



The Use of Metamodel-based Approach for Designing Healthcare Applications

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Abstract: Recently, the use of Model-Driven Engineering (MDE) via metamodeling approach is gaining more attention for software applications development. The community from the healthcare domain also attempts to employ the metamodel approach for producing quality healthcare applications. Healthcare applications have become an imperative in every attempt to improve healthcare management. Numerous studies reported that the healthcare domain is seen as a complex and unique domain, which involves dynamic characteristics. In addition, it is widely recognized that the increase of information exchange in the healthcare domain is caused by the diversity of healthcare data. This has led to the increase use of information technologies in the healthcare industry so as to enhance the healthcare delivery process via healthcare applications. However, the complexity of healthcare information leads to ineffective models and design of healthcare applications. Modeling the healthcare processes and developing healthcare applications are challenging tasks. Hence, the advances of MDE have influenced the use of the metamodeling technique in the development of healthcare applications. Various metamodels are developed as a solution to provide a clear healthcare process model and a correct healthcare application. The aim of this paper is to analyse the use of the metamodel-based approach in designing healthcare applications. We believe that the metamodel-based approach would improve the development of healthcare applications.

Keywords: Metamodel, healthcare application, model-driven engineering

1. Introduction

In recent years, the use of Model-Driven Engineering (MDE) via the metamodeling approach is increasing in various domains for software applications development. The community from the healthcare domain also attempts to employ MDE via the metamodel approach for producing quality healthcare applications. A study by [1], reported that the use of computer-based systems in the healthcare industry is expanding with the intention to enhance healthcare delivery. According to Tuomainen et al. [2] modeling has been used widely in healthcare to enhance knowledge sharing, processing, and requirements for documentation of the solutions related to healthcare information systems/applications.

However, the complexity of healthcare information leads to ineffective models and designs of healthcare applications [3]. Modeling the healthcare processes and developing healthcare applications are challenging tasks. Furthermore, the authors in [4-5], claimed that information exchange in the healthcare domain is demanding due to the diversity and variability of the healthcare data. Similarly, Lahboube et.al [6] reported that the implementation of healthcare applications is a difficult process because it involves various stakeholders and professional disciplines in the

healthcare processes. Although modeling has been used widely in many domains, describing a complex system such as healthcare applications at multiple levels of abstraction and with several views is not an easy task.

Hence, the advances of MDE have motivated the use of modeling techniques in the healthcare domain. Software engineers and domain experts can use modeling languages via metamodels to describe the healthcare processes. Several researchers applied MDE via the metamodel-based approach in the design of healthcare applications. For instance, work by [7] used a model-driven framework to develop personalized health monitoring (PHM) applications. Likewise, Abuseta [8] presented a metamodel proposed for the Healthcare Monitoring System (HMS). Their study considered the use of the Internet of Things (IoT) and the context awareness approach for HMS.

This paper reports on the progress of an ongoing investigation on healthcare applications using the metamodel-based approach that is being done. This paper also highlighted the benefits that the metamodel-based approach could bring to healthcare applications as well as the challenges of applying MDE via the metamodeling approach. The remainder of this paper is structured as follows: Section 2 introduces some background information and the motivation of this work. Then, Section 3 explains our research approach followed by Section 4, which describes several metamodel designs for the healthcare domain. The benefits/contributions of the metamodel-based approach in healthcare applications and the quality attributes of the metamodel designs are then discussed in Section 5. Finally, we conclude the paper and give some suggestions for studies that still need to be done.

2. Background and Motivation

MDE via the metamodeling approach has been applied in many domains, such as automotive, business process engineering, education, etc. Furthermore, the literature on MDE and the metamodeling approach are substantial. Most researchers report on the significance and the impact of the usage of MDE via the metamodeling approach. The advances of MDE have also motivated the use of modeling techniques in the healthcare domain. Both MDE via the metamodeling approach and healthcare systems are crucial topics. Numerous studies reported that healthcare domain is recognized as a complex and unique domain, which involves dynamic characteristics [1-9]. Due to the complexities in the healthcare domain, modeling is seen as a way to manage and understand the healthcare complexities [2],[6]. However, describing a complex system such as healthcare applications via models with several abstractions and views is a challenging task. Therefore, healthcare processes need to be carefully defined in order to represent it in a meaningful model. In addition, a model is ineffective if it does not contribute to healthcare application implementation [9].

