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A Conceptual Framework for Maturity Evaluation of BIM-based AR/VR Systems based on ISO Standards

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Abstract. Maturity evaluation of BIM-based Augmented Reality (AR) and Virtual Reality (VR) systems is a challenging issue that requires ensuring their effectiveness and reliability. However, the lack of appropriate evaluation methods, tools, and standards for these systems makes this task even more complex. In this context, this paper proposes a conceptual framework for evaluating the maturity of BIM-based AR/VR systems, by using ISO standards. It represents a first and important step towards developing a standardized maturity model for such systems. The proposed framework enables the identification of fundamental concepts related to the evaluation of BIM-based AR and/or VR systems' maturity. This ranges from identifying the evaluation goals to interpreting the final findings to identify mechanisms to evaluate outcomes. This framework is based on ISO/IEC TS 33061 standard for determining maturity levels and ISO/IEC 15939 for identifying measurement concepts. Evaluation can be performed either globally or in a customized way. The global evaluation considers all aspects of the system, while customized evaluation allows users to select specific key elements according to their requirements. A feasibility study, conducted by academic experts in the field, has been carried out in order to validate the proposed framework.

Keywords: Maturity, Evaluation, BIM-based AR, BIM-based VR, ISO standards.

1 Introduction

The Architecture, Engineering, and Construction (AEC) industry has been significantly impacted by technology, especially with the introduction of Building Information Modeling (BIM), which has been developed and adopted to help countries achieve accelerated growth [1][2]. BIM has been recognized as a transformative force that can revolutionize project processes by offering a unique approach to asset design and construction. It induces increased productivity, reduced failure costs, and innovative collaboration methods [3]. However, the practical application of BIM presents challenges that can prevent projects from realizing their potential advantages [4]. For this reason, immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) have been integrated to address these challenges and improve the construction process. This has given rise to BIM-based AR and BIM-based VR systems, which provide an engaging and immersive environment for creating and visualizing multi-dimensional simulations of construction projects [5][6][7]. These

systems can also highlight diverse project aspects and provide invaluable assistance throughout all stages of the project [7]. However, to ensure the ongoing development and improvement of these innovative systems, it is essential to evaluate their maturity. Maturity evaluation is generally considered an essential process that helps companies make decisions when it comes to implementing these technologies and refining them to meet the needs of the construction industry [8].

In this context, maturity evaluation for BIM-based AR/VR systems can help companies make more informed decisions regarding investment in technology and develop more effective strategies for adopting augmented and virtual reality. When reviewing the literature, only two research studies have currently been found on the maturity evaluation of these systems [8][9], which suffer from several limitations. The first study [8] proposes a framework applied exclusively to BIM-based VR systems. The second study [9] proposed an approach for BIM-based AR/VR maturity evaluation without taking into account basic evaluation concepts such as measures and evaluation criteria. In this paper, we propose a more comprehensive maturity evaluation framework that can be applied to both BIM-based AR and VR systems, based on standards and measurement concepts. This framework serves as a first step towards creating a standardized maturity model.

To address this need, the objective of this study is to propose a conceptual framework for assessing the maturity of BIM-based AR/VR systems using ISO standards, specifically ISO/IEC TS 33061 [10] and ISO/IEC 15939 [11]. It enables the identification of key concepts related to the evaluation of BIM-based AR/VR systems' maturity, from defining the evaluation objective to interpreting the final results. Two modes of evaluation are used: a global evaluation that assesses all aspects of the system and identifies any issues, and a customized evaluation that allows users to select specific key elements according to their requirements. Further, our framework not only measures the maturity level of BIM-based AR/VR systems, but also provides analyses and interpretations of the results based on ISO/IEC 15939 standards, which can help identify mechanisms for transitioning from one maturity level to another.

The remaining part of this article is structured as follows: Section 2 introduces a synthesized background and the current state of the art on our subject. Section 3 describes the main concepts of the proposed maturity evaluation framework for BIM-based AR/VR systems based on ISO Standards. Section 4 presents a feasibility study of the proposed framework in order to demonstrate its validity in an academic context. It subsequently discusses the main findings and presents future perspectives of the proposed framework. Finally, Section 5 concludes the paper.

2 Background & Current State of the Art

Over the past decade, BIM-based AR/VR systems have undergone extensive research and development. In this section, we aim to provide a comprehensive background on these systems and review the existing related works on methods for evaluating their maturity.

2.1 BIM-based AR/VR systems

BIM-based AR/VR is a natural progression from the adoption of BIM in the AEC industry [12]. The lack of interoperability and difficulty in visualizing complex geometries in the BIM model made it challenging to incorporate AR/VR technologies [13]. However, experts in immersive technology worldwide are working diligently to develop pragmatic AR/VR solutions that align with BIM processes and meet clients' specific requirements and objectives [14]. Recently AR and VR technologies have demonstrated an excellent capability for improving current technologies and offering a better quality of life [15]. By overlaying virtual information into the real world or creating immersive virtual environments, these technologies provide new ways of visualizing and interacting with the built environment [16]. The use of AR and VR in the AEC industry shows capacity to enhance design, construction, and operation processes, as well as improve communication and collaboration among stakeholders. These technologies are bringing out unimaginable modification and advancement in various construction issues, as it enables users to interact with a building model in a more intuitive and immersive way [7]. The importance of BIM-based AR/VR systems has had an enormous impact on the construction industry, and many applications can benefit a construction project, from design and visualization to construction sequencing and safety analysis [7].

