

A Strategy to Specify Customizable Interoperability Maturity Models for Software Systems

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Abstract. *Interoperability enables transparent communication between systems and can be achieved through syntactic, semantic, pragmatic, and organizational levels. Maturity models have been used to check systems' maturity. However, these models have been criticized for needing more empirical validation and effective methods to help their specifications, thus harming their adoption. This work presents Amortisse, a maturity model to check interoperability in software systems, and the methodology for its customization and evolution. The results show Amortisse's feasibility in measuring the interoperability maturity of systems, and the methodology allows the development of the first version and its evolution.*

Keywords. *Interoperability; Maturity Model; Methodology; Interoperability Assessment.*

Resumo. *Interoperabilidade permite a comunicação transparente entre sistemas e pode ser alcançada por meio de níveis sintático, semântico, pragmático e organizacional. Modelos de maturidade têm sido utilizados para verificar a maturidade de sistemas. No entanto, esses modelos têm sido criticados por necessitarem de mais validação empírica e métodos eficazes para auxiliar suas especificações, prejudicando assim sua adoção. Este trabalho apresenta Amortisse, um modelo de maturidade para verificar a interoperabilidade em sistemas de software, e a metodologia para sua customização e evolução. Os resultados mostram a viabilidade de Amortisse em mensurar a maturidade de interoperabilidade de sistemas, e a metodologia permite o desenvolvimento da primeira versão e sua evolução.*

Palavras-Chave. *Interoperabilidade; Modelo de Maturidade; Metodologia; Avaliação de Interoperabilidade.*

1. Introduction

Interoperability is the ability of heterogeneous systems to inter-communicate transparently and often consists of the following levels: (i) syntactic, which ensures the exchange of information among systems based on message standard; (ii) semantic, concerns on communication meaning; (iii) pragmatic, provides that systems share the same communication intention; (iv) dynamic, where systems take into account business

rules; and (v) organizational (or conceptual), where constraints and business rules are aligned [Braga et al. 2017], [Sinderen and Asuncion 2010], [Wang and Tolk 2009]. Some scenarios require syntactic and semantic interoperability, while others, pragmatic and organizational, depend on the system's maturity and knowledge. While there is a need to agree on the structure and meaning of shared information, the intended effect of business-level collaboration and alignment is equally important [Sinderen and Asuncion 2010]. Among several challenges for systems to provide interoperability, identifying the requirements to achieve the desired interoperability is among them.

Several works that propose solutions to support the implementation of interoperability requirements offer isolated solutions, focusing on a certain level, such as syntactic, semantic, and/or pragmatic [Asuncion et al. 2011], [Correa 2012], [Kerzner 2019], [Vivek 2019]. However, interoperability can evolve according to business needs or application domains. The work of [Santos et al. 2021] pointed out more than thirty interoperability types addressed in twenty-three secondary studies. Moreover, the concept of interoperability has changed due to the widely needed collaboration among systems, things, devices, etc. The authors [Motta et al. 2017] argue that interoperability should be rethought to fulfill contemporary software systems, go beyond software and hardware heterogeneity, and so address the ability of things (an object, a place, an application, or anything that can engage an interaction in a system) to interact for a specific purpose, considering their differences (development platforms, data formats, culture, legal issues).

Due to the constant software systems evolution, it is important to provide an instrument for both, help organizations identify the current interoperability level of their systems, and assist in other levels of achievement. Maturity Models (MM) can help with these issues. Maturity can be understood as a state or condition explicitly defined, managed, measured, and controlled in a particular discipline of an organization or domain [Correa 2012]. A MM is usually used to support internal and/or external benchmarks of an organization's aspect and improvement guidelines. MM has been employed to understand, plan, and evolve software systems, and processes. A MM follows a stage growth approach, presenting levels in a linear and unidirectional path from the lowest to the highest [Carvalho et al. 2019]. The higher the level, the greater the quality of its services and processes and the possibility for implementation improvements.

Over the past few decades, there has been a growing interest in maturity models including interoperability [Carvalho et al. 2019], [Carvalho et al. 2017], [Lehmkuhl et al. 2013], such as web and social media [Duane and O'Reilly 2012], [Lehmkuhl et al. 2013], analysis [Cosic et al. 2012] the consulting area [Fath-Allah et al. 2015], industry [Gazarain and Errasti 2016], business intelligence [Qusheh et al. 2017], scrum [Almeida and Jorge 2017], project management [Kerzner 2019], artificial intelligence [Messom et al. 2019] and logistics [Carvalho et al. 2017], [Facchini et al. 2020]. Despite these research works, maturity models have been immersed in criticism for lack of empirical validation, misguided structural assumptions, and being too simplistic to be helpful, leading to poor adoption [Carvalho et al. 2019]. Additionally, MM proposals are focused on a specific domain and, therefore, have predetermined levels, stages, and requirements described in a high level of abstraction, which does not always represent the specific characteristics and organizations' needs [Rezaei et al. 2014] [Leal et al. 2019]. MM's evolution to adapt to new domains and organization requirements is not trivial.

This paper presents a strategy that comprises Amortisse (mAturity Model fOR inTeroperability In Software SystEms), a maturity model to check interoperability in software systems, and the methodology for its customization and evolution. Amortisse has four dimensions (related to interoperability levels) and five maturity levels. It also has a set of interoperability capability indicators (e.g., requirements) to evaluate systems. Aiming to explicitly make Amortisse's design rationale, the activities performed, strategies and techniques adopted, and artifacts produced were organized in the methodology [Monteiro et al. 2020]. This methodology systematizes elements involved in MM development, such as MM domain requirements, organization of related concepts into levels, dimensions, and the path to maturity. As a result, Amortisse can be better understood, validated, and customized to specific demands. Therefore, our solution comprises the Amortisse and its maintenance and evolution methodology. While organizations may use Amortisse to measure the interoperability level of their systems and as an instrument to support software evolution in order to achieve the desired interoperability level, our methodology helps Amortisse customization and evolution.

We evaluated Amortisse through two case studies and also evaluated user perceptions concerning aspects such as usefulness and consistency. We hope that sharing our proposal with the community for future improvements will encourage MM developers and users to adopt maturity models as an interoperability achievement.

Besides the introduction, Section 2 presents the underlying concepts of this work and State of the art; Section 3 describes the maturity model development methodology; Section 4 describes the Amortisse; Section 5 describes the Amortisse assessment; and finally Section 6 presents concluding remarks and opportunities for future work.

2. State of Art

This section describes some concepts related to maturity models (Section 2.1), interoperability (Section 2.2) and Rasch Model (Section 2.3). It then analyzes current solutions (Section 2.4) concerning maturity models for the interoperability domain.

2.1. Maturity Models

Maturity can be defined as “the state of being complete, perfect or ready” [Lahrmann et al. 2011]. It thus implies evolutionary progress in the demonstration of a specific ability or the accomplishment of a target from an initial to a desired or typically occurring end-stage. In the Information System discipline, maturity is regarded as a measure to evaluate the capabilities of an organization [de Bruin et al. 2005]. Following Becker et al. (2009), MMs endorse this evaluation by outlining anticipated, typical, logical, and desired evolution paths. Furthermore, Mettler et al. (2009) argue that, as formality is incorporated into organizational development activities, decision-makers are given a pragmatic instrument to determine whether potential benefits have been realized or not.

A Maturity model usually encompasses five important components: (i) maturity stage also known as levels or maturity score, and it describes the main goal of the maturity in a stage; (ii) dimension, which represents critical factors for success in the analyzed domain, and may contain subcategories [Carvalho et al. 2019]; (iii) subcategory, represents second-level variables on which a dimension depends on. A subcategory groups requirements related to a specific subject of the evaluated entity; (iv) requirement or assessment question represents a necessity of the domain under evaluation that should

be reached. It is usually directly linked to the subcategories with a maturity score or stage; and (v) maturity assessment follows a path (to maturity), which usually is linear, from the lowest to the highest maturity stage. Moreover, maturity models usually have two parts: (a) a generic design structure comprising different stages, each with different dimensions and sub-categories; and (b) hierarchical relationships between the typical components of the maturity model. MMs are an established means to document and guide organizations' development using capability stages systematically.

MM can be specified using two different approaches: top-down or bottom-up [De Bruin et al. 2005]. In a top-down approach, a fixed number of maturity stages is initially specified and further corroborated with some characteristics (i.e., assessment items, e.g., requirements) that support first assumptions about the maturity distribution into dimensions and subcategories [Lahrmann et al. 2011]. In a bottom-up approach, distinct characteristics are determined and then clustered into maturity stages.