A study by [10], discussed that MDE is a software engineering (SE) technique that focuses on constructing and utilizing domain models rather than on computing (or algorithmic) concepts. The authors in [11] stated, that the main goal of MDE is to employ techniques for transforming abstract views of software to concrete implementation that could lower the cost and effort of complex systems development. Metamodels and models are the main artefacts in MDE supported with appropriate tools. Instantiation of the metamodel then produces a concrete model. In general, a metamodel means model of a model. According to [12], a metamodel is “*an explicit model of the constructs and rules needed to build specific models within a domain of interest*” [12]. A model facilitates the understanding of a problem and supports effective communication with various stakeholders [9]. Thus, to describe complex systems such as healthcare applications at multiple levels of abstraction and with several views, software engineers and domain experts can use the modeling languages via metamodels.

Thus, an effective method to model the complexities of healthcare processes is by using the MDE via the metamodel-based approach. The MDE approach has been used in the healthcare domain. Various metamodels are developed for domains of healthcare, such as HIS supervision metamodel [6], metamodel for Dynamic Clinical Checklist support system [13], metamodel for Community Care [14], and many others. For instance, the work by [15] proposed an integration method of Audit Trail data into the generic OpenSLEX metamodel to support the analysis of healthcare data from several views (e.g. patients, doctors, resources). Similarly, the research work from Kiourtis et al. [4], that presented semantic interoperability across multiple electronic health records (EHRs) via ontologies and the MDE approach. The authors described how the datasets of EHR are transformed into syntactic models, metamodels and semantic structure [4]. Likewise, in [16], the authors presented their work on using the Health Level Seven (HL7) metamodel in an MDE context. According to the authors [16], their short-term objective is to consider connecting both the Unified Modeling Language (UML) and HL7 metamodel as a design solution in an MDE context for requirement and analysis levels [16]. These are just to mention a few relevant examples of metamodel approach applied in healthcare applications. Although many researchers develop the healthcare applications using the metamodeling approach, issues with the quality of metamodels need to be addressed. There is a need to employ the metamodel-based approach for designing healthcare applications. In addition, it is essential to produce quality metamodel designs for healthcare applications.

3. Research Approach

Our research aim is to propose a framework for assessing the quality of the metamodels designed for healthcare applications. The duration to complete this research is two years and we started our research at the end of 2019. This research is an extension of our previous research work on model driven software engineering. Our current research is to investigate and assess the metamodel approach used in healthcare applications. There are several steps that must be performed before we can propose a framework for assessing the quality of the healthcare applications’ metamodel. Thus, our research approach to achieve our aim is based on the following methodological steps:

Phase One: Identification and analysis of the existing metamodeling approach in the healthcare applications domain.

Phase Two: Proposing a framework for assessing the quality of the metamodel design of the healthcare application.

Phase Three: Designing and implementing a prototype of an assessing metamodel tool based on the proposed framework.

Phase Four: Proving of concept for the proposed framework via assessing the quality of metamodel of healthcare applications.

Phase Five: Validation of the proposed framework against the metamodel quality attributes.

Phase Six: Conducting a usability evaluation for the proposed framework via healthcare application providers.

This paper is not to report about the framework, but to summarize the findings which we have already obtained from the phase one and partly from the phase two activities of the research. In phase one, we attempted to gain a better understanding of the metamodeling approach used in the healthcare domain. Thus, we compiled and analyzed the literature that discussed about MDE via the metamodeling approach in healthcare applications. In the still ongoing phase two activities, we have already identified and gathered from the literature, several quality attributes for assessing a metamodel design. The findings from these two phases would be used to assist us to produce an appropriate framework for assessing the quality of the metamodel design of a healthcare application.

