Towards AR/VR Maturity Model Adapted to the Building Information Modeling

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Abstract. The challenge of improving the efficiency of the different phases of a building or infrastructure life demands considerations of innovative technologies such as Augmented Reality (AR) and Virtual Reality (VR). During this last decade, AR/VR systems for construction started to be emerged. These applications aim to virtualize or augment in real time the content of the Building Information Modeling (BIM) in order to support continuous improvement. To ensure the maturity of these applications, implementing a maturity model is needed. Based on literature, several maturity models for BIM have been proposed. However, it stays generic and needs to be adapted to the AR and VR technologies in the BIM context. To that end, we started in this paper by proposing an adapted AR/VR maturity model for BIM that aims to evaluate the maturity of these technologies according to the BIM lifecycle. This model has been conceived based on a mapping between three existing maturity models corresponding to AR, VR and BIM technologies from the most adapted existing works that deal with our goal. As a result of this mapping, three maturity levels have been identified and a detailed description of each level has been established. This model will be proposed to construction companies in order to evaluate their maturities on the use of AR/VR technologies.

Keywords: Virtual Reality, Augmented Reality, BIM, Maturity, Model.

1 Introduction

In a world where technology is used in every sector of the industry, the Architecture, Engineering, and Construction (AEC) sector is no exception. The building information modeling (BIM) is a set of interacting policies, processes, and technologies that allow the creation of infrastructures' models during and across their complete lifecycle [1] [2]. This process assists teams in taking the best decisions in construction projects by helping them on conceive, visualize, run simulations, and collaborate easily [3]. The challenge of improving the efficiency of the different phases of a building or infrastructure life demands considerations of innovative technologies. Virtual tools are considered as a part of Smart Working as they support the decision-making process. The emergence of these new technologies has changed the industry from mechanical systems adoption to highly automated assembly lines. Augmented Reality (AR) and Virtual Reality (VR) are two emerging technologies in this field that create partial and complete virtual environments [4] [5]. In the context of next-generation building design, these two technologies can improve the BIM by allowing users to visualize the data of the developed 3D model and to connect to its data in real-time [3]. The earliest functional of VR and AR systems were developed in the 1990s, and these technologies are used today as one of the most promising technology in the industry 4.0 context [6]. It is increasingly used in many application fields, such as industry, construction, maintenance, engineering, and education [7].

Today these technologies have started to be used with the BIM and need to be further developed. Thus, as a first step, we are interested in this article to study and determine if these technologies meet the needs and expectations of BIM. To this end, we are studying the maturity of the AR and VR technologies compared to BIM in order to determine the quality of the services and processes offered by these technologies and to identify possible improvements. In the literature, there are many maturity models for evaluating BIM, however, they are generic and must be adapted to AR and VR technologies in the BIM context. To the best of our knowledge, no work has defined an AR/VR maturity model adapted to BIM.

Looking for this scenery, we proposed in this paper, an adapted AR/VR maturity model for BIM based on existing and the best-known maturity models adopted in the literature. This model is designed based on a mapping between three existing maturity models corresponding to AR, VR and BIM technologies.

This article is organized as follows: Section 2 introduces a brief background about AR, VR, BIM and maturity models concepts and the previous works about our subject. Section 3 describes our proposed AR/VR maturity model for BIM in order to evaluate the maturity of these technologies with BIM according to model maturity levels. Finally, Section 4 concludes the paper, presents a discussion that highlights some limits of our proposal and outlines some future perspectives.

2 Background

This section presents the background of our research. First, we define the concepts related to VR, AR, BIM and maturity models. In the following, we present recent research works proposed in literature.

2.1 BIM, Maturity Models, VR, AR Concepts

Building Information Modeling (BIM) is an intelligent 3D model-based process that gives Architecture, Engineering and Construction (AEC) professionals the insight and tools to improve efficiency when building plans, designing and managing buildings and infrastructure [3]. It implies the creation of 3D models and a significant amount of information, both geometric and semantic, related to the modeled infrastructure and buildings [1]. Although BIM is not used universally by the entire construction world because it is not a standard and it has a high implementation cost as well, it is usually implemented in large projects, including 3D views. Therefore, it allows the visualization of projects in four, five or six dimensions, integrating the notions of time, money, and human resources [8].