Most research has revealed that the BIM-based AR and/or VR system has the potential to enhance the construction industry by improving many of its current practices. As stated by Lopez et al. [17], the design phase is one of the primary areas in the construction industry that has implemented VR for BIM. This is done to facilitate collaborative visualization, enhance various aspects of the construction process, and design applications. Moreover, using VR to visualize and interact with a realistic representation of a BIM 3D model enables users to detect errors and identify risks. Additionally, this research shows that VR can potentially enhance the performance of professionals in the AEC industry by facilitating the creation of project timelines, cost estimation, and logistics planning. By using a BIM-based VR system, stakeholders can engage with the project by visualizing and selecting finishing elements within the construction project, such as color and texture of carpet, window types and styles, wood types, etc.

In another study [18], it was noted that BIM-based AR has multiple applications across the various phases of a construction project, including design, construction, and post-construction. During the design phase, it can aid in communication and marketing efforts before any physical construction work begins. However, during construction, AR can optimize tasks such as layout, excavation, positioning, inspection, coordination, supervision, commenting, and strategizing. Moreover, AR can be utilized in building lifecycle applications after the construction process is complete.

In a study by Li et al. [14], three different applications of AR and VR in construction safety were presented. The first application concerns hazard identification or risk recognition, which depends on the planning team's ability to detect and analyze potential dangers that may occur during the construction process. The second application concerns safety training and education, based on improving the cognitive learning experience of users during the construction phase. The third application of AR technology concerns safety inspection and instruction in construction. AR can be used

to visualize construction drawings in a 3D representation, instead of physically carrying 2D drawings to the site. This enables quicker and more efficient decision-making during safety inspections and instruction. Furthermore, AR can be used as a tool to analyze disaster damage by comparing a previously saved base image to the actual image of the structure after an event such as an earthquake, facilitating faster decision-making and response times.

2.2 Related Works on the Maturity Evaluation of BIM-Based AR/VR Systems

As the adoption of BIM, AR, and VR technologies in the AEC industry continues to grow, various researchers have proposed maturity models to evaluate it and identify potential areas for improvement, and optimize the benefits of these technologies in accordance with the needs of construction companies [9]. This section discusses existing maturity models for BIM-based AR/VR systems as a starting point for establishing our framework.

A maturity model is a tool used to evaluate an organization's level of maturity based on predefined Key Performance Indicators (KPIs) (Assila et al., 2020). It typically consists of a maturity matrix that outlines the essential key elements of the project to be evaluated, including aspects, criteria, sub-criteria, and evaluation measures. This can include data interpretation methods and evaluation methods that are generally based on the classification of maturity levels, with higher levels indicating a greater degree of maturity [19][20].

There have been only a few research papers published to evaluate the maturity of BIM-based AR/VR systems. Among these papers, we mention the study by Assila et al. [9]. The proposed maturity model in this study resulted from a mapping between the BIM maturity model proposed by Dakhil et al. [21] and the augmented reality and virtual reality maturity models suggested by Hammershmid et al. [22]. The matrix of the maturity model consists of three levels of maturity classification. The first level focuses on the visualization of BIM using AR and VR, the second level involves the interaction, configuration, and collaboration of BIM with AR and VR, while the third level emphasizes full BIM collaboration, immersion, problem detection, and solution suggestion through AR and VR. The model outlines seven aspects, including visualization, interaction, configuration, full immersion, full collaboration, problem detection, and finding solutions, to provide a comprehensive assessment of the implementation of BIM-based AR/VR technologies. The proposed maturity model aims to help companies determine their current level of maturity and identify opportunities for improvement. However, the model has two main limitations. Firstly, it is a conceptual approach that lacks a validation method. Secondly, the model does not define evaluation measures, which may affect its effectiveness in practice.

In another study, a new evaluation tool was proposed by Alarcon et al. [23] to assess the maturity of AR in the aerospace industry. This method primarily focuses on the technology components, including hardware elements such as sensors, chips, speakers, and display systems, as well as software features such as object recognition, tracking, interaction libraries, and remote assistance tools. The authors subjectively examined each component and estimated its related maturity. The framework was validated through multiple statistical tests, while also identifying opportunities for enhancement and areas that require further exploration. The study provides valuable perspectives to

guide future advancements. However, the evaluation method utilized in the study is not well-defined, which presents a limitation.

More recently, [8] proposed a maturity model for evaluating BIM-based VR systems' maturity during the project's design phase. The proposed model was developed based on expert interviews and a review of research from other industries as similar research was lacking in the AEC industry. The model identifies three distinct stages of VR implementation: commissioning, usage, and post-usage, which are segmented into five main areas based on their focus: preparation, immersion, inspection, collaboration, and side effects. The team established criteria and measures for each area, resulting in a framework that can assist users in selecting BIM-based VR systems based on their preferences and requirements. Moreover, this model provides a consistent quantitative assessment method using well-defined and comprehensive measures and criteria. However, some inconsistencies in the scoring metrics still exist due to the varying characteristics of participants. It's worth noting that BIM-based VR evaluation services are limited to the design phase, and the final evaluation score was calculated using a five-point Likert scale.

