, execution and presentation of results. In the planning phase, a study schedule is established and a protocol is drawn up that includes the research questions, evaluation criteria, information collection mechanisms and analysis method. In the execution phase, the study is carried out according to the defined protocol, and finally, in the results presentation phase, the findings are presented clearly and concisely.
- **Phase 2: objective of the solution.** As we mentioned above, the objective of this thesis is to investigate and propose a methodological framework to ensure quality in the development of applications for the metaverse, using the Model Driven Engineering (MDE) paradigm. The project will be validated with a real case in the health field. To achieve this, the current state of the metaverse in the healthcare environment will be analyzed, metamodels will be defined to model and execute metaverse scenarios, transformation rules will be established to derive necessary artifacts from the execution model, and a CASE tool will be developed to support the use practicality of the proposed solution. In this context, this phase aims to investigate and propose a framework based on methodological framework to ensure quality in the development of applications for the metaverse
- **Phase 3: design and development.** This phase involves 2 steps: (i) designing a novel metaverse metamodel and its associated semantic constraints as well as MDE-based theoretical bases the framework; and (ii) developing a tool to back up the application of our metamodel and to automate parts of the framework.
- **Phase 4: demonstration and evaluation.** Regarding validation, two classical techniques will be used: (i) experimentation, based on the Juristo and Moreno [6] approach,

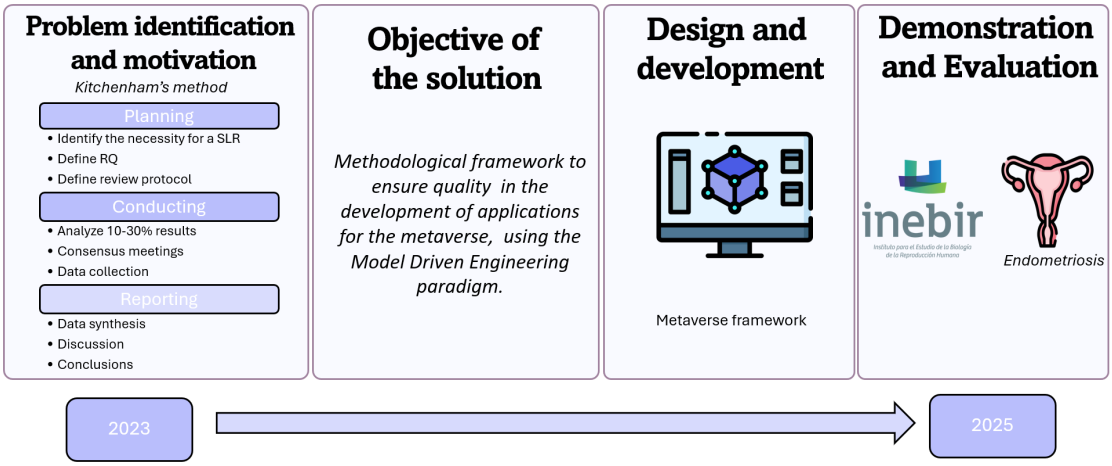

Figure 1: The proposed methodology for the PhD project

which proposes a life cycle that includes the definition of objectives, design and execution of experimentation and analysis of results; and (ii) the case study. A case study is an empirical methodology used to investigate complex and dynamic problems in software engineering. It is characterized by its flexibility and the ability to collect qualitative data in a programmed and systematic way, allowing conclusions to be drawn based on empirical evidence. Also, this method adds value to existing knowledge since it is based on a previously established theory. To guide our case studies, we will follow a set of guidelines proposed by Runeson and Höst [7], which consist of five phases: design of the case study, preparation of data collection, data collection, data analysis and reporting of results. Although data collection and analysis can be done incrementally, it is important to set specific objectives from the beginning of the case study. These guidelines will help us to ensure that our approach is systematic and rigorous, and that the results obtained are reliable and useful. This is a work in collaboration with a private clinic (Inebir), which is helping to define the model from the practical context and will also offer the possibility of validation for the treatment of patients with endometriosis.