4. Metamodels in Healthcare Applications

4.1 Multi Metamodels for Healthcare Systems

Rabbi et al. [17] used a flexible metamodeling approach, i.e., multi metamodels for healthcare systems due to the complexities of the information requirements in the healthcare domain. They introduced a multi metamodeling approach that could manage healthcare complexity issues. They suggested that the multi metamodel approach for designing healthcare systems was an appropriate methodology. Different concerns of the healthcare systems and the various stakeholders that are involved in the healthcare processes can be managed via multi metamodels. The paper [17] describes about using a metamodeling hierarchy via five metamodels that are involved in healthcare systems. These five metamodels are 1) user access modeling, 2) health process modeling, 3) process monitoring modeling, 4) user interface modeling, and 5) data sources modeling. The work of Rabbi et al. [17] was concerned with the requirements for providing user friendly interfaces for various users involved in healthcare processes. Users interact with parts of the process and parts of the data source and get several alerts from the monitoring module. The five metamodels are coordinated via links that are connected to each of the metamodels. A brief description of this is shown in a simplified metamodel hierarchy in Fig. 1. The authors reported that using multi metamodels to describe different aspects of a healthcare system could support abstraction and low coupling between models [17].

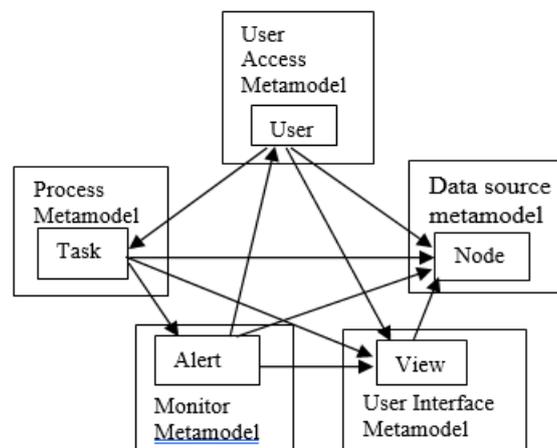


Fig. 1 - Multi metamodeling hierarchy proposed by [17]

4.2 HIS Supervision Metamodel

Lahboube and Souissi [6] developed a hospital information system (HIS) metamodel based on MDE via the metamodeling approach using UML class diagram [6]. They reported a similar complexity issue as stated in the work of Rabbi et al. [17]. Lahboube and Souissi [6] also claimed that the deployment of HIS is challenging because dealing with healthcare processes, the hospital financial, and organizational environments are difficult process. Thus, the authors [6] proposed a multidimensional supervision metamodel to resolve the HIS deployment issue. This

multidimensional supervision metamodel is known as *HIS Supervision MM*. Lahboube et al. [6] used an approach that supported the combination of multi-aspects and multidimensions to produce the supervision metamodel. The paper [6] describes the design of *HIS Supervision MM* with three dimensions. The three dimensions are Project dimension, Business Process dimension, and System of System (SoS) dimension. These three dimensions are defined and structured into three metamodels: Project MM, Process MM, and SoS MM. Next, the metamodels are organized into three packages: project package, process package, and SoS package. For simplicity purposes, we modelled the authors' metamodel using an ArgoUML [18] tool. A brief description of this is shown in Fig. 2. The metamodel proposed by the authors [6] had been validated via the deployment of the HIS project in a real hospital environment at the HMIMV in Rabat, Morocco.