To conclude this section, it is worth noting that several limitations have been identified in existing maturity models, including issues related to the stage of application, lack of validation methods, evaluation methods, and consistency. Therefore, this paper proposes a conceptual framework based on measurement concepts, standards, and best practices in evaluation. This framework serves as a first step towards developing a more standardized maturity model for the evaluation of BIM-based AR/VR systems.

3 The Proposed Conceptual Framework for BIM-Based AR/VR systems Maturity Evaluation Based on ISO/IEC Standards

3.1 The Main Concepts of the Proposed Conceptual Framework

This section aims to present the overall structure of the proposed framework to ensure a clear understanding of its components and how it operates. Figure 1 illustrates the main concepts of the proposed conceptual framework for the evaluation of BIM-based AR and VR systems maturity.

The framework is composed of three parts, based on the most relevant guidelines and measurement standards to ensure its effectiveness and consistency.

The initial part defines the necessary key elements for maturity evaluation and offers concrete examples. These key elements were established from the Capability Maturity Model Integration (CMMI) and the Project Management Maturity Model (PMMM) [24][25] that state the necessity of defining areas of interest to be evaluated. According to these models, areas of interest indicate the aspects of the studied project or system to be covered and evaluated. In our study, as shown in Figure 1, the areas of interest represent the aspects of BIM-based AR/VR systems such as technology and collaboration. In addition, ISO/IEC 15939 standard emphasizes the importance of using specific criteria and measures for evaluation purposes and provides guidelines on how to develop and interpret them [11]. This standard [11] provides a comprehensive process for defining a suitable set of measures that address specific information needs.

It allows for the determination of how the measures and analysis results are applied, as well as for determining the validity of the analysis results. In turn, the criteria specify the particular elements within the studied aspect that will be evaluated and provide a better understanding of the intended goal. Usually, breaking down criteria into sub-criteria provides additional details and clarity, leading to greater precision and understanding of the aspect being evaluated. These criteria and/or sub-criteria can be evaluated in a subjective or objective manner through measures. The measures serve as a way of achieving the intended objective by providing defined metrics that can be applied to reach a final decision on the maturity [11]. For example, in our study on BIM-based AR/VR systems, technology is an aspect that needs evaluation. It is segmented into software and hardware criteria. As illustrated in Figure 1, navigation is a sub-criteria for the software criterion that can be measured via two measures: convenience and capability of navigation, in order to achieve the intended evaluation objective.

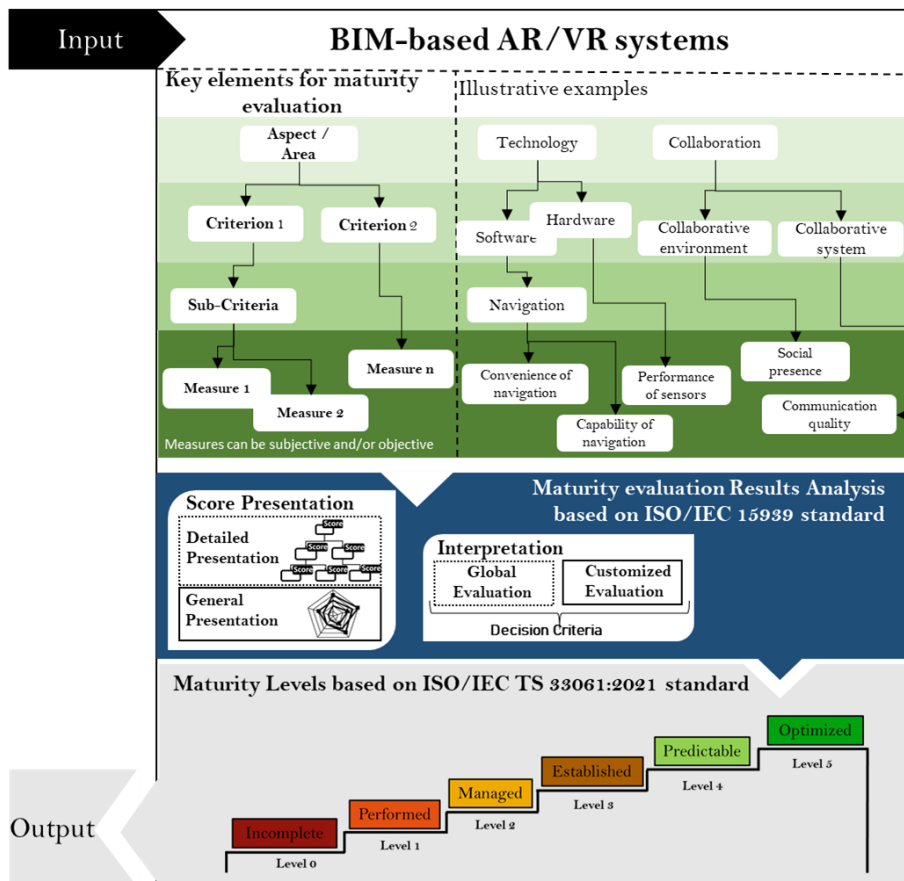


Fig. 1. The proposed conceptual framework for BIM-based AR/VR maturity evaluation based on ISO measurement standards and guidelines.