MMs have proliferated across a multitude of domains since the concept of measuring maturity was introduced by the Capability Maturity Model (CMM) from the Software Engineering Institute (SEI) [De Bruin et al. 2005]. The SEI has created six maturity models and then incorporated three legacy CMMs into one, named the Capability Maturity Model Integration – CMMI [Chrissis et al. 2011]. CMMI has evolved significantly since its creation. Currently, version 3.0, released in 2023, unified its previous models into a single, comprehensive framework. The model is no longer the property of the SEI and is now administered by the CMMI Institute, a subsidiary of ISACA [ISACA 2024]. The CMMI has motivated consultants to develop some models for several proposals, thereby increasing their adoption of CMMI [Chrissis et al. 2011].

Whilst maturity models are high in number and broad in application, there needs to be more documentation on developing a theoretically sound MM. Limited knowledge is available on delineating the MM path evolution systematically and instantiating the corresponding MM [Brocke 2019]. More distinct development processes have been discussed to assist MM development, e.g., in [Becker et al. 2009 and [De Bruin et al. 2005]. One standard development framework forms a sound basis to guide the development of a model and then enable the evolution of the model. Furthermore, whilst decisions within the phases of this framework may vary, the phases themselves can be reflected in a consistent methodology that can be applied across multiple disciplines.

2.2. Rasch Model

The Rasch model [Lahrmann et al. 2011] is a psychometric model that statistically measures individuals' abilities. For example, it is possible to measure the student's ability in a subject using questionnaire responses.

Rasch's model uses a logistic function to relate the probability of a correct response to an item to the difference between the person's ability and the item's difficulty. It also defines parameters to characterize the respondents' proficiency and the items' difficulty.

The construction of a Rasch model starts with the data collection, using, for example, a questionnaire. Then, a statistical software fits the Rasch model to the response data to estimate the parameters for each item and person. Finally, the results are analyzed to evaluate how well the data fits the assumptions of the Rasch model.

2.3. Interoperability

Interoperability has become a critical non-functional requirement as distributed computing, web, and service-oriented architecture have overcome organizational barriers, connecting previously isolated business data [Marciel et al. 2024]. Interoperability is commonly related to application collaboration, regardless of the technologies used, e.g., methods, programming languages, and environments.

The Levels of Conceptual Interoperability Model (LCIM) is the framework for assessing the degree of conceptual representation between interoperable systems, which classifies interoperability into seven levels: no interoperability, technical, syntactic, semantic, pragmatic, dynamic, and conceptual [Fewell and Clark 2003]. Since LCIM, several authors have categorized interoperability into levels. For example, the work proposed in [Santos et al. 2021] adopts LCIM as a reference and includes a new interoperability level, the Organizational. Some common interoperability levels are: 0 - stand-alone systems that have no interoperability [Correa 2012]; 1 - syntactic interoperability, which introduces a common structure to exchange information, i.e., a common data format is applied [Correa 2012]; 2 - semantic interoperability, when a common information exchange reference model is used [Correa 2012]; 3 - pragmatic interoperability, when the interoperate systems are aware of the methods and procedures that each system is employing [Correa 2012]; 4 - organizational interoperability, encompasses business rules and organizational policies and can be focused on process modelling and realigning information architectures of organizations to promote collaborative work [Correa 2012]; 5 - dynamic interoperability, considers that a system operates on data over time and the state of that system will change [Tolk et al. 2007]; 6 - conceptual interoperability, where systems are entirely aware of each other information, processes, contexts, and modelling assumptions [Tolk et al. 2007]. For instance, some systems may require syntactic and semantic interoperability, while others require the organizational level. Problems occur when exchanging information among heterogeneous systems, such as programming language differences or ambiguity in the development environment. Full interoperability is the capacity of a system to achieve all desired interoperability levels from the most basic to the most specific [Boscarioli et al. 2017].

Strategies to solve syntactic and semantic interoperability are quite stable in the literature. A standard usually performs syntactic interoperability, and semantic interoperability is addressed by ontology or thesaurus [Wang et al. 2009]. Several researchers deal with pragmatic interoperability [De Moor 2005], [Lee et al. 2007], [Liu et al. 2014], [Marciel et al. 2024], [Evripidou and Tamari 2007] and [Ribeiro et al. 2019]. Although both syntactic and semantic levels have consensual definitions, neither pragmatic, dynamic, nor organizational interoperability have a commonly shared one. The increasing amount of work in the area potentiates confusion and ambiguity in using these terms, making it difficult to have a comprehensive view of related or similar interoperability proposals and, so, hindering information systems from achieving the desired interoperability. The authors of [Santos et al. 2021] have pointed out more than 27 different names of interoperability, e.g., incompatible solutions, ambiguous messages interpretations, and difficulty in achieving the desired interoperability.

As Interoperability is one of the aspects that can be measured in an organization's software systems, over the past few decades, there has been a dramatic interest in maturity models for different specific domains [Carvalho et al. 2019]. However, Interoperability

can evolve according to business needs, and maturity models can be an instrument for both, helping organizations identify the current interoperability level of their systems and assisting them in other levels of achievement.

2.4. Interoperability Solutions

There are some proposals concerning the inter-communication among systems. Recently, pragmatic interoperability, as an LCIM intermediate level, has attracted attention of a lot of works, such as [Lee et al. 2007], [Liu et al. 2014], [Marciel et al. 2016], [Evripidou and Tamari 2007] and [Ribeiro et al. 2019]. Many existing maturity models have been developed for different purposes, such as [Clark and Jones 1999], [Fewell and Clark 2003], [Chen, 2013] and [Rezaei et al. 2014]. These proposals usually focus on a level.

The LISI (Levels of Information System Interoperability) maturity model defines interoperability between information systems [Clark and Jones 1999]. It focuses on technical interoperability, i.e. the ability to share information using Ethernet or fiber net, and the complexity of interoperations between information systems. LISI comprises five levels: Isolated, Connected, Functional, Domain and Enterprise. LISI enables building an interoperability matrix to represent the potential for each system to interoperate with others and displays the level at which the interactions will potentially occur.

The OIM (Organizational Interoperability Maturity Model) deals with the ability of organizations to interoperate [Fewell and Clark 2003]. It extends the LISI model to assess organizational issues at the business company interoperability level. OIM comprises five levels: Independent, Ad hoc, Collaborative, Integrated and Unified. OIM covers business areas focusing on organizational issues in an enterprise context, and it does not address technical, semantic or syntactical aspects. The EIMM (Enterprise Interoperability Maturity Model) [Chen 2013] aims at evaluating enterprise modelling/model maturity and covers data, service and process interoperability issues.

The authors of [Rezaei et al. 2014] present a maturity model for the interoperability of ultra-large-scale systems, a new generation of distributed software systems composed of various changing, inconsistent or even conflicting components distributed in a broad domain. Some important characteristics of these systems include their considerable size, global geographical distribution, and operational and managerial independence of their member systems. By using the interoperability level of the component system of one ultra-large-scale systems, its maturity level can be determined. By proposing a framework, the authors tried to increase the interoperability of the component systems in ultra-large-scale systems based on the interoperability maturity levels. Consequently, their interoperability is improved.

SPICE (Software Process Improvement and Capability Determination) is a general model for process maturity [Guédria et al. 2015]. Although not explicitly designed for interoperability, it is important because a higher maturity of enterprise processes may contribute to developing interoperability between enterprises. SPICE can also be used to evaluate the maturity of this process. Additionally, this paper presents a comparative showing among some interoperability maturity models (LISI, OIM, LCIM, EIMM, and in [Rezaei et al. 2014]). It concludes that they are partial models that only deal with some aspects of the enterprise interoperability domain. SPICE was a key project, a reference for developing other process reference models and assessment methods, such as the ISO/IEC 15504 series of standards and the ISO/IEC 33000 family.

The Interoperability Maturity Model (IMM) [Knight et al. 2020], proposed by the U.S. Department of Energy (DOE), is a MM for the information and communications technology integration of intelligent devices and systems in various electric power system technology domains, such as interaction with transmission and distribution infrastructure, and distributed energy resources in customer systems. IMM comprises 32 criteria, grouped into six categories for quantifying the state of interoperability in a technology integration domain. The six categories are related to interoperability levels: technical, informational, organizational, operation and performance, safety and security, configuration and evolution. Each criterion has five levels of descriptions (initial, managed, defined, planned and optimized) that can be used to assess interoperability maturity related to the categories. The first step in measuring interoperability is identifying a target integration situation and the interfaces that support it. Then, decide whether to apply for the whole IMM or part of it. The choice of parts (categories) to use may be driven by known interoperability deficiencies or specific drivers that cause the stakeholder(s) to prioritize one category over another. The report presents an example of IMM use, but no formal evaluation is provided. Except for IMM, each of these maturity models aims to assess interoperability through different perspectives, approaches and metrics, but using a linear path to maturity without considering equifinality, i.e. an entity or system can achieve the same result from different initial conditions and through different paths. However, while IMM levels and stages are fixed, Amortisse structure (level, stage, and requirements) can be customized, for instance: a new level representing a distinct interoperability type can be added. Additionally, Amortisse is domain independent and IMM target is the electric power system domain.