BIM in the construction sector is considered a break technology since it leads to a paradigm shift. It encourages companies to abandon their traditional practices and adopt emerging practices. The implementation of BIM generally results in a redefinition of practices and processes in order to increase the efficiency and the consistency of BIM collaborative design and enhance the quality of information delivered to stakeholders involved in a project lifecycle [9] [10]. However, BIM technologies in companies are often integrated in a less structured way [11] [12]. Thus, BIM maturity models are proposed as a solution to identify and prescribe good practices in order to manage technological, procedural and organizational changes [13] [14] [15]. Maturity models are tools used to measure and evaluate organization maturity according to defined KPIs. These models are presented as per levels ranging from basic level until to mastery and high performance [16]. The set of proposed models brings together good BIM implementation practices around three main dimensions: Technology, Organization and Processes or Protocols [17]. Thus, the maturity assessment aims for capturing the actual state of organization according to model maturity levels.

In the context of construction or building operations, Augmented and Virtual reality technologies prove to be effective, immersive and /or real-time tools allowing visualizing complex situations in the workplace, to reinforce risk prevention knowledge [18].

Augmented Reality (AR) is an innovative technology allowing superimpose virtual objects on real-world images for user interaction [19]. It has made leaps and bounds over the past few years. With the explosion in power of mobile devices, AR now allows the use of glasses or a smartphone to create a virtual layer that the user can see through, showing actual data, in our case BIM data [20]. While virtual reality is a technology that allows users to have total immersion and navigate in a virtual environment, in order to explore it and interact with 3D objects [21]. This technology is generally carried out via advanced display devices, such as immersive headsets (HMD - Head Mounted Displays).

By providing an immersive or real-time virtual environment, stakeholders can gain a better view of the physical context of the construction activity, task or structure on site in order to make more informed and precise design decisions [22]. In addition, the deployment of these technologies allows a gain in productivity and an efficient presentation of the future building to customers [23].

2.2 Related Work

Maturity Models for BIM. Today, the countries, which use BIM in a developed way, had adopted maturity models in accordance with the needs of their company. The maturity models were built to meet a specific context and needs. Most models are built from the Capability Maturity Model CMM [24] [25] [9]. Its objective is to qualify companies so as to know if they have the capacities to meet the objectives of an IT project.

To date, around ten BIM maturity models have been developed. The main models published in the literature are often compared in relation to their country of origin, organizational scale, year of publication, type of models and style of evaluation [26] [27]. The work of Succar [28] [29] is one of the most cited authors on the subject of BIM maturity. It had built its maturity model by distinguishing between BIM capacity and maturity.

The evolutionary character of its concept can however be underlined since the first publications of this same author [28] dating from 2009, proposed three phases of maturity BIM which were then reconsidered and replaced by the concept of capacity [30] [31]. This is to apprehend the implementation of BIM in stages, since it is by nature doomed to create innovative breakthroughs and gain momentum within companies [29].

More recently, Dakhil et al [32] have proposed a model inspired by the model of Succar et al [28] (see Figure1).

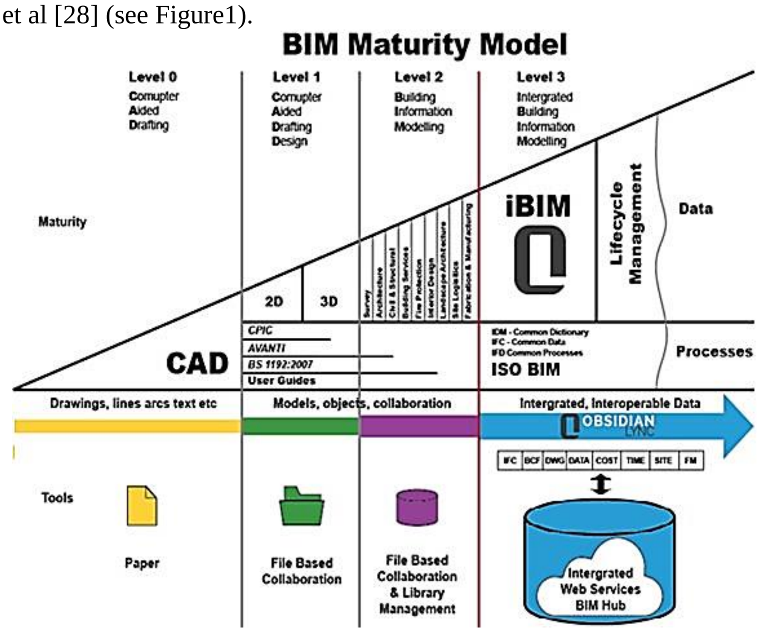

Fig. 1. BIM Maturity Model proposed by Dakhil et al.,[32]