The second part of the framework focuses on the process of analyzing the measurement results obtained from the first part in accordance with the ISO/IEC 15939 standard [11]. The analysis can be either detailed or more general and can be performed based on predefined decision criteria, which will be detailed in the following section.

Finally, the third part of the framework defines the maturity levels that have been selected to evaluate the studied key elements and generate a final decision as the output of the process. This step is based on the ISO/IEC TS 33061 standard [10], which provides guidelines for assessing the maturity of an organization's software engineering processes and identifies six maturity levels: (0) incomplete, (1) performed, (2) managed, (3) established, (4) predictable, and (5) optimized.

Further details regarding the proposed framework will be described in the next section

3.2 Conceptual Framework Description for BIM-based AR/VR Systems Maturity Evaluation

This section aims to provide a detailed description of the proposed framework, including an in-depth analysis of each of its components (parts) as presented above.

The Key Elements for BIM-based AR/VR Systems Maturity Evaluation. The essential key elements for evaluating BIM-based AR/VR maturity include aspects, criteria, sub-criteria (if necessary), and measures. We identified these concepts as a first step in our framework by conducting an in-depth analysis of existing studies proposed by [8][9][23]. This analysis involved two main steps. The first step involved identifying and removing repetitive aspects, criteria, sub-criteria, and measures. The second step focused on determining elements that address the same subject, keeping only one, and placing it in the appropriate category. The key elements obtained concerning the main covered aspects, criteria, and sub-criteria, along with a list of examples of measures, are presented in Table 1.

Table 1. The key elements for evaluating BIM-based AR/VR maturity, along with a list of examples of measures based on existing studies.

Aspects (Area)	Criteria	Sub-Criteria	Measures Examples
Technology [23]	Hardware [23]		System efficiency (sensors, chips, display, speakers) [23]
	Software [23]	Interaction system [8,23]	Capability and convenience of the interaction system [8,23]
		BIM software [26]	Convenience of BIM software [26]
Immersion [8]	Visual immersion [8]		Immersion consistency [27]
	Behavior [28]		Physical presence in a virtual environment [28]
	Interactivity [29]		Sense of agency [29]

Aspects (Area)	Criteria	Sub-Criteria	Measures Examples
Collaboration [9]	Collaborative environment [9]		Social presence or co-presence [30] Awareness [30] Interpersonal trust and spatial faithfulness [31]
	Collaborative system [9]	Real-time modification [8]	The ability of users to modify and visualize data in real-time [9]
Side effect [8]	Dizziness [8]	Communication quality [32]	Quality of text-based tools, avatars, visual sharing, and voice chat
	Fatigue [8]	Multiple users platform [8]	Capability and convenience of Multiple users platform [8] Occurrence time [8] Severity [8] Occurrence time [8]
BIM interaction and configuration with AR/VR [9]	Data visualization [9]		Severity [8] Ability of AR/VR devices to change the type of data [33] Effectiveness of visualization in improving BIM data understanding [33]
	Tangible interaction [9]		Effectiveness of AR/VR in supporting tangible interactions with virtual models [34] Range and ease of use of options and tools available for modifying virtual elements [34]
Detection problems and suggestion solutions with AR/VR [9]	BIM file [8]		File format compatibility, Convenience, and complexity [8]
			Effectiveness of solutions in resolving problems [23]

As illustrated in Table 1, a maturity evaluation of a BIM-based AR/VR system consists of six essential evaluation aspects: technology, immersion, collaboration, side effects, BIM interaction/configuration with AR/VR, and detecting problems and suggesting solutions with AR/VR. Each aspect is further divided into corresponding criteria and sub-criteria, as necessary, with a list of examples of corresponding measures.

Starting with the technology aspect, it encompasses a set of criteria that ensure the efficiency and productivity of the experienced system in the AEC sector. This includes

the information system, represented by software criterion, and the equipment, represented by hardware criterion [7][35]. According to Alarcon et al. [23], Kim et al. [8] and Kozlenko et al. [26], software criterion includes two sub-criterion. The first is the BIM software, which is measured by its convenience [26]. The second sub-criterion includes the interaction system [8][23], referring to the interaction libraries, AR/VR authoring tools, and remote assistance tools, which are evaluated based on their capability and convenience. On the other hand, hardware criterion refers to all physical components that make up BIM-based AR and/or VR systems, such as sensors, chips, optics, display systems, and speakers [23]. Typically, these elements are evaluated based on their efficiency [23]. The second aspect addressed is immersion. In the AEC industry, immersion refers to the degree of realism experienced when visualizing and interacting with the augmented or virtual environment of the BIM model [8]. Immersion evaluation depends on several criteria. Firstly, the visual immersion refers to the similarity between the virtual representation and the real world [8]. This can be measured by its consistency, accuracy, and level of detail [27]. The second criterion concerns the behavior of users in a virtual environment and whether it is realistic or not. This is evaluated based on the user's physical presence in the virtual world. Users are considered behaviorally immersed if their actions in the virtual environment are similar to those in reality [28]. The third criterion concerns the interactivity between users and the virtual environment, and it is measured by the level of naturalism in manipulating or controlling objects in the virtual environment. In other words, it is the "sense of agency" experienced by the user [29].