Amortisse provides an inductive form of structuring dimensions and levels, making it possible to guide oneself through different paths among its dimensions and levels. Furthermore, interoperability differs among domains and presents an important evolutionary process, leading to the need for maturity models to evolve together. For this purpose, Amortisse was specified using a pre-defined methodology which can be applied to the Amortisse needs for evolution and adaptation to new situations faced by the systems and software of a given organization. Furthermore, the capabilities and requirements used in those related works could be added to Amortisse to fulfil specific domain aspects. Sections 3 and 4 present the methodology and the Amortisse MM, respectively.

3. Maturity Model Development Methodology

This section introduces the methodology adopted for the Amortisse maturity model specification [Monteiro et al. 2020]. This methodology was defined systematically through a sequence of steps, artifacts, roles, and potential technologies and strategies. This was based on a prior systematic review [Monteiro and Maciel 2020b] that aimed to investigate the state of the art in maturity model proposals. While defining the Amortisse model, we discerned an absence of a theoretical foundation underpinning the qualitative approaches frequently utilized to establish MM definitions [Santos et al. 2021]. Information about MM specification was frequently dispersed throughout the literature and described at a high level of abstraction, lacking sufficient detail for practical application. To address this issue, we conducted an in-depth analysis of various maturity models to identify key elements (such as dimensions and stages), select strategies for defining these elements, and specify artifacts for documenting them. Furthermore, all activities conducted throughout the process were comprehensively documented. The

resulting methodology is presented here and evaluated by validating Amortisse in real-world scenarios (Section 5). As the construction or customization of maturity models may necessitate new definitions or adjustments, such as addressing emerging requirements, this methodology can be continuously improved.

Figure 1 shows an overview of the methodology life cycle, which comprises six phases: Scope, Design, Model Content, Model Construction, Implementation, and Maintenance. The methodology adopts the bottom-up strategy, so the maturity model components are first identified, and the stages are defined. Each phase is composed of tasks to be performed toward the model specification. For example, the Scope phase aims to define the model scope and comprises two tasks, set domain and set components. Moreover, phases are sequentially executed, i.e. the artefacts produced in the Scope phase are required to perform the Design phase and so on.

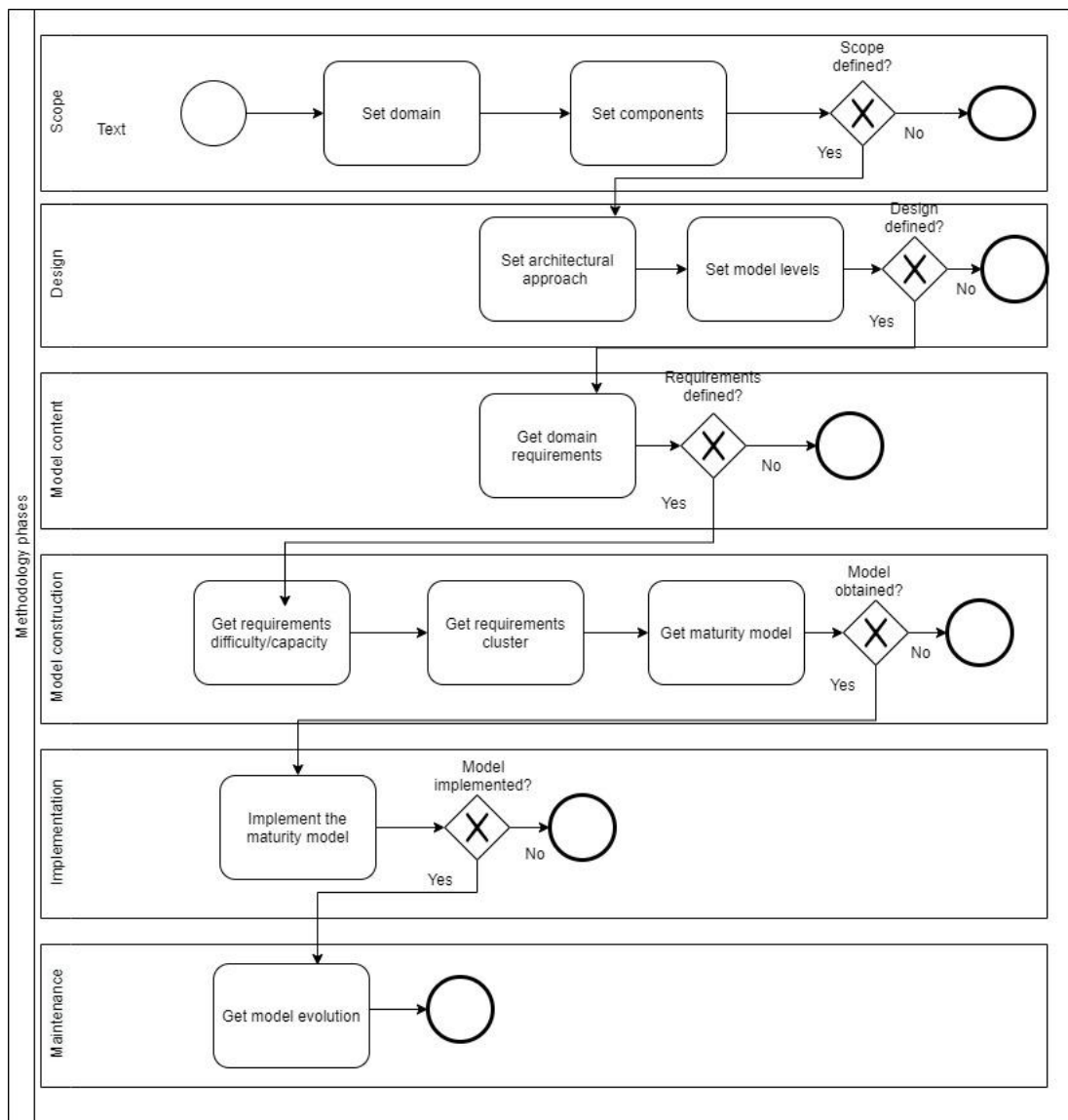


Figure 1. Proposed life cycle [Messom et al. 2019]

MM specification starts in the Scope phase. Its main goal is to properly specify the model scope for a specific domain, necessary to determine outer boundaries for the

model usage and possible extensions. This phase comprises two tasks: Set Domain and Set Components. The Set Domain task consists in understanding the domain by applying one or more methods for knowledge acquisition, such as literature reviews, interviews and so on. Although a systematic literature review is not mandatory, it can give a deep understanding of historical and contemporary domain issues. As part of this task, stakeholders are also identified to participate in the rest of the methodology phases specifying and validating the MM. In the task Set Components, the domain components (or categories) and sub-components (or subcategories) are obtained. Components represent the domain concepts used to classify requirements (identified in the third phase). The stakeholders identify them according to the domain necessities, e.g., in the interoperability domains important concepts, such as network and security can be mapped as components of the model. Each of these will represent a set of associated requirements.

The second phase is named Design and aims to specify MM architecture, i.e. models dimensions and stages (or levels). The first task in this phase, the Set architectural approach, is to define what approach should be taken in the maturity stages to delineate the evolution path. Our methodology recommends adopting a top-down or bottom-up approach depending on the domain features [De Bruin et al. 2005]. With a top-down approach, definitions are written first, and then measures are developed to fit the definitions. With a bottom-up approach, requirements and measures are determined first and then definitions are written to reflect these. A top-down approach works well if the domain is relatively new and there is little evidence of what is thought to represent maturity. Whichever approach is chosen, uncertainties related to the evolution path must be considered [Metter 2010], especially when dealing with new domains or domains in constant change. For example, when specifying an MM for an emerging domain, maturity stages may be uncertain, as the concepts are still unstable.

To define the maturity stages, qualitative methods are often adopted, for example, standardized questionnaires to assess the requirements level of difficulty. Some authors [Dekleva and Drehmer 1997] recommend the use of Item Response Theory (IRT) [De Ayla 2018] to support the definition of MM maturity stages. This theory aims to improve the reliability and validity of standardized questionnaires and tests that conclude item difficulties or participants' skills. An example is the Rasch algorithm-based approach [Lahrman et al. 2011] and the hierarchical cluster analysis [Field 2013]. So, using the selected approach, the MM stages are defined (Set model levels task) e.g., based on methods adopted in building maturity model constructs (conceptual, qualitative and so on). In existing MM, a common design principle is to represent maturity as several cumulative stages expressing a logical progression through the stages, i.e., the highest stages are based on the requirements of the lower stages. This was popularized by the CMM and appears to have broad acceptance. Stages should be named with short labels that give a clear indication of the internship's intent. The number of stages may vary from model to model, but what is important is that the stages are distinct and well-defined.