The latter offers maturity levels that correspond to the gradual and continual improvement of processes, technologies and strategies within each BIM stage. As illustrated in the Figure 1, this model proposed four main levels from level 0 to level 3. The level 0 is based on the use of unmanaged Computer Aided Design (CAD) to create drawings. The level 1 allows to manage the CAD in 2D or 3D format where the company engaged industry standards within the modeling process such as BS1192 with commercial data and is managed by stand-alone finance and a cost management package. In addition, this level allows combining the 2D drafts with 3D models in a common Data Environment. The level 2 allows to manage 3D environment held in separate discipline tools with parametric data and commercial data managed by Enterprise Resource Planning. Thus, several additional dimensions such as time calculation are added. Furthermore, this level ensure a full collaboration and partial interoperability using distinct CAD models. During this stage, integration occurs based on proprietary interface or bespoke middleware. While the level 3 is based on a full collaboration and a full integration in a cloud based environment. It is based on a fully open interoperable process and data integration enabled by IFC. This level, named integrated BIM, allows managing the data and information by a collaborative model server.

Maturity Models for Augmented and Virtual Reality Technologies. Based on literature, only one work has been proposed on this subject. In this work, Hammerschmid [33] has proposed a first draft of virtual and augmented reality maturity model. It aims supporting companies in deciding for or against VR and/or AR. Two maturity models have been proposed concerning respectively virtual and augmented reality where each one is composed by five levels. The VR maturity levels are defined as follows: The first level is to view 3D model in virtual word. The second is to adjust background to 3D model. The third level is the interaction in the virtual world. The fourth level is the configuration of the 3D models, and the level 5 is the total immersion. While the five AR maturity levels are described as follows, the first level indicates that products or environment are tracked and recognized by AR devices. The second level indicates that objects and information are displayed. The third level mentions that the objects and information can be configured. The fourth level concerns connecting other people to share information and presentations. The fifth level indicates that problem areas are automatically recognized and suitable solution suggestions are displayed. This model has been tested in four companies based on the focus group discussions to evaluate their maturity in the use of virtual and augmented reality. As a result, analyses show firstly that all companies wanted to deal more attention with the technologies by applying the VR/AR application in more products before enhancing the application itself. Further, the finding show that the majority of these companies have already in application in the field of marketing and sales, and all of them have high potential in the field of customer service and human resources. Moreover, all four companies were able to handle the model and need just slightly changes of the levels to fit their needs.

Summary. Based on these related works, two conclusion are drawn. The first concerned the AR/VR maturity model [33] which remains a first draft that needs to be tested in other companies working on other fields, in our case, the building field. The second concerned the existing BIM maturity models. Despite their diversity, these models have no empirical confirmation and no model has been identified as a universal model to impose on the entire construction industry.

Since some companies, whatever their fields of application implement augmented and virtual technologies without analyzing their own needs, it is necessary to use a more adaptable maturity model, which helps them to visualize and determine the benefits of these technologies. In the field of building, BIM solution aims to generate a data model containing the maintain building information along the whole lifecycle of a building project. The model offers different information extracted from different data relating to different steps of lifecycle. Today, both the augmented and virtual reality are integrated in the building design process. Yet, to our knowledge, there is currently no AR/VR maturity model suitable for BIM. Thus, we argue that the integration of the existing maturity models are essential to obtain better refined AR/VR maturity model adapted for BIM.

3 Augmented Reality/Virtual Reality Maturity Model for BIM

Considering the limited number of researches, the analysis of the maturity of AR/VR in the construction field (especially in BIM) is today in these early stages. The aim of this work is to define an adapted AR/ VR maturity model for BIM based on the existing and the best-known maturity models in the literature. Those includes the BIM Maturity Model proposed by Dakhil et al.,[32] and the AR/VR maturity model proposed by [33] (see Section 2.2).