An essential aspect to consider when evaluating BIM-based AR/VR systems is the collaboration. Its importance lies in the success or failure of the work. Effective collaboration leads to a better understanding between users and successful task completion. Poor communication, on the other hand, may result in incomplete tasks and failure [8]. According to [9], the collaboration aspect depends on two criteria. The first criterion evaluates the collaborative environment, while the second criterion evaluates the collaborative system. The collaborative environment refers to the environment in which participants interact and is usually measured through three measures. The first measure is social presence or co-presence, which depends on verbal and nonverbal cues such as facial expressions, vocal cues, gestures, and physical appearance [30]. The second measure refers to awareness, such as mutual awareness related to the responsiveness of the participants to others' needs, and collaborative awareness that involves being aware of what others are doing in the project [30]. The third measure refers to interpersonal trust and spatial faithfulness between users, which is reflected in people's performances when they are doing a task [31].

The evaluation of collaborative system criteria depends on real-time modifications, which are measured through the ability of users to modify and visualize data in a virtual or augmented environment [9]. The quality of communication is also important, and this includes the quality of text-based tools, avatars, visual sharing, and voice chat [32]. In addition, the evaluation process should consider the capability and convenience of multiple user platforms [8].

The side effects aspect refers to the undesired effects and symptoms that occur after using BIM-based AR/VR systems. According to [8], the side effects aspect is divided into two criteria referred to dizziness and fatigue, and both are measured through their occurrence time and severity.

Assila et al. [9] presented an interesting perspective on the correlation between BIM and AR/VR. They suggested that there is another aspect to consider in the evaluation process, specifically the interaction and configuration between BIM and AR/VR, which involves three distinct criteria that are important to understand this relationship. The first criterion concerns data visualization, which is usually measured by evaluating the ability of AR and VR devices to change the type of data and the effectiveness of these devices in improving the user's understanding of BIM data [33]. While the second criterion concerns object manipulation in the virtual environment which is known as tangible interaction, and it is measured by evaluating how well and easily these VR and AR technologies support this type of interaction [34]. In addition, [8] added that the correlation between AR/VR and BIM software involves an important criterion for evaluation, which relates to the BIM files. These files have a significant impact on the communication between software tools and AR/VR technologies, and their importance can be determined based on factors such as the complexity of the BIM model, format compatibility, and convenience.

Lastly, the ability of a BIM-based AR/VR system to identify problems and suggest solutions was considered the last aspect to consider [9]. The effectiveness of the proposed solutions in addressing problems serves as the evaluation measure for this aspect [23].

Results Representation and Interpretation Based on ISO/IEC 15939 Standard for BIM-Based AR/VR Systems Maturity Evaluation. The interpretation of measurement results is a crucial step in developing a correct and efficient analysis. As illustrated in Figure 2, our framework first ensures a global evaluation of the maturity of BIM-based AR/VR systems, taking into account all aspects to be evaluated. Second, it allows for a customized evaluation, providing evaluators with greater flexibility in choosing the elements to be evaluated. In this case, evaluators can select the relevant elements aligned with their needs and project requirements for a customized evaluation. Regardless of the type of evaluation chosen, this phase is based on the ISO/IEC 15939 standard, which defines an analysis process for presenting and interpreting the results of measures based on decision criteria.

According to this standard, decision criteria are defined as thresholds that describe the level of confidence in a given result [11]. The use of this concept allows the definition of rules to interpret the results of one or more measures at a time, and therefore identify, in our study, the level of maturity of the evaluated element (criterion/sub-criterion/ aspect). Initially, we have defined three possible formats to represent a rule, where M is a measure used for evaluating a criterion or a sub-criterion; X and Y are the thresholds to be set by the evaluator; and SCL is Sub-Criteria Level; CL is Criteria Level; and AL is Aspect Level. As a reminder, we have six levels of maturity ranging from 0 to 5 based on the ISO/IEC TS 33061 standard [10]. In the following, we provide examples of rules in case a criterion or sub-criterion is evaluated by a single measure:

- (1) *if (score M (> or <) X) then criteria/sub-criteria Level is SCL/CL*
- (2) *if (X < score M < Y) then criteria/sub-criteria Level is SCL/CL*

- (3) *if* (criterial Level = CL1 and criteria 2 Level= CL2... criteria n = CLn) *then* Aspect Level is AL (in the case where an aspect is composed of n criteria, AL is calculated as the sum of level scores divided by the number of criteria)

The first two rules (1) and (2) allow determining the maturity level of a criterion or sub-criterion when it is evaluated by a single measure. Meanwhile, the third rule enables determining the maturity level of an aspect composed of one or more criteria.

The resulting maturity level is represented by a rounded integer. To provide more information on the calculated aspect score level and the maturity levels of each criterion, we propose presenting the result graphically as illustrated in Figure 2 (see detailed presentation). This representation helps the evaluator identify the source of problems described by the lowest maturity level(s) and, consequently, determine the necessary recommendations to improve maturity and facilitate the transition from one maturity level to another. Moreover, we suggest a radar graph that highlights the final score level of each evaluated aspect to obtain a more general presentation (see Figure 2 general presentation). These presentation options allow users to visualize the results clearly and communicate them effectively to designers.