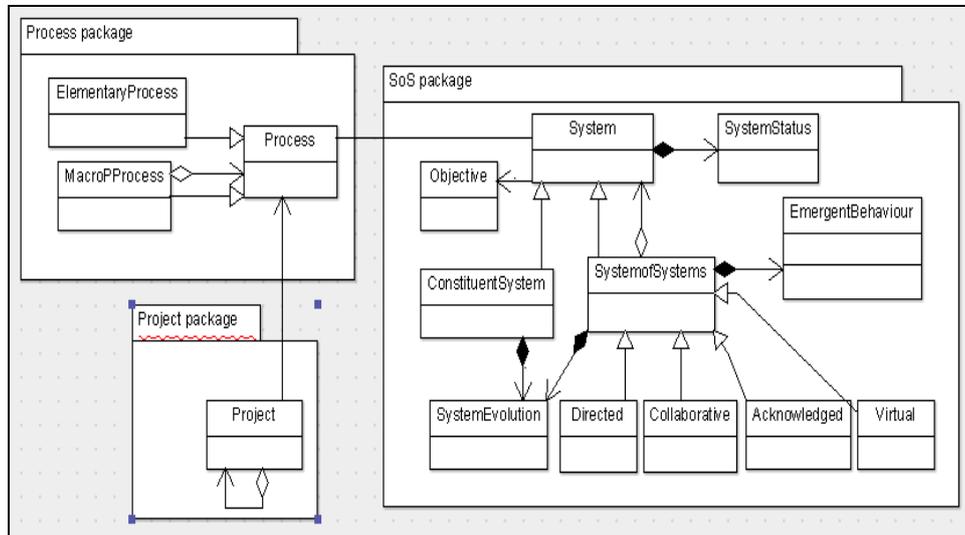


Fig. 2 - HIS Supervision metamodel by [6]

4.3 Dynamic Clinical Checklist Metamodel

Checklist is one of the widely used techniques in hospitals to improve medical care quality and to lessen unnecessary errors [13]. However, static paper-based and simple digital checklists always introduce unexpected mistakes [13]. Thus, Nan et.al [13], [19] proposed a dynamic clinical safety checklist metamodel which allowed the model-based development of dynamic checklist support systems. They used the Business Process Model and Notation (BPMN) to show the clinical workflow model and the Guideline Interchange Format (GLIF) to illustrate the clinical rule model. The dynamic checklist metamodel was developed via three-steps- 1) problem domain analysis, 2) investigation of the existing modelling approaches, and 3) development of a metamodel. The metamodel was developed by obtaining the related concepts of a dynamic checklist and then specifying the class hierarchies and attributes. The authors [13],[19] defined three packages or groups for the dynamic checklist metamodel based on their analyses. The three packages were - *Clinical Pathway* package to represent the clinical activity, *Clinical Rule* package to specify the clinical algorithm for a clinical task and *Checklist Sheet* package to show the format and content of the checklist. For simplicity purposes, we modelled the authors' metamodel using an ArgoUML [18] tool. The classes for each package are shown in Fig. 3, Fig. 4, and Fig. 5. The three packages were linked to one another. Details of these classes can be referred to in [19]. Finally, after the metamodel development, they validated the metamodel's feasibility via two case studies (a coronary artery bypass graft peri-operative checklist and a percutaneous coronary intervention peri-operative checklist) and by using a prototype of the dynamic checklist decision support system, Tracebook. The authors reported that their metamodel managed to reduce the load in developing the checklist support system and the checklists contents were updated continuously without changing the source code of the Tracebook system [19].

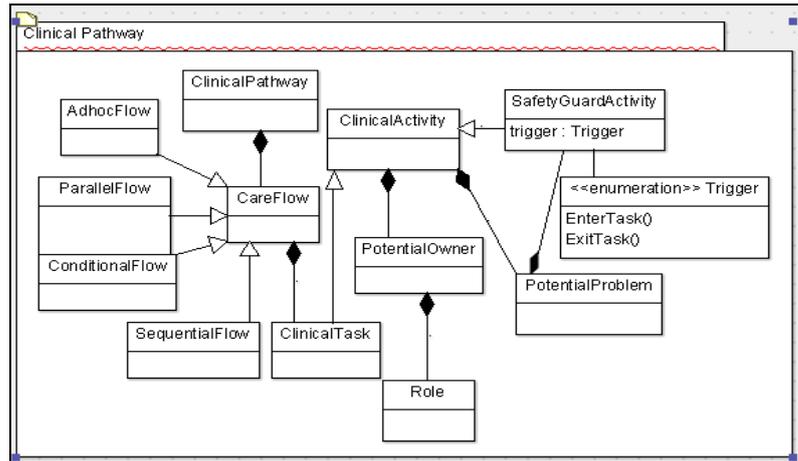


Fig. 3 - Clinical pathway package proposed by [9]