Once the scope and design of the model are agreed upon, it is time to define the Model Content in the third phase (Model Content). In this phase, it is necessary to specify the requirements of each domain component (or class or category) identified in the Scope phase. These requirements are important to determine which are the maturity assessment of them and how this can be measured (task Get domain requirements in Figure 1). For example, syntactic interoperability can be measured through network requirements and data exchange in the interoperability domain. Therefore, the outputs of this phase are the

requirements obtained for each component (or class or category) of the Scope phase and their eligibility, i.e. whether a particular requirement should be considered in the scenario. A short questionnaire can be designed to aid stakeholders in this phase.

The Model Construction phase aims to get a first draft MM. The model has to be populated by setting the level of each requirement in its respective dimension. We recommend the use of a pilot study to set up what is the effort to implement a requirement in a given scenario. During the pilot study, it is possible to find the difficulty or capacity (Get requirements difficulty or capacity task) of each requirement and build a hierarchy of clusters (Get requirements cluster task) to generate the MM (Get maturity model task).

In the Implementation phase, the model must be made available for use to verify its extent to generalizability (Implement the maturity model task in Figure 1). Once the model has already been developed and tested, for example, in the pilot study of the previous phase, the initial MM (draft version) should be used in a real scenario to evaluate the maturity of something (e.g. a development process, a system, among others) from another stakeholder. The system maturity level indication is an expected result. Different methods can be used here, like brainstorming [Snyder 2011] with specialists in a survey.

The Maintenance aims to aid model maintenance and further development when, for example, some model elements get obsolete, new requirements emerge, and assumptions on the different maturity stages are affirmed or refuted. It is essential to reflect on how to handle alterations in model design and deployment even in an early stage. A repository can support this task. As an input for this phase, we can consider resources, such as domain requirements, to keep up the model's growth and use.

Table 1 summarizes the artifacts of each methodology phase. The first column (Table 1) shows the phases and the others the input and output artefacts consumed and produced in them. For example, during the Scope phase, the results of a literature review (or other methods of knowledge acquisition) are used as a reference to define the model scope, identify the stakeholders and specify model categories and subcategories.

Table 1. MM Methodology Artifacts

Methodology Phase	Input Artifacts	Output Artifacts
Scope	Results of a literature review (or other knowledge acquisition method)	Model scope Stakeholders name Categories and subcategories
Design	Maturity Model structure (CMM-like, Likert-like, questionnaires, Maturity matrix or grid)	Maturity model architecture (dimensions and levels)
Model Content	Components, dimensions, questionnaires results	Domain requirements classified according to the components Requirement eligibility
Model Construction	Dimension, requirements and levels	Draft maturity model
Implementation	Draft maturity model	System maturity level indication Validated maturity model
Maintenance	Resources, e.g. unit of analysis	Updated maturity model

4. Amortisse (mAturity Model fOR interoperability In Software SysTems)

This section presents Amortisse, which aims to assess the interoperability level of given software systems. Extra material can be found at <https://u.pcloud.link/publink/show?code=IYftrtK>.

Organizations can use Amortisse to identify what requirements their systems should fulfill to achieve the desired interoperability dimension, i.e., Amortisse can assess the effectiveness of systems interoperability, figuring out what capabilities they should acquire to improve their performance. When applying Amortisse, approaches like focus groups or brainstorming [Snyder 2021] can be used by team leaders to indicate which requirements are met or are missing by a system and also the effort to obtain them, e.g., focus groups can be used to analyze the team perception concerning requirements relevance or completeness and brainstorming to get ideas of new requirements.

Amortisse is structured in dimensions and levels (Figure 2). While a dimension identifies the interoperability desired to measure in a system, a level measures the system maturity within each dimension. Each dimension is composed of measurable requirements (capability indicators) that make it possible to collect evidence to assess the interoperability level that a system achieves in that dimension. In this first release, Amortisse dimensions are related to the currently most common interoperability levels found in the literature: syntactic, semantic, pragmatic and organizational, and Amortisse considers the web service domain. The web service domain was chosen because the interoperability of syntactic and semantic definitions and solutions is relatively stable.

Each dimension comprises five maturity levels (stages) that define the interoperable system achievement. Stage one is the lowest degree of interoperability, and five is the highest, i.e. most significant ability to interoperate. Figure 3 shows Amortisse levels: Stage 0 represents a lack of ability to interoperate; Stage 1 represents some knowledge about the requirements needed to interoperate; Stage 2 represents shared knowledge of what needs to be done to interoperate; Stage 3 represents an alignment of knowledge and systems to interoperate; Stage 4 indicates a representation of processes and systems in workflow; and Stage 5 represents knowledge of the system's weaknesses and processes to evolve.

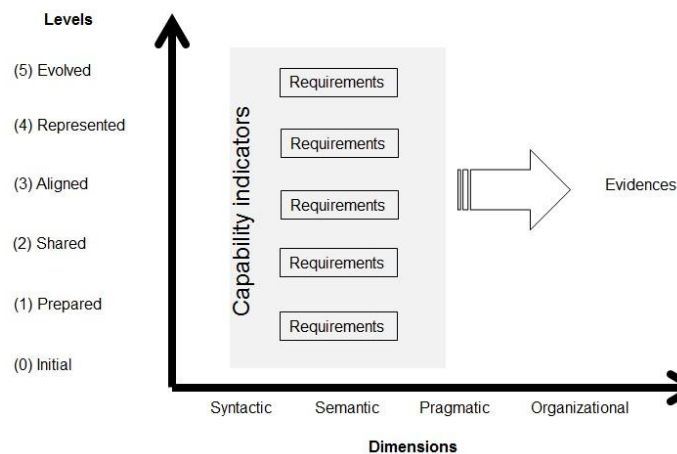


Figure 2. Amortisse structure

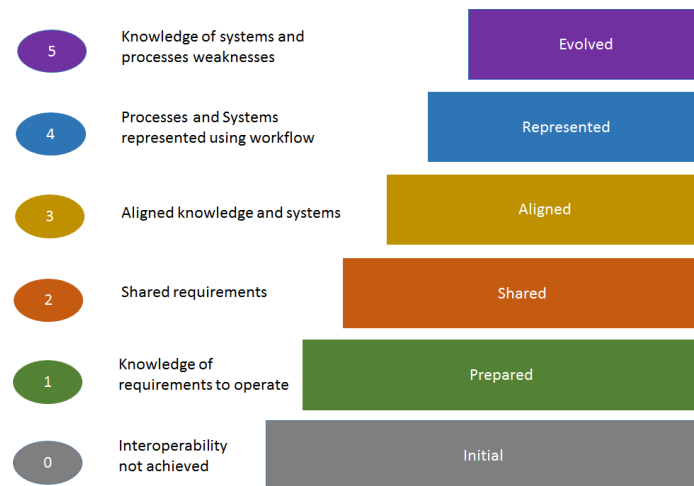


Figure 3. Amortisse maturity stages

Each requirement is assessed based on a rating scale, where N = interoperability not achieved (from 0 to 15%), P = interoperability partially achieved (from 15 to 50%), L = interoperability largely achieved (from 51 to 85%) and F = interoperability fully achieved (from 86 to 100%) which demonstrate the fulfilment of the interoperability requirements (Figure 3). So, to evolve between the maturity stages, it is important to meet all the requirements. Achievement of capability indicators does not intend to be all-inclusive nor applicable in its entirety. It is possible to achieve different capability stages for different dimensions. The Capability indicators aggregate requirements (presented in the next section on tables 3, 4 and 5) used to assess system interoperability.

Figure 4 summarizes Amortisse main elements and their relationships. Amortisse (Figure 4 (a)) contains interoperability requirements organized in dimensions, and levels. It is used to assess systems interoperability, i.e. communication, connection and collaboration among systems. This evaluation is performed by the involved stakeholders (Figure 4 (b)), which can be systems analysts, domain specialists, managers and so on. To perform the evaluation, it is necessary to analyze the involved systems, consider the domain requirements and collect data using techniques such as questionnaires, interviews or brainstorming (Figure 4 (c)). These are the input of the assessment process, which aims to generate as output the mature score for each dimension (Figure 4 (d)).

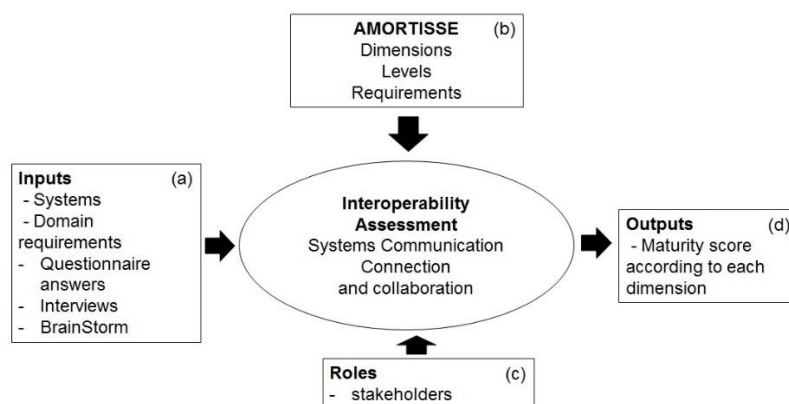


Figure 4. Amortisse assessment process and its involved elements

4.1. Amortisse Specification

This section presents the Amortisse specification following the methodology of Figure 1. Frequently, maturity models lack a sound foundation or are derived based on an arbitrary design method. Amortisse was specified according to a pre-defined methodology to understand how each model element was specified and to support extensions. The next subsections present the Amortisse specification according to the methodology.