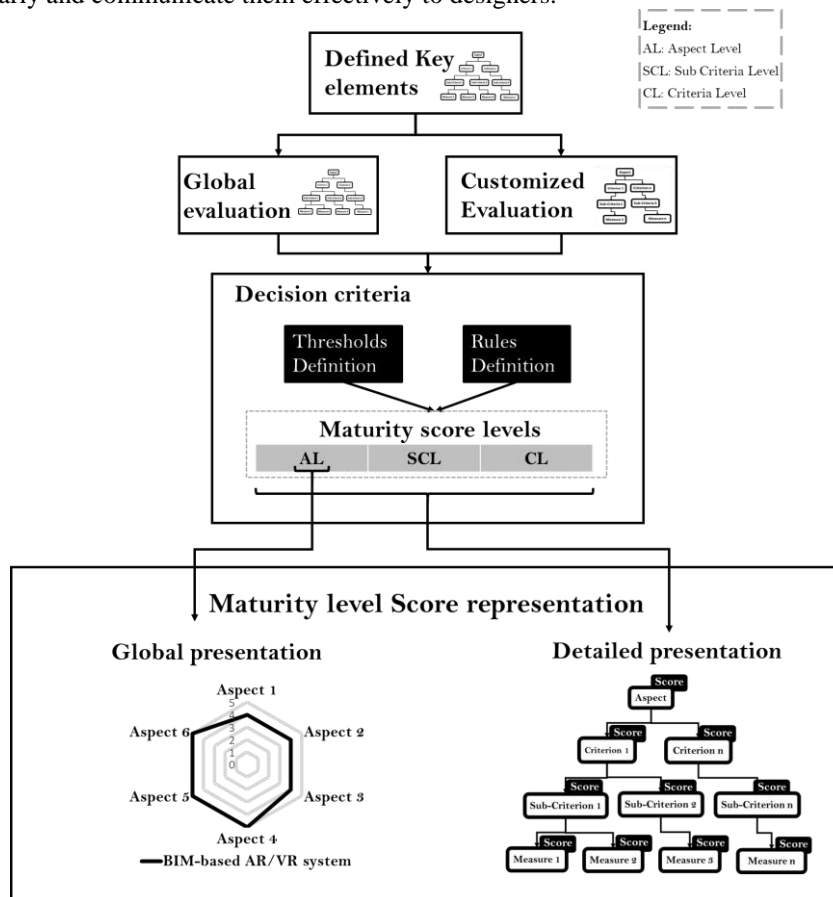


Fig. 2. The proposed maturity evaluation analysis process.

In the following section, we present more details on the maturity levels.

Maturity Evaluation Levels for BIM-Based AR/VR Systems. As mentioned earlier, the maturity levels in our study are based on the ISO/IEC TS 33061:2021 [10] standard, which includes six levels ranging from 0 to 5. These levels are grouped into categories such as Incomplete, Performed, Managed, Established, Predictable, and Optimized. They range from basic process organization to continuous process improvement and refinement at the highest levels. In our proposed framework, we assess the criteria that can include sub-criteria and aspects elements rather than the overall system evaluation. Thus, as illustrated by Figure 3, we have adapted the six maturity levels, defined by ISO/IEC TS 33061:2021 [10] standard, to address all key elements for maturity evaluation. This is based on satisfaction level, relevance, and appropriateness of measure's obtained results, as well as their suitability to meet our specific needs. Taking into account these six levels of maturity, five thresholds must be defined during the evaluation in order to identify the ranges of each level of maturity. For your information, the selection of these thresholds is crucial. However, it is very delicate to decide on the appropriate values for these thresholds. Therefore, the intervention of an expert at this stage is important [36]. The expert must take into account the contextual information of the system being evaluated, including the users involved in the evaluation, the software and hardware equipment, and the physical environment.

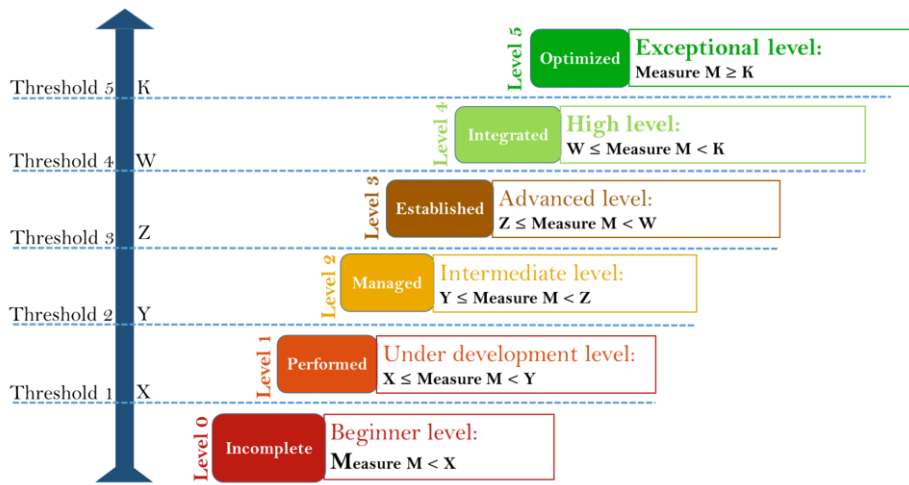


Fig. 3. ISO/IEC TS 33061:2021 maturity levels and their significance according to BIM-based AR/VR systems.