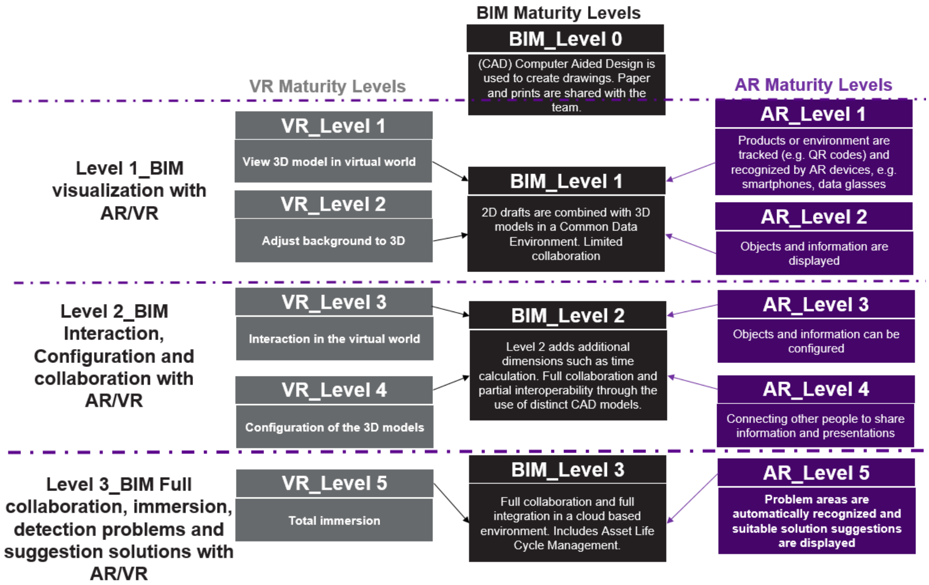

Fig. 2. The proposed AR/VR maturity model for BIM

As illustrated in the Figure 2, our proposed model is conceived based on a mapping between these two models according to their maturity levels. It includes three maturity levels. The level 1 is named BIM Visualization with AR/VR. The level 2 is named BIM Interaction, Configuration and Collaboration with AR/VR, and the level 3 is the BIM Full collaboration, Full immersion, detection problems and suggestion solutions with AR/VR. In the following, we present the features introduced in each level.

3.1 Level 1: BIM Visualization with AR/VR

As illustrated in the Figure 2, we decided firstly to eliminate the level 0 from the BIM model since it is based on the use of the CAD (computer Aided Design) to create, prints and shared 2D models on paper, which means that this level is overtaken by the AR/VR technologies.

The first level, called BIM visualization with AR/VR, is the result of a mapping between the first two maturity levels of AR/VR model and the first maturity level of

BIM model. This mapping comes from two sub-mappings. The first concerns the virtual reality and BIM and the second concerns the augmented reality and BIM. As illustrated in the Figure 2, the level 1 of BIM allows combining the 2D drafts with 3D models in a common Data Environment. This means that this level allows only visualizing the 3D model.

By integrating the AR/VR technologies, this first level of BIM corresponds, on the one hand, with the first two levels of VR maturity model relating respectively to the visualization of the 3D model in virtual word and the background adjustment to 3D model. On the other hand, this level corresponds with the level 1 of AR maturity model that indicates that object or environment are tracked and recognized by AR devices and the level 2, which indicates that objects and information are displayed.

Consequently, these two sub-mapping allow us to identify two main functionalities on which this level is based, respectively:

- The visualization of the BIM model in virtual word and the adjustment of its content in virtual reality; Several VR devices can be used to visualize the BIM content, among them we quote Samsung Gear VR[1] [34], Oculus Rift[2] [35].
- The tracking, the recognition and the display of the BIM model based on AR device. There are two significant ways to track and recognize a BIM model with AR. The first is based on location-based systems, using physical sensors to position objects and users such as Bluetooth Low Energy (BLE) beacons [2] or Wi-Fi positioning [19]. The second way concerns vision-based systems, by using feature points put on site and detected by cameras, such as markers [19] [36] or natural features tracking [20] [36]. Thus, in this case, users place two markers on the construction site and capture the scene, and the augmentation can be accurately and automatically achieved, by computing a "projective space" of two-selected reference images [37]. Regarding display techniques, AR is introduced on the construction site, firstly, using a headset that is worn on-site to allow the display of 3D models on the real world as done by [36]. In this way, the worker can see the BIM components directly over the real world. In a second way, using smartphones or other mobile devices [36] [2].

3.2 Level 2: BIM Interaction, Configuration and Collaboration with AR/VR

This level integrated three main components respectively, the interaction, configuration and collaboration. It is the result of a mapping between the third and fourth maturity levels of AR/VR model and the second maturity level of BIM model. As a result, two sub-mapping are defined. The first concerns the virtual reality and BIM and the second concerns the augmented reality and BIM (see Fig.2). Those later have two main functionalities, respectively: (1) BIM interaction and configuration with AR