4.1.1 Scope Phase

Interoperability is usually classified in layers, representing potential barriers that hamper collaboration among systems. An interoperability architecture should combine network, platform, data, message, and software architecture to make systems communication possible. Table 2 presents the interoperability levels, i.e. the scope of our maturity model, ordered to give a view of the systems and technology. Levels and their components were selected and defined based on the most cited interoperability types in literature [Ribeiro et al. 2019], [Santos et al. 2021]. While syntactic and semantic interoperability concepts are well established, pragmatic and organizational concepts are not. However, current research often points out that aspects related to message context (pragmatic level) and organization business (organization level) should be considered in systems collaboration [Ribeiro et al. 2019], [Santos et al. 2021]. The output of this phase was a component list (grouping) for the interoperability assessment. Table 2 presents the Scope phase output artifact, column 1 shows the interoperability levels, and column 2 its related components.

Table 2. List of components (groupings) generated as output in Scope phase

Interoperability Level	Components
Organizational	Organizational and cooperation policies, workflows and business rules
Pragmatic	Use, intention, context, effect, meaning and understanding
Semantics	Language or taxonomy or ontologies
Syntactic	Devices (smartphones) Interface (browser) Data format (XML) and delivery (web services) Applications and protocols Database Framework Security Network

4.1.2 Design Phase

Following the methodology, in the Design phase we should specify the MM architecture, i.e. define MM dimensions and stages. Our model focuses on how maturity is measured, not on what maturity represents. We adopted the bottom-up approach to defining the maturity stages, i.e. we previously identified the interoperability components to then decide on interoperability levels. Based on the Scope phase results, the model architecture was structured into four dimensions, representing the levels of interoperability.

We also defined five maturity stages for each dimension, which represents a 5-point Likert scale. They are named Level 1, Level 2 and so on, expressing a logical progression. The Likert scale is often used to develop a maturity model [De Bruin et al. 2005]. Level 0 represents a lack of capacity to interoperate; Level 1 certain knowledge about the requirements to interoperate; Level 2 shared knowledge of what needs to be done to interoperate; Level 3 an alignment of knowledge and systems to interoperate;

level 4 indicates a representation of the processes and systems in workflows; and level 5 an understanding of weaknesses in systems and processes to evolve.

4.1.3 Model Content Phase

In this phase, it is necessary to find what needs to be measured in the maturity assessment model. So, the first task is to specify interoperability requirements for each component of each dimension. For our model, an initial requirements list (presented in tables 3, 4 and 5) has been created based on the components identified for the interoperability domain. For example, requirement ID 1 *Message exchanged in the interaction between systems services has the use intention for the receiver* is associated with the intention component in the pragmatic dimension (see Table 3). Then, the eligibility of the requirements must be assessed, and requirements can be added or removed. We chose a pilot study to determine the requirements eligibility when participants should point out if the requirement should comprise the model content list or not.

The study context was a widely used scenario, the interoperability between a hospital and a laboratory information system [Asuncion et al. 2011] concerning two situations: the lab cannot understand the intent of the hospital because the lab has a different understanding of the context in which the hospital is operating; the laboratory can understand the intention of the hospital. Now both have the same understanding of context. For example, considering that the hospital is in an emergency context and requests a report from the laboratory. If the laboratory understands this request as usual, it will respond to it as a non-urgent request. If the laboratory can perceive the hospital's intention, the response will be sent urgently. We developed a web software according to this scenario, which considers that laboratories offer services, among them the report service in level of urgency, emergency and standard. The service consumer, e.g. the hospital, sends contextual information to characterize the request. This contextual information is represented through schemas containing the context dimensions, e.g. how the data will be obtained, who is the requestor, what the entity is doing or intends to do and why the action. A web service checks whether the message has the information needed to perform queries based on the intent and the contextual information and search the service in a base. If so, the WSDL link is obtained and sent to the requester to make the service call. Otherwise, the requester is notified that the information is not sufficient.

We conducted a pilot study with seven academic participants, doctors and master students working on an interoperability research project. Participants evaluated requirement (tables 3, 4 and 5) eligibility by answering a questionnaire through semi-structured interviews. The questionnaire was structured following the four interoperability dimensions (syntactic, semantic, pragmatic, and organizational), where each question represents a requirement (from tables) of one of these dimensions. Thirty-one questions were specified, all of them using a 5-point Likert scale which is assumed to have different levels of difficulty. So, participants indicated the difficulty of achieving its requirement in the scenario, five for extremely difficult to one for extremely easy. Based on the collected answers, the list of the initial requirements was then measured by basically counting answered questions.

Table 3. Requirements of Pragmatic dimension

ID	Pragmatic Interoperability Requirements
1	Message exchanged in interaction among systems services contains the use intention of the receiver
2	Message intention is clearly and explicitly defined
3	Message is sent automatically, via a communication channel established between parties
4	A standard to represent message intention is unambiguously established
5	A standard to represent message intention is understood and shared by involved parties in interaction
6	Message effect is compatible with your intention
7	The exchanged message context is clearly and explicitly defined
8	A context standard of the exchanged message is unambiguously established
9	The context standard of the exchange message is understood and shared

Table 4. Requirements of Organizational dimension

ID	Organizational Interoperability
10	Organizational intentions, such as business rules and organizational policies are clearly and explicitly defined
11	An organizational intent standard is unambiguously established
12	Organizations intention pattern is understood and shared
13	A continuous communication channel among the parties is established
ID	Organizational Interoperability
14	Responsibilities and agreements are established among the parties
15	Responsibilities and agreements are performed, negotiated and monitored
16	Information about service use (who, how, where, when) is stored and shared
17	Collaborators' context (social, cultural, workspace and so on) is clearly and explicitly defined
18	A standard to represent the collaborators' context is unambiguously established
19	A standard for representing collaborators' context is understood and shared by the involved parties in collaboration
20	Mechanisms to support the trust among the parties are established
21	Organizational intentions are enriched with historical information about shared resources and collaborators' contexts, to better meet the expectations

Table 5. Requirements of Semantic and Syntactic dimension

ID	Semantic Interoperability
22	Among systems, disjoint concepts are represented unambiguously
23	There are strategies to represent, unambiguously, general concepts
24	There are strategies to represent, unambiguously, specific concepts
25	There are strategies to represent, unambiguously, concepts with overlapping meanings used in interactions among systems
26	Among systems, there is no ambiguity regarding the concepts (general, specific, overlapping)
	Syntactic Interoperability
27	Network infrastructure policies and specifications are understood
28	Applications policies and specifications and base protocols for system operation are understood
29	Policies and specifications that define a uniform way to the transit of encoded data are understood
30	Policies and specifications that define the rules for encoding data using the representation of structures and descriptors according to standardized languages are understood
31	Policies and specifications to provide access to all the information systems are understood

4.1.4 Model Construction Phase

The main goal of this phase is to generate the initial maturity model according to the elements specified in the previews phase: dimensions, stages and requirements. So, the requirements just elected, based on the degree of difficulty in their achievement, must be distributed in the stages of their respective dimension.

Each requirement difficulty, defined in the Model Content phase according to the scenario adopted, i.e. the questionnaire answers, were inserted for analysis in the Rasch algorithm using the Ministep Software [Liu 2010], i.e. using the Rasch algorithm, capabilities and difficulties are tested against estimates based on an item response

function. So, difficult requirements have a higher measure than easy ones [Liu 2010]. The result of this step is a flat list of ordered requirements, comprised of columns one and two of Table 6. In column one, requirements are represented in the format of the Rasch algorithm. Therefore, \$Coef\$i08 represents the requirement of ID 8, semantic dimension, Systems use the same symbol to represent the disjoint and overlapping concepts which achieve the measurement 15 343 (Table 6, column 2).

Although empirical conclusions can be drawn from such a list, the item difficulty measures do not allow the requirements among the maturity stages. For instance, should requirements 08 and 02, which reached item difficulty values 15.343 and 14.815, be placed in the distinct or same stage? Therefore, to carry out this allocation, once the results were extracted, it was necessary to put values in a cluster analysis to get the Amortisse draft version finally. The cluster analysis is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters) [Romesburg 2004]. The clustering algorithm grouped the difficulty items into stages. That is, the analysis of the values achieved by each requirement difficulty item indicates at what dimension stage of maturity the requirement should be allocated in the MM. For clustering, we used hierarchical cluster analysis of SPSS (squared Euclidean distance, Ward's method [Field 2013] and set the desired number of maturity stages to five, Table 6 column three. Table 7 presents a slice of the Rasch results organized according to Amortisse levels and dimensions, and Table 8 presents the same data using the requirements description.