As illustrated in Figure 3, the significance of each level is as follows:

- **Level 0 (Incomplete):** Represents the beginner level. It refers to a situation in which the score of the measured element is below the defined threshold X. In this case, the element being studied has not yet reached the minimum level of

satisfaction required to meet the needs of users. Furthermore, the results obtained are inadequate and may result in a negative user experience.

- **Level 1 (Performed):** Represents the under development level. It describes a scenario where the score of the measure falls within the first two predetermined thresholds (X and Y). This indicates that there is progress toward increasing satisfaction levels, achieving desired outcomes, and comprehending user expectations. However, there are still areas that require enhancement.
- **Level 2 (Managed):** Represents the intermediate level. It refers to a situation in which the score of the studied measure falls between the second and third defined thresholds (Y and Z). This indicates that the studied elements are delivering acceptable results, meeting user expectations, and yielding satisfactory levels of satisfaction. Nevertheless, there are still some minor improvements to be made.
- **Level 3 (Established):** Represents the advanced level. It corresponds to a scenario where the studied measure score falls between the third and the fourth predefined thresholds (Z and W), suggesting that the analyzed components are producing relevant results. The users are highly satisfied with their experience, and their expectations are mostly fulfilled, except for only a small number of areas requiring additional enhancements.
- **Level 4 (Predictable):** Represents the high level. It refers to a situation where the measured score falls between the fourth and fifth predefined thresholds (W and K). This indicates that the elements being studied are generating extremely relevant outcomes, exceeding the users' expectations, and resulting in an excellent level of satisfaction.
- **Level 5 (Optimized):** Represents the exceptional level. It refers to a situation in which the score of the studied element is higher than the fifth defined threshold K resulting in extremely relevant outcomes. In such cases, user satisfaction is exceptional, as their expectations are not just surpassed but also anticipated, leading to a delightful experience.

4 Feasibility Study & Discussion

In this section, we first present the conducted experimentation to study the feasibility of our framework, followed by a discussion reporting the limitations and new perspectives based on the analysis of the results obtained.

The Conducted Experiment and the Obtained Findings. To evaluate the validity and feasibility of our proposed framework, we conducted a survey that included a detailed report outlining the framework and a series of Likert scale statements aimed at gathering feedback. We invited five academic experts with PhDs and backgrounds in BIM and AR/VR systems to participate in the survey and provide comments on their choices. The Likert scale statements are rated on a seven-point scale, ranging from strongly disagree (1) to strongly agree (7). The proposed survey evaluates the framework in two ways. Firstly, a general evaluation is conducted that requires respondents to evaluate the framework as a whole. This is done to measure the framework's solidity in theoretical foundations and proven practices, its relevance in

achieving the evaluation's objectives, its clarity, feasibility of implementation, and ease of understanding. Secondly, a specific evaluation is conducted through two statements to evaluate specific parts of the framework, notably the appropriateness of the proposed approach for interpreting the results and the relevance of the proposed maturity levels. The statements we proposed for the survey are defined as follows:

- *Statement 1:* The proposed framework is based on a sound theoretical basis or established best practices
- *Statement 2:* The proposed framework is relevant to evaluate the maturity of BIM-based AR/VR systems
- *Statement 3:* The proposed framework offers a clear and structured process for evaluating the maturity of BIM-based AR/VR systems.
- *Statement 4:* The proposed framework is practical and feasible to implement.
- *Statement 5:* The proposed framework is easy to understand.
- *Statement 6:* The results interpretation approach provides a clear way to interpret the results of the evaluation
- *Statement 7:* The proposed maturity levels for evaluating BIM-based AR/VR systems are coherent, clear, and understandable.

It is worth noting that statements 1 to 5 evaluate general aspects of the framework, while statements 6 and 7 evaluate specific parts within the framework. In addition, we provided an opportunity for academic experts to add any comments they wish.

The gathered scores on defined statements are illustrated in Figure 4 below.

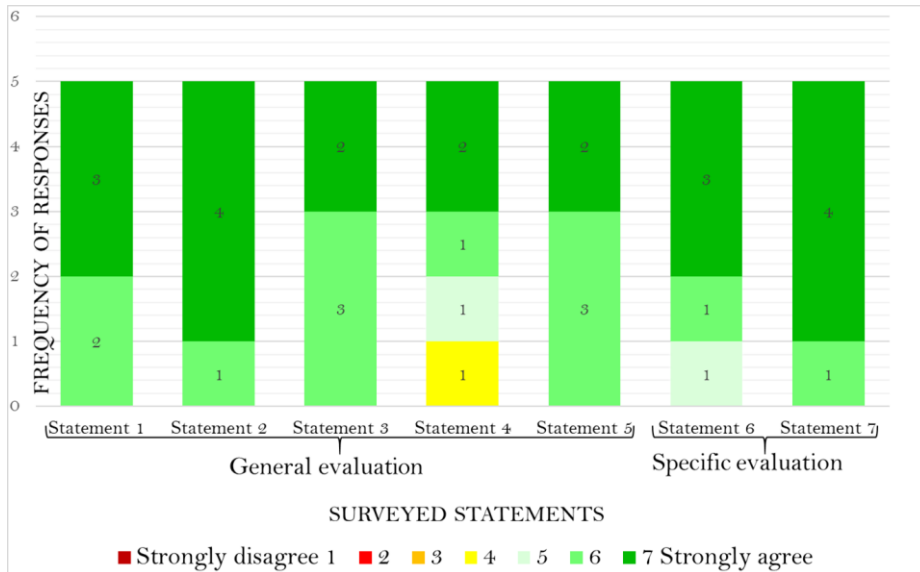


Fig. 4. Academic expert findings based on a seven-point Likert scale for the seven defined statements.