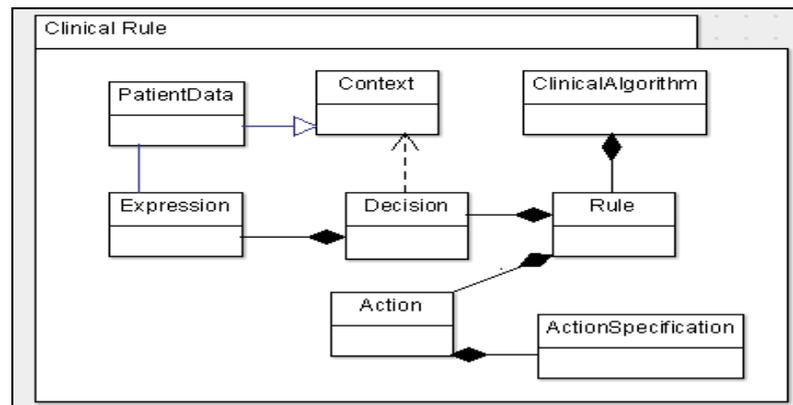


Fig.4 - Clinical rule package proposed by [9]

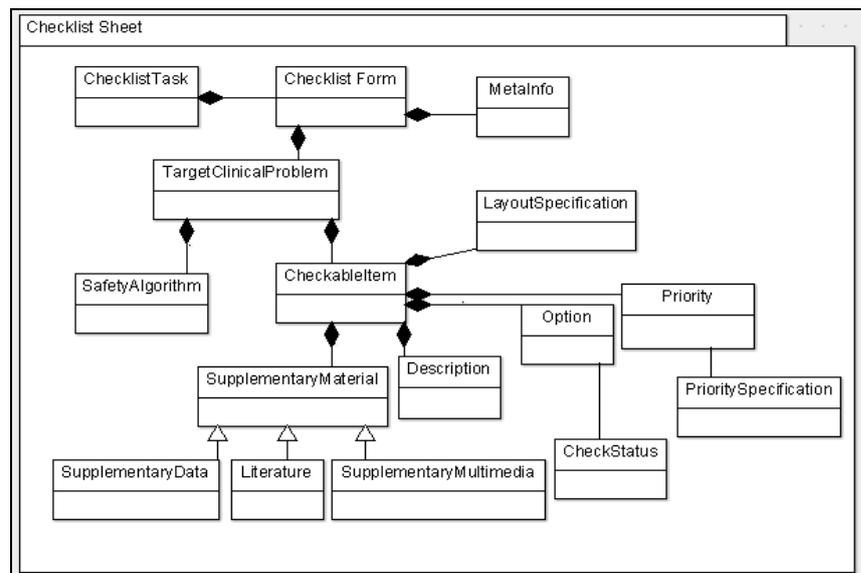


Fig. 5 - Checklist sheet package proposed by [9]