Table 6. Rasch algorithm and Cluster analysis: results slice

Requirements	Item difficulty	Level / Stage
\$Coef\$i08	15.343	5
\$Coef\$i02	14.815	5
\$Coef\$i04	13.107	4
\$Coef\$i20	13.107	4
\$Coef\$i29	2.435	3
\$Coef\$i03	1.762	2
\$Coef\$i05	0.905	1
\$Coef\$i07	0.519	1

Table 7. Maturity model draft version

Dimension	Level 1	Level 2	Level 3	Level 4	Level 5
Organizational	\$Coef\$i18	\$Coef\$i14	\$Coef\$i21	\$Coef\$i20	\$Coef\$i10
Pragmatic	\$Coef\$i09	\$Coef\$i03		\$Coef\$i04	\$Coef\$i02
Semantics	\$Coef\$i26		\$Coef\$i23	\$Coef\$i24	\$Coef\$i22
Syntactic	\$Coef\$i27	\$Coef\$i31	\$Coef\$i29		\$Coef\$i30

4.1.5 Implementation and Maintenance Phase

After obtaining an initial version of our interoperability MM, we should apply it in a real scenario to verify its applicability. We performed two case studies (Section 5.1 and 5.2).

5. Amortisse Evaluation

Validations involving humans are very challenging since they usually have many activities that people with different levels of expertise perform. Therefore, they should be carried out in phases, where each phase evolves from the previous one. Amortisse evaluation was carried out in two phases: (i) a case study to evaluate Amortisse applicability in the web and internet domain; and (ii) a case study to evaluate Amortisse

evolution using a cloud domain. We also performed an interview to get the user perception about aspects related to Amortisse's usefulness, consistency, scope, among others. So, the first case study showed Amortisse's feasibility; the second case study showed Amortisse's evolution to another domain, and the interviews showed the user's perception of different aspects when using Amortisse. Replications of these studies are being planned. We adopted qualitative methods due to the limited number of people with knowledge in the interoperability domain and maturity evaluation in organizations.

Table 8. Maturity model slice

	Level 1	Level 2	Level 3	Level 4	Level 5
Organizational	A standard to represent the collaborators' context is unambiguously established	Responsibilities and agreements are established among the parties	Organizational intentions are enriched with historical information about shared resources and the collaborators contexts, to better meet the expectations	Mechanisms to support the trust among the parties are established	Organizational intention, such as business rules, and organizational policies are clearly and explicitly defined
Pragmatic	The context standard of the exchange message is understood and shared	Messages are sent automatically, via a communication channel established between parties		A standard to represent message intention is unambiguously established	Message intention is clearly and explicitly defined
Semantics	Among systems, there is no ambiguity regarding the concepts (general, specific, overlapping)		There are strategies to represent, unambiguously, general concepts	here are strategies to represent, unambiguously, specific concepts	Among systems, disjoint concepts are represented unambiguously
Syntactic	Network infrastructure policies and specifications and understood	Policies and specifications to provide access to all the information systems are understood	Policies and specifications that define a uniform way to the transit of encoded data are understood		Policies and specifications that define the rules for encoding data using the representation of structures and descriptors according to standardized languages are understood

5.1. Applicability Case Study

To evaluate the applicability of using Amortisse in real scenarios, we performed a case study on an e-government application hosted on the web platform. The study adopted Amortisse to identify the interoperability maturity level of a set of systems of a governance organization in Brazil that deal with systems for traffic control. It was performed at a government partner software house, developing services for citizens and several government organizations. The study was conducted according to the guidelines proposed by Wohlin et al. (2012).

5.1.1 Case Study Design

The study identifies the interoperability maturity level of three software systems: a mobile application that allows traffic guards to apply traffic fines, a web portal for citizens to query their driver's license information, and an information system (desktop client

system) to manage enforcement penalties laws on drivers. These systems allow for a collaborative relationship among the city hall administration, state government and the population regarding traffic public order and tickets.

The main goal of the study was defined according to Goal Question Metric (GQM) [Basili et al. 2994] template in Figure 5. Based on this goal, we defined two questions to guide the validation: Question 1: Do Amortisse MM dimensions cover the interoperability scope needed to be measured? With this question, we want to identify if the dimensions were well defined, i.e. whether Amortisse comprises the necessary dimensions. Question 2: Are Interoperability requirements sufficient to measure interoperability in every dimension? With this question, we want to identify if the requirements are sufficient to measure maturity in each dimension and level.

Participants are company employees with knowledge of software infrastructure and development. We selected seven participants by applying a questionnaire to assess their interoperability skills and knowledge, e.g., we asked them to conceptualize interoperability and exemplify the interoperability types they knew using the company context. There is one Senior software architect, two total network analysts, two full software engineers, one Junior analyst, and one DevOps engineer. Most (71%) are over 30 years old, and 57% have worked in this company for over four years. Therefore, they have proper knowledge of the organization's business processes and technological infrastructure.

Analyze Amortisse
For the purpose of evaluating its feasibility in measure the interoperability level of systems
Related to dimensions, levels and requirements
From the respective of system analysts
In the context of a set of information systems in a real company

Figure 5. Case study main goal according to GQM template

Participants applied Amortisse MM to measure the interoperability level of the involved systems. Data collection was carried out directly by applying an interview guided by the researcher through an online questionnaire during the study execution. So, the participants should answer, for each requirement of tables 3, 4 and 5, if it was met or not by the analyzed systems.

5.1.2 Case Study Execution

The study lasted two and a half hours and was conducted in three phases: (i) the researcher introduced Amortisse to the participants, as it was the first time they had used it; (ii) participants analyzed which Amortisse requirements were met by the systems. They collected some evidence (e.g., identify data structure) to guide their answers about requirement fulfillment, using the rating scale presented in section 4 or the correspondent Linkert scale (e.g., 5 - the requirement is completely met, 1 - the requirement is not met.). Analysis was guided by an online questionnaire; (iii) finally, participants evaluated in a focus group session the requirements disposition through model dimensions and levels, i.e., the researcher presented the suggestion of requirement associated with each

dimension, and participants discussed to approve them. During the study, the researcher played the role of presenter in the first phase and interviewer in the other two phases.

5.1.3 Data Analysis

The collected data can be analyzed using different methods, e.g. statistical and qualitative methods. Due to the number of participants, we decided to adopt a qualitative one, a brainstorming session. Therefore, we promoted a group discussion where participants analyzed all the questionnaire data for each question to achieve a consensus.

Due to the variation of knowledge among participants, answers related to syntactic interoperability showed a disagreement among participants, while in the other dimensions, the results were balanced. For example, junior analysts and full software engineers are closer to the organization's business and functional requirements, while network analysts and DevOps are involved with technology infrastructure. As a highlight, it was essential to have a software architect profile as a group member, and he had a holistic view of the software systems. After brainstorming session, participants updated their answers and achieved a consensus. Tables 9, 10, 11 and 12 show the responses. The (+) markings indicate that the system fulfils the requirement, i.e. more than 75% of the responses state that the system's requirements were 4 (met) or 5 (wholly met), and the (-) markings indicate the system did not achieve the requirement.

Table 9. Organizational Interoperability

Levels	Organizational Interoperability Dimension
1	(+) Collaborators' context (social, cultural, workspace and so on) is clearly and explicitly defined (+) Responsibilities and agreements are performed, negotiated and monitored (-) An organizational intent standard is unambiguously established (-) A continuous communication channel among the parties is established (+) A standard to represent the collaborator's context is unambiguously established
2	(+) Responsibilities and agreements are established among parties (+) A standard for representing collaborators' context is understood and shared by the involved parties in collaboration
3	(+) organizational intentions are enriched with historical information about shared resources and collaborators' contexts, to better meet the expectations
4	(-) An organizations' intention pattern is understood and shared (+) Mechanisms to support the trust among the parties are established (+) Information about service use (who, how, where, when) is stored and shared
5	(+) Organizational intentions, such as business rules and organizational policies are clearly and explicitly defined

Table 10. Pragmatic Interoperability

Level	Pragmatic Interoperability Dimension
1	(-) A standard to represent message intention is understood and shared by involved parties in an interaction (-) The message exchanged in interaction among systems/services contains the use intention of the receiver (+) The context standard of the exchange message is understood and shared
2	(+) A standard to represent the context in which the exchanged message is inserted is unambiguously established (+) The message is sent automatically, via a communication channel established between parties (+) The exchanged message context is clearly and explicitly defined
3	
4	(-) A standard to represent message intention is unambiguously established
5	(+) The message effect is compatible with your intention (-) Message intention is clearly and explicitly defined