The histogram in Figure 4 represents the feedback obtained from the experts who participated in the survey. The x-axis shows the seven statements, while the y-axis represents the frequency of responses, ranging from one to five. The bars for each

statement indicate the different response options, which are color-coded to indicate the level of agreement or disagreement, ranging from strongly disagree to strongly agree.

According to the survey results, all participants provided overall highly positive feedback regarding the proposed framework. In fact, for statement 1, all participants strongly agreed with a score of "6" and "7", confirming that the proposed framework is based on solid theoretical foundations and established best practice standards. These ratings indicate that the framework is thoughtful, effective, and has the potential to provide a robust and credible approach to evaluating the maturity of BIM-based AR/VR systems.

In addition, as shown in Figure 4, the findings revealed that the proposed framework is well aligned with the intended objectives of evaluating the maturity of BIM-based AR/VR systems, as all participants strongly agreed as reflected in the score of "6" and "7" on statement 2. This indicates that the experts who participated in the survey perceived the proposed framework as relevant to the evaluation's objectives.

Regarding the clarity and structure of the proposed evaluation process, a total satisfaction of all participants was observed. This is supported by the results of Statement 3, which received 40% ratings of "7" and 60% ratings of "6".

The feedback on statements 4 and 5 further reinforces the positive perception of the proposed framework's usability and applicability. For Statement 4, the majority of participants expressed high levels of satisfaction regarding the feasibility of implementing and using the proposed framework. For Statement 5, all participants reported being fully satisfied with the framework's ease of understanding. These results confirm that the framework is not only feasible and easy to implement but also easily comprehensible. Note that the presence of a neutral response for Statement 4 implies that there may be some areas for improvement.

The survey results on statements 6 and 7 indicate a highly positive perception regarding the evaluation of specific areas. The proposed approach for interpreting results was found to be clear and useful by the participants, demonstrating the framework's success in providing a feasible approach to understanding, presenting, and interpreting the results of BIM-based AR/VR systems. Sixty percent of participants rated it with a score of "7," while the remaining 40% gave it a rating of "6" and "5," respectively. Moreover, the evaluation results effectively demonstrate an excellent coherence between the proposed maturity levels. Thus, all participants found the levels well-organized and easy to understand.

Discussion and Future Perspectives. While the feedback provided by participants confirms the feasibility of the proposed framework, some limitations and comments were mentioned. Specifically, some participants found that the details on the data interpretation approach were insufficient and that the proposed rules were not clear enough to be easily understood. These limitations may have affected their assessment of the ease of implementation of the proposed framework. These issues can be attributed to the fact that our study deals with hypothetical thresholds that require the intervention of evaluation experts and further specifications for each measure to be taken into account. In this paper, we have only identified three decision criteria rules as a first step in this framework, considering only the case when each criterion has only one measure and not considering the presence of multiple measures for each criterion. Therefore, more rules should be developed for all proposed cases.

Furthermore, it was noted that the maturity levels show a minor difference between level 4 and level 5, which is limited only to a theoretical difference and may be difficult to achieve in reality. Consequently, further explanation regarding maturity levels is needed to clarify their significance and practicality.

In addition to the limitations identified from the survey feedback, several other limitations of the study should be noted. The validation method used in the study only involved feedback from academic experts, which may not fully capture the perspectives of industrial experts who have more practical experience. Therefore, it is important to consider input from industrial experts in future studies to assess the applicability of the proposed framework. The identified key evaluation elements in this study are not exhaustive and are considered as examples from the literature. Thus, more research should be conducted to validate and identify more key elements through interviews with experts.

In conclusion, to enhance the usefulness and applicability of the proposed framework, future work should consider the transition between levels. This could be achieved by defining recommendations for each level to help companies and users improve their project's maturity and move from one stage to another.

5 Conclusion

This paper presents a conceptual framework for evaluating the maturity of BIM-based AR/VR systems in the AEC industry. The framework serves as an important step for establishing a more standardized maturity model with the same goal. It was developed by analyzing existing frameworks and based on known models and standards such as CMMI, PMMM, ISO/IEC 15939, and ISO/IEC TS 33061:2021. The evaluation process begins with identifying key elements and then defining aspects, criteria, and sub-criteria with appropriate evaluative measures. The proposed framework includes an analysis process for data interpretation and results representation. The framework defines six levels of maturity for assessing the maturity findings of the studied system. To validate the framework, a descriptive report containing evaluation statements was evaluated by five academic experts. Feedback revealed a positive response to the overall framework and specific evaluation aspects, although some comments were made regarding the maturity levels and the analysis process to understand the results.

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