4.4 ArcheER Metamodel

One of the main goals in the medical informatics domain is to have a complete and precise specification of the information structure of the Electronic Health Record (EHR) [5]. As stated in [5], clinical information models (CIMs), EHR reference models and medical terminologies are the three main components used to represent health information as applied by the dual modeling approach. However, a study by [20], claimed that appropriate computer-based supporting

tools to support dual modeling of the conceptual database schemes through the concepts of archetypes were still lacking. Thus, Araújo et al. [20] introduced a metamodel that explained the concept of EHR and also supported the design of conceptual schemas of Health Information System (HIS) applications. Their metamodel consisted of abstract classes illustrating clinical care, demographic information of patients, knowledge data and administrative data of a health service provider organization [20]. The authors introduced their ArcheER metamodel and a Computer-Aided Software Engineering (CASE) modeling tool, known as ArcheERCASE to support the database modeling of HIS applications [20]. The ArcheERCASE tool was based on the proposed ArcheER metamodel. One of the main objectives was to support users in the modeling of unique EHR using a dual modeling approach. A simplified metamodel of ArcheER is shown in Fig. 6. It was modelled via an ArgoUML [18] tool. Details of the attributes for the metamodel can be referred to in [20].

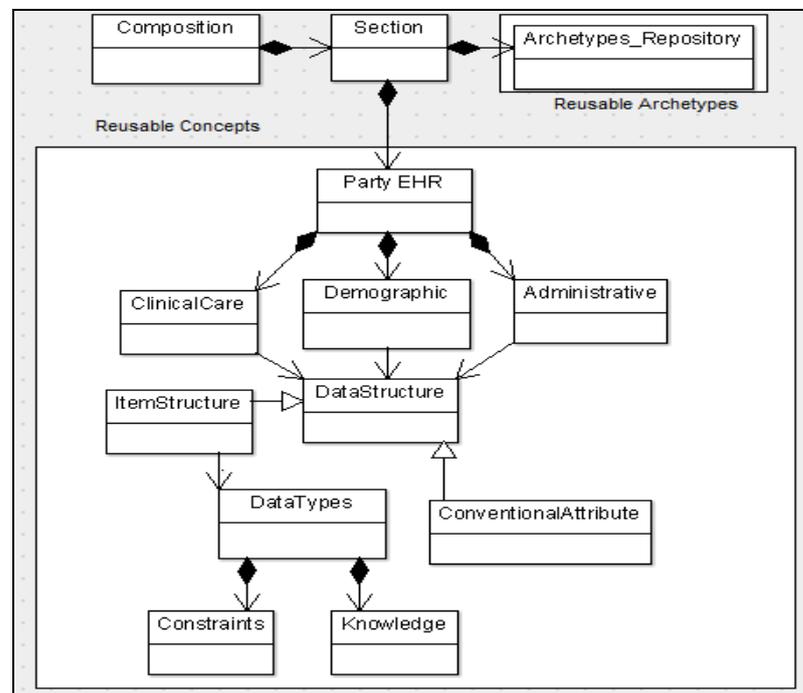


Fig. 6 - Metamodel of ArcheER proposed by [20]

5. Discussion

In this section we discuss the findings obtained from the activities conducted in phase one and partly in phase two of our research. We highlight the benefits/advantages of applying the metamodel approach for designing the healthcare applications. Next, we discuss briefly the metamodel quality attributes.

There are many efforts in developing computer-based applications for healthcare. However, this paper focuses on the use of MDE via the metamodeling approach in designing applications for the healthcare domain. The previous section shows various metamodel designs in a specific context/scope within a healthcare domain. There are various notations to represent the designs of metamodels. The UML is one of the notations, which is widely used to represent a metamodel. The work by [6] and [20] used UML to show their metamodel designs. The work proposed by [17], used the Diagram Predicate Framework (DPF) to represent their metamodel design. In [13, 19], the authors employed the Business Process Model Notation (BPMN) to represent the metamodels. Although different researchers use different notations/approaches, the main concern of metamodeling is to be able to describe and represent the concepts of a specific healthcare domain with a valid model's abstraction levels.

Table 1 lists some of the main advantages/benefits from the four proposed metamodel designs specifically in the healthcare domain as stated in the previous section.