Table 11. Semantic Interoperability

Level	Semantic Interoperability Dimension
1	(+) There are strategies to represent, unambiguously, concepts with overlapping meanings used in interactions among systems (+) Among systems, there is no ambiguity regarding the concepts (general, specific, overlapping)
2	
3	(+) There are strategies to represent, unambiguously, general concepts
4	(+) There are strategies to represent, unambiguously, specific concepts
5	(+) Among systems, disjoint concepts are represented unambiguously

Table 12. Syntactic Interoperability

Level	Syntactic Interoperability Dimension
1	(+) Network infrastructure policies and specifications are understood
2	(+) Applications policies and specifications and base protocols for system operation are understood (+) Policies and specifications to provide access to all the information systems are understood
3	(+) Policies and specifications that define a uniform way to the transit of encoded data are understood
4	
5	(+) Policies and specifications that define the rules for encoding data using the representation of structures and descriptors according to standardized languages are understood

Amortisse achieves complete adherence on stages 2 and 3 for all interoperability dimensions according to these data. Four requirements must be considered at stage 1, two of them at the stage of pragmatic interoperability and two at the organizational stage. At stage 4, two requirements were not fulfilled, in the organization and pragmatic dimensions. At stage 5, one requirement is missing at pragmatic interoperability. Table 13 summarizes the systems scores in this case study according to each dimension and level. There is no pre-requirement among the levels, i.e. it is possible, for example in the organizational dimension, to achieve 60% at level 1 and 100% at level 2.

Table 13. Scores summary

Dimension/ Level	1 Prepared	2 Shared	3 Aligned	4 Represented	5 Evolved
Organizational	60%	100%	100%	66%	100%
Pragmatic	30%	100%	-	0%	50%
Semantic	100%	-	100%	100%	100%
Syntactic	100%	100%	100%	-	100%

Table 14 shows the possible scores of each stage, i.e. which requirements must be met to achieve each level, considering a vertical progression between dimensions. For example, to achieve level 1, it is necessary to meet eleven requirements: five of organizational interoperability, three from pragmatics, two from semantics, and one from syntactic. In this case study, the company reached 7 of the 11 possible requirements. If the company obtains 100% at all levels, it has achieved full interoperability. In the horizontal progression, i.e. into the dimensions, the organization obtained 100% in the syntactic and semantic dimensions, which can ensure complete connectivity between systems and information correctly interpreted by the receiving system.

Table 14. Possible and achieved score in each level

	Level 1	Level 2	Level 3	Level 4	Level 5
Possible score	11	7	3	5	5
Achieved score	7	7	3	3	4

Related to Question 1, Do tAmortisse MM dimensions cover the interoperability scope needed to be measured? participants highlighted the importance of representing dimensions as interoperability types since there is a relationship between them and could realize the relationship among them. For instance, syntactic interoperability is necessary to achieve semantics and so on. Therefore, we have a positive evaluation of Question 1, i.e. Amortisse dimensions fulfilled the company's needs. Concerning the requirements identified for each dimension (Question 2: Are Interoperability requirements sufficient to measure interoperability in every dimension?), Amortisse is composed of thirty-one interoperability requirements, which are an initial effort to verify the interoperability of software systems in different domains. Participants considered this set of requirements enough to verify the interoperability of the company scenario. During the study, execution participants did not point out unnecessary requirements or missing ones. These requirements do not intend to be exhaustive nor apply in their entirety. Suitable subsets to the context and scope of the assessment should be selected and possibly increased with new requirements. Therefore, Question 1 and Question 2 evidence the Amortisse applicability to measure the interoperability maturity of these systems. Additionally, we could observe several interoperability requirements were implemented within the application source code and not by independent services as in current academic research trends, i.e. using traditional software development methods, where functional and non-functional requirements are identified in early systems development stages. Therefore, new requirements could be added to Amortisse level five to measure this feature.

The results presented in tables 9, 10, 11, and 12 allowed us to identify the strengths and weaknesses within the organization, supporting investment according to its real needs. It is up to the organization to understand and decide the areas that still need more attention and investment in line with current capabilities to interoperate.

5.2. Evolution Case Study

This study aims to assess Amortisse's ability to evolve for new domains. We choose a cloud computing scenario, which presents several distinct interoperability issues from the web applications scenario used as a reference to specify Amortisse's initial version. The Maintenance phase suggested guidelines were followed (Section 4.1.5). So, while the Amortisse case study presented in Section 5.1 considered a scenario with a traditional web architecture based on three independent systems, we now adopt a scenario with Service Oriented Architecture (SOA) that relies on cloud and internet environments. The results of this study should identify which requirements need to be excluded or added for Amortisse to be able to measure interoperability in this new scenario.

5.2.1 Case Study Design

The study aims to analyze Amortisse's ability to evolve into new domains. This goal is defined according to the GQM template [Basili et al. 1994] in Figure 6. Based on this goal, we defined the following research question to guide the study: Can Amortisse evolve to analyze interoperability in a different domain from its first version? With this question, we aim to observe if it is possible to customize the requirements previously defined for the Amortisse model, i.e., include, exclude, or change some requirements.

This case study was applied to a software company that offers a Dashboard infrastructure. The Dashboards can be customized for different purposes in which images

and text information can be displayed. For instance, they have dashboard clients for public or private surveillance needs. This infrastructure comprises several services (e.g. Keystone, Image, Networking, DataStore) that should use different APIs (Table 15). Currently, the software company offers thirteen different services, and Clients may request some specific cloud platforms to be used.

Analyze Amortisse
For the purpose of evaluating its capacity for evolution
Related to requirements customization
From the perspective of systems analysts
In the context of new scenarios

Figure 6. Evolution study main goal according to GQM template

Table 15. Services of dashboard cloud infrastructure

Service name	Environment name	Service description
Identity Service	Keystone	User management
Compute service	Nova	Virtual machine management
Image service	Glance	Manages Virtual image distribution
Dashboard	Horizon	Provides GUI console via a Web browser
Object storage	Swift	Provides Cloud Storage
Block storage	Cinder	Storage Management for Virtual Machine
Network service	Neutron	Virtual Networking Management
Orchestration Service	Heat	Provides Orchestration function for Virtual Machine
Metering Service	Ceilometer	Provides the function of Usage measurement for accounting
Database Service	Trove	Database resource Management
Data Processing Service	Sahara	Provides Data Processing function
Bare Metal Provisioning	Ironic	Provides Bare Metal Provisioning function
Messaging Service	Zaqar	Provides Messaging Service function
Shared File System	Manila	Provides File Sharing Service
DNS Service	Designate	Provides DNS Server Service
Key Manager Service	Barbican	Provides Key Management Service

Six employees participated in this study, one was a system analyst, one a networking expert, and four were software developers experts on cloud platforms. Most of them (71%) are over 30 years old. At least half have more than four years of experience working on cloud platforms and have participated in the entire development life cycle, now working on its maintenance and customization for new customers. The scenario comprises a set of services available to the end-user through a dashboard. Final users can interact with systems through a dashboard. All services are authenticated through a typical identity service, and services interact through public APIs (Application Program Interfaces), except when system administrator commands are required, CLIs are used.

The study was conducted in phases: participants measured interoperability in the new scenario using Amortisse; they have to identify requirements that do not fit the cloud computing scenario as well as proposed a list of new requirements specific for the new

scenario that should be included in Amortise; and indicated the dimension and level which the new requirement should be placed according to Amortise structure.

5.2.2 Study Execution

The study lasted three hours. First, the participants received training, including introducing the Amortisse model. After that, to measure the infrastructure interoperability in the new scenario using Amortisse, we repeat the same strategy of the case study. The participants filled out a questionnaire answering about each requirement. All questions used a Likert scale ranging from one to five (one - less effort, five - more effort). In summary, the infrastructure only fulfils the syntactic interoperability requirements. Like in the first case study, we promote a brainstorming section where participants discussed whether cloud requirements would be eligible and if some should be excluded for Amortise. Table 16 presents the cloud requirements suggested by the participants. At this point, consensus about the requirements eligibility was considered. Participants stated that no requirement should be removed from Amortisse because they are planning additional functionalities and these requirements should be useful. Finally, they answered a questionnaire to determine each requirement dimension and level. All questions used a Likert scale ranging from one to five (one - less effort, five - more effort).

5.2.3 Data Analysis

The participants' requirements analysis indicated that only the *time-to-market* requirement should not be placed for this new scenario, perhaps because it is a requirement with high granularity and is difficult to measure. Unlike the systems used in the first case study, this dashboard is a basic infrastructure that may be customized for different purposes. Thus, beyond Cloud Platforms aspects, this specificity impacted the participants' analysis. Related to the case study question, participants could perform all the proposed steps to update Amortisse for Cloud Domains and then apply the Amortisse new version to measure the Dashboard Infrastructure.