This comprehensive methodology is structured in a systematic and rigorous manner, addressing both comprehensive literature review and practical action in solving specific metaverse problems, with the objective of contributing to knowledge and effective application in this emerging field.

3. Proposed solution and preliminary results

In the field of software engineering, quality means good products that meet customer expectations, constraints, and requirements [8]. Quality is the most important factor for software development, as it is directly related to the success of a software project.

The model of a software process is precisely used to ensure software quality, represent a

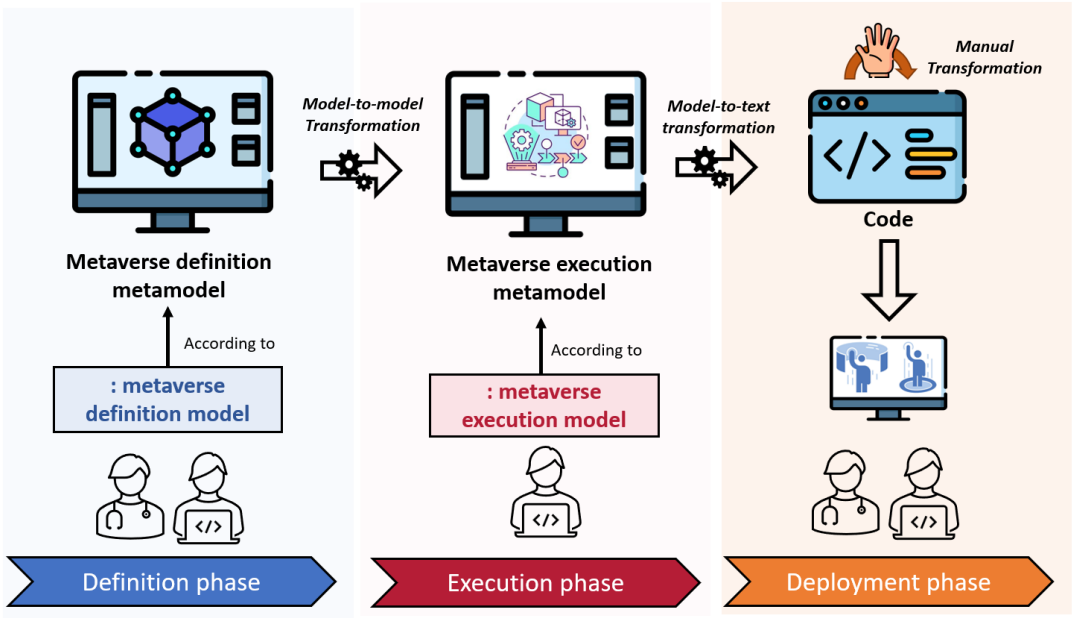

Figure 2: Phases of the model-driven framework of our proposal

variety of task configurations, manage the project duration, improve the process and scope to execute the process understanding. In model-driven engineering (MDE), software development is proposed using models that cause transformations to be performed to generate code or another model with characteristics of a given technology (or lower level of abstraction). As the transformations are performed, it can be observed that the models become more concrete and the abstract model is transformed into another one compatible with a given technology or platform [9]. The metaverse environment is being built on many advanced technologies such as VR, AR, artificial intelligence (AI), fifth generation (5G) broadband network, cloud services, machine learning (ML), and sensors of various types in addition to operating systems and software tools [10]. These various tools create more complexity. Resource management of these technologies can become a challenge for organizations.

This section presents the phases that constitute the proposal and the main objectives, as well as the activities identified to achieve them. We propose three main phases: definition, execution and deployment, as shown in Figure 2.