Table 1 - Advantages of metamodel approach in healthcare applications

Proposed metamodel design	Advantages/Benefits
Multi metamodels for healthcare systems [17]	Supports flexibility in modifications of one metamodel without changing the other metamodels because different concerns of a system are separated into multi metamodels [17]
HIS supervision metamodel [6]	Provides design engineers the adaptability in building metamodels according to the constraints and specifications of their organizations [6].
Metamodel for dynamic clinical checklist [13, 19]	Offers a platform independent model which is not restricted to a specific modeling languages and execution engines [13, 19].
ArcheER metamodel [20]	Facilitates changes and extensions to be managed in the layer of archetypes [20].

The advantages listed in Table 1 matched with the advantages that were reported in the literature related to MDE and the metamodeling approach. We highlight here, some of the important advantages of a metamodel-based approach:

- i) Managed and reduced complexity [17, 21-24,] – with metamodel, large complex systems such as healthcare application could be managed and simplified as clear representations. Decomposing the complexity by structuring the metamodel via a metamodeling hierarchy and capturing only important aspects would facilitate understanding of the information flow and requirements of the problem domain.
- ii) Offered abstract representation [21-24]- a metamodel offered the creation of an abstraction of a problem domain by defining the set of concepts, properties, relationships, and constraints. Abstraction is a simplification because irrelevant details are ignored and only the relevant details of the problem domain are represented. Furthermore, the metamodel may be expressed at different levels of abstraction as to avoid complexity.
- iii) Allowed flexibility - [17, 23]- by separating the different concerns of a system, a metamodel could be used to represent different aspects and views of a system.
- iv) Quick understanding of the concepts [22-24] – a visual metamodel helps us to visualize a system and understand the concepts being defined for the domain in an easy way.

The four metamodels that we described in the previous section appeared to have the four advantages listed above. Other advantages/benefits reported in the literature are - increased productivity, facilitated integration, support of maintainability and interoperability, reduced developmental cost, and improved communications between stakeholders [22-24].

Despite the benefits stated above, a crucial factor in the success of MDE projects in the healthcare domain is the quality of the metamodels [25]. Thus, metamodels in any domain require careful construction. The evolution of metamodels is a big challenge, as they tend to be central artifacts with many tools that depend on them. Ma et al. [26], reported that “*it is unavoidable that metamodels have quality defects because their design is related to the cognitive ability of designers*” [26]. Table 2 shows the quality attributes as suggested by Ma et al. [26] to assess the quality of metamodels. For instance, properties of syntactical correctness and well-structuredness imply the syntactic quality. Similarly, the capability quality of a metamodel is related to functionality and reusability. These quality attributes could be applied to examine the quality of metamodels designed for healthcare applications.

Table 2 - Quality attributes for assessing metamodels by [26]

Quality attribute	Quality Property
Syntactic quality	Syntactical correctness, Well structuredness
Semantic quality	Semantic validity, Semantic consistency, Semantic completeness
Pragmatic quality	Understandability, Change to clarify
Capability quality	Functionality, Reusability
Evolvability quality	Change to evolvability, Extendibility

With the increasing use of the metamodeling approach, we would like to emphasise that designing quality metamodels for the healthcare domain is essential to assure that the healthcare applications are quality and reliable enough to be used. Despite the benefits that we stated above, there are challenges in employing MDE via the metamodel approach. In [22], the authors presented a set of main challenges in the MDE, which they classified in terms of technical, social and community challenges [22]. The technical challenges consist of foundation, domain, and tool challenges. For instance, the lack of good tools to support the implementation of MDE is one of the challenging factors [22]. One of the

issues in social challenges is to allow for domain specific MDEs, such as MDE for banking, MDE for health, etc. The challenges reported by [22], could impact MDE via the metamodeling approach applied in the healthcare domain.

6. Conclusion and Future Work

In this paper, we presented four examples of healthcare applications applying MDE via the metamodel-based approach. Based on our research findings and analysis, we highlighted how MDE via the metamodeling approach managed the complexities for designing large healthcare applications. As for future work, we plan to formulate a framework for assessing the quality of metamodel designs of healthcare applications. Then, we will implement a proof-of-concept via a prototype of a metamodel tool based on the proposed framework.

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