5.3. Threats to Validity

To prevent bias in the validation, we now discuss some threats to its validity. Regarding internal validity, to decrease the threats regarding the participants' level of expertise, the study selected specialists and applied a questionnaire to ensure their knowledge. We also gave them a presentation about Amortisse before they conducted the study. The study was performed in a company with limited participants concerning external validity. So, results generalization is limited to scenarios that share similar characteristics. We followed Wohlin's (2012) guidelines to perform the case study activities regarding construct validity. Finally, concerning conclusion validity, the study did not use a statistical method to evaluate the results, which may influence the conclusion. Besides this, concerning the methodology proposed to guide Amortisse's specification, its use in new domains may require adaptations of the defined activities and artifacts.

Table 16. Requirements Questionnaire

Requirement	Description	Eligibility (Yes/No)	Effort (1 to 5)
Cost	Cost can influence cloud type.		
Time-to-market	The ability to deliver products or services within a flexible time frame is a common factor in creating a cloud.		
Revenue opportunity	Revenue opportunities vary by cloud intent and use case.		
Compliance and geo-location	Organizations may have legal obligations and regulatory compliance measures that may require a certain workload or data that is not located in certain regions.		
Security	The importance of security varies depending on the type of organization that uses a cloud. For example, financial institutions generally require higher security requirements.		
Service level agreement	Service level agreements (SLAs) must be developed in conjunction with business, technical and legal information.		
Migration, availability, site loss and recovery	Organizations using cloud-based services can embrace business diversity and adopt a hybrid cloud design to spread their workloads across multiple cloud providers.		
Network design	Includes decisions on the need for interconnection.		
Support and maintenance	It considers maintenance, support and availability tasks.		
SLA considerations (operational)	Define availability levels that will impact the cloud design cloud to provide redundancy and high availability.		
Logging and monitoring	Clouds require appropriate monitoring platforms to identify and manage errors.		
Data plane and control plane	Maintain the availability of instances, networks, storage, and additional services.		
Site loss and recovery	Strategies must be implemented to understand and plan for recovery scenarios.		

5.4. Interview Study: User Perception Evaluation

To get insights into the user perception when using Amortisse, at the end of the case studies, participants were invited to a semi-structured interview where twelve participants gave their opinion concerning Amortisse usefulness, consistency, and clarity.

The interview was organized into three questions: *Question 1: What is Amortisse usefulness as a supporting tool for interoperability assessment?* to understand how much Amortisse facilitated or hindered systems interoperability assessment. *Question 2: How do you rate the consistency among the requirements, dimensions and levels used in the Amortisse model?* to identify whether the participants understand and agree with the relationships among these elements. *Question 3: How easy is it to apply Amortisse, i.e. is it clear how the systems evaluation process should be carried out?* to identify whether the instructions for using Amortisse can be understood by participants.

The interview was conducted by the researcher. Participants sent their answers through an electronic form using the following scale: 1 - very bad, 2 - bad, 3 - neutral, 4 - good, and 5 - very good. The results were analyzed according to each question. Regarding *Usefulness*, 66.6% of the participants rated Amortisse as very good and 33.3% as good in evaluating systems interoperability evidencing that Amortisse is helpful and facilitates the assessment process. Related to *Consistency* and *Clarity*, for both, all participants rated as very good (50%) or good (50%). This indicates that for the participants the model elements, i.e. dimensions, levels and requirements, are clearly defined and coherently related. Table 17 summarizes some participants' comments. These are initial data with important feedback that will be carefully analyzed to improve the model. The results indicate a positive perception of the participants regarding the

Amortisse use as a tool to assess systems interoperability. However, these assessments were carried out in the researcher's presence and we noticed that it will be necessary to improve the requirements description and develop new artefacts to guide the MM application and customization. This initial study has a potential bias related to the small size of the participant and it is essential to perform replications.

Table 17. Participant' comments during the interview

Aspect	Participant comment
Utility	"Amortisse makes us think about the solutions adopted and plan for future ones."
Clarity	"I believe that the most critical point is the requirements description. It could be improved."
Clarity	"The strategy seems to be comprehensive for the cloud context. However, requirements need a more detailed description to improve evidence collection."
Consistency	"Amortisse visual diagramming and modelling make interoperability concepts easy to understand."

5.5. Discussion

Amortisse is a MM to support systems interoperability assessment in software systems. Its rationale is systematized in a methodology, enabling its evolution. e.g., requirements may be included or excluded to fit different scenarios. The methodology does not intend to be complete, but a reference for Amortisse's specialization and for the specifications of new models. Continuous improvements can be applied for new elements. Instead of high-level requirements that usually comprise other interoperability assessment models, Amortisse is suitable for the organization's needs that guided its first version. The requirements of the syntactic level explicitly cope with aspects of web technologies, as it is the current software development platform. The pragmatic interoperability was included as an Amorissee level. Interoperability MM usually does not consider pragmatic interoperability type as part of its structure [Rezaei et al. 2014]. The Amortisse MM has been developed with the purpose of supporting the assessment of systems interoperability in software systems environments. In contrast to other interoperability assessment models, which frequently concentrate on high-level requirements, Amortisse was expressly designed to address the distinctive requirements of the organization during its initial development. To illustrate, the syntactic level requirements explicitly address contemporary platforms, including web, cloud, and IoT technologies, which serve as the underlying infrastructures for numerous information systems in the present era. Moreover, a considerable number of applications must be context-aware, particularly in circumstances where dynamic conditions impact operations. This resulted in the incorporation of pragmatic interoperability as a discrete level, a category frequently neglected in other models [Rezaei et al. 2014].

The specification of Amortisse was developed following a structured methodology based on the approach proposed by Monteiro et al. (2020). It provides a systematic, step-by-step guide that delineates the model's fundamental components and their application during the assessment process. The methodology was designed to facilitate continuous improvement, enabling the addition or removal of requirements to adapt to different scenarios serving as a reference for refining Amortisse and assisting in developing new maturity models. Its strategic goal is to facilitate the adoption of the maturity model and provide flexibility for updating or defining new elements as needed, ensuring that Amortisse can be customized for new scenarios.

Amortisse's validation process has been incremental, and essentially qualitative. The quantitative method requires an adequate number of study participants. Literature

and industry show that this kind of assessment better uses few specialists than a large number of participants with common Knowledge. Therefore, we carried out two studies that assess the MM applicability and its ability to evolve and evaluated cross-cutting aspects, such as usefulness, according to user perception. Although these validations do not provide statistical analyses, they were conducted with experts and showed evidence for the proposal's feasibility. During the evaluation process, we noticed that the industry professionals have some knowledge about interoperability as a non-functional requirement but are not aware of all its categorization levels. During Amortisse's explanation, some questions arose, but often the professionals related some previous situations faced while developing a system. As a highlight, standards and middleware platforms were often the software solution pointed to achieve technical and syntactic interoperability. However, the inside system code solution was often applied to achieve other higher levels of interoperability. In that case, interoperability is developed using low cohesion and high coupling solutions. Amortisse usage could help offer an opportunity to think about new possibilities and, as an insight, high cohesion and loosely coupled interoperability solutions should be considered as new requirements.

Although the web domain has solved technical, syntactic, and semantic interoperability issues, Cloud, IoT, and Smart domains present new ones. We considered, therefore, that Amortisse offers a new strategy compared to the current models since it describes the model construction enabling it to be evolved. This strategy is especially important in a constantly evolving domain such as interoperability.

6. Conclusion and Future Works

MMs aim to assist organizations in improving the way it performs, a certain aspect guiding them towards the desired achievement. This paper introduced the Amortisse, a MM for software and system interoperability assessment, and a MM methodology, which makes its rationale explicit. Initially, a methodology for MM specification was proposed. Then, based on a well-known academic scenario, Amortisse first version was specified. After that, Amortisse was evaluated in a case study and in an exploratory study applied to different domains. The results of these studies provided evidence that in these scenarios, Amortisse was feasible to measure the interoperability of the involved systems.

Adopting a methodology to conduct Amortisse specification makes the Amortisse extension easier for other domains. The methodology provides step-by-step the activities that should be performed to define new requirements, distributes them into the dimensions and levels and so on, i.e. all the rationale involved in the model specification is documented. This rationale is essential to allowed comparison to other maturity models. The results show our strategy feasibility as Amortisse was able to measure the interoperability maturity of the systems, and the methodology allows the development of the first version and its maturity model evolution. The value to organizations of applying such a model lies in measuring and assessing domain capabilities at a given point in time. Amortisse can help organizations better understand existing domain capabilities, enabling benchmarking among other organizations. It can be an important instrument to support their interoperability goals, and contributing standardization.

For future work, Amortisse should be updated using evaluation results. To improve both the Amortisse and the methodology, we are now working on the case study replication in other domains. Besides, statistical methods are being considered to be used in data of different case studies, aiming to give a better understanding of the case study

results. By sharing our proposal, we aim that the community could perform new replications and, therefore, bring improvements and insights to the Amortisse proposal.

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