1. A **definition** phase: During this stage, the vision of the project is clarified, establishing the main goal of creating a functional metaverse. The specific objectives that will guide the development are defined and a detailed metamodel will be developed that will serve as a reference framework for the construction of the metaverse, addressing key aspects such as data structure, user interaction and the integration of virtual content.
2. An **execution** phase: Here a second metamodel is developed focused on the execution parameters of the virtual entities within the metaverse. Using model-to-model transformations from the definition metamodel, a preliminary version of the execution models is

generated. This involves defining how virtual entities interact, how they move, how they respond to user interaction, and other aspects of their behavior in the virtual environment.

3. An **implementation** phase: In this stage, the developed solution is taken to a real platform for implementation. The first version of the executable code is derived via a model-to-text transformation from the execution model. The process engineer can then step in to make manual adjustments and configurations to the draft code, tailoring it to the specifications of the target platform. This process ensures that the solution is optimally and functionally deployed in the real metaverse environment.

The thesis project is currently in an advanced stage of development. The systematic literature review (SLR) has been completed and is in the process of review by a recognized academic journal, listed in the Journal Citation Reports (JCR), specifically in the Information and Software Technology Journal. In parallel, the main focus is on the definition phase of the metamodel framework. Here, the conceptual and methodological foundations for the research project are being established. Specific objectives are defined, a detailed metamodel is developed, and the essential parameters that will guide the implementation of the proposal are outlined. This process lays the solid foundations necessary for the success of the research in building the proposed metaverse.

4. Related works

This section provides a brief description of the proposals where the metaverse is applied in the healthcare context.

In [3], the authors review the fields where the metaverse makes contributions in multiple areas of society, analyzing the benefits and challenges from various perspectives.

In [11], the authors review and identify areas of application of the metaverse in the health field. The use of the Metaverse in the healthcare context is expanding rapidly. It is now widely used in other areas, such as medical interventions and health care delivery; in medical imaging, it has many applications due to the fundamental change in the nature and quality of the image.

The authors' goal in [12] was to exploit the ramifications of the expansion of metaverse applications in mental health. It reviews the novelties that can be included or are already implemented in the metaverse, as well as outlining the advantages and limitations of the impact of the metaverse on mental health.

In [13] the authors state that the Metaverse appears to be beneficial in helping both patients and medical professionals in many aspects of their work that involve the use of these technologies, but that there are nevertheless many challenges to consider.

The literature review in the field of metaverse and software engineering, included in the studies mentioned above, reveals a substantial lack of research focused on the development of specific methodologies to ensure software quality in metaverse environments. Although systematic reviews of metaverse environments have been conducted [14] and methodological approaches have been proposed for concrete proposals [15, 16], most of them do not comprehensively address the unique complexities of the metaverse. No specific review has been found to support this statement, but the previously mentioned works provide a basis for these conclusions. This gap in the literature provides a valuable opportunity for the proposed research,

which aims to develop a robust methodology based on Model Driven Engineering (MDE) and Action Research approaches. The combination of these methodologies will enable a deeper understanding of the specific challenges of software development in the metaverse and provide practical guidelines for improving software quality in this emerging context.

This thesis project is situated in the growing field of metaverse application in healthcare and software engineering. Building on previous research examining the contributions of the metaverse in society and its specific application in healthcare, this research focuses on the development of a methodological framework for quality control in the development of metaverse applications in healthcare.

5. Conclusions

The metaverse has an impressive potential for many segments of society, including the healthcare context. This doctoral research project aims to propose a methodological framework to ensure quality in the development of applications for the metaverse, proposes to use the paradigm of Model Driven Engineering. It is framed in the field of software engineering in the context of the metaverse and has a planned validation with a real case of application in the health field.

Recognizing the uniqueness and complexities of metaverse environments, it highlights the critical need for a specific and agile approach, such as the one proposed here, to address the particular challenges that arise in developing applications in this emerging environment. The implementation and practical validation of this methodological framework in the healthcare sector will not only contribute to the improvement of the quality of metaverse applications, but will also pave the way for future innovations in the convergence between cutting-edge technologies and healthcare.

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References

[1] J. Thomason, Metahealth -how will the metaverse change health care?, Journal of Metaverse Journal of Metaverse, 1 (2021) 13–16.

[2] S. Mystakidis, Metaverse, Encyclopedia 2 (2022) 486–497. URL: https://www.mdpi.com/2673-8392/2/1/31. doi:10.3390/encyclopedia2010031.

[3] Y. K. Dwivedi, L. Hughes, A. M. Baabdullah, S. Ribeiro-Navarrete, M. Giannakis, M. M. Al-Debei, D. Dennehy, B. Metri, D. Buhalis, C. M. Cheung, K. Conboy, R. Doyle, R. Dubey, V. Dutot, R. Felix, D. Goyal, A. Gustafsson, C. Hinsch, I. Jebabli, M. Janssen, Y.-G. Kim, J. Kim, S. Koos, D. Kreps, N. Kshetri, V. Kumar, K.-B. Ooi, S. Papagiannidis, I. O. Pappas, A. Polyviou,

S.-M. Park, N. Pandey, M. M. Queiroz, R. Raman, P. A. Rauschnabel, A. Shirish, M. Sigala, K. Spanaki, G. Wei-Han Tan, M. K. Tiwari, G. Viglia, S. F. Wamba, Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy, International Journal of Information Management 66 (2022) 102542. URL: https://www.sciencedirect.com/science/article/pii/S0268401222000767. doi:https://doi.org/10.1016/j.ijinfomgt.2022.102542.

[4] K. Peffers, T. Tuunanen, M. A. Rothenberger, S. Chatterjee, A design science research methodology for information systems research, Journal of management information systems 24 (2007) 45–77.

[5] B. Kitchenham, S. Charters, Guidelines for performing systematic literature reviews in software engineering 2 (2007).

[6] N. Juristo, A. M. Moreno, Basics of software engineering experimentation, Springer Science & Business Media, 2013.

[7] P. Runeson, M. Höst, Guidelines for conducting and reporting case study research in software engineering, Empirical software engineering 14 (2009) 131–164.

[8] M. A. Akbar, J. Sang, A. A. Khan, Fazal-E-Amin, Nasrullah, M. Shafiq, S. Hussain, H. Hu, M. Elahi, H. Xiang, Improving the quality of software development process by introducing a new methodology–az-model, IEEE Access 6 (2018) 4811–4823. doi:10.1109/ACCESS.2017.2787981.

[9] J. A. García García, M. J. Escalona Cuaresma, C. M. Ruiz Cutilla, M. Alba, Ndt-glossary: A mde approach for glossary generation, in: ICEIS 2011: 13th International Conference on Enterprise Information Systems (2011), pp. 170-175., SciTePress, 2011.

[10] S. Hollensen, P. Kotler, M. O. Opresnik, Metaverse–the new marketing universe, Journal of Business Strategy (2022).

[11] A. Garavand, N. Aslani, Metaverse phenomenon and its impact on health: A scoping review, Informatics in Medicine Unlocked 32 (2022) 101029. URL: https://www.sciencedirect.com/science/article/pii/S235291482200171X. doi:https://doi.org/10.1016/j.imu.2022.101029.

[12] S. Usmani, M. Sharath, M. Mehendale, Future of mental health in the metaverse, General Psychiatry 35 (2022) e100825. doi:10.1136/gpsych-2022-100825.

[13] M. Ahmadi Marzaleh, M. Peyravi, F. Shaygani, A revolution in health: Opportunities and challenges of the metaverse, Excli Journal 21 (2022) 791–792.

[14] C. Song, S.-Y. Shin, K.-S. Shin, Exploring the key characteristics and theoretical framework for research on the metaverse, Applied Sciences 13 (2023) 7628.

[15] H. Ye, L. Wang, Metaversebench: Instantiating and benchmarking metaverse challenges, BenchCouncil Transactions on Benchmarks, Standards and Evaluations 3 (2023) 100138.

[16] S. Joshi, P. Pramod, A collaborative metaverse based a-la-carte framework for tertiary education (co-mate), Heliyon 9 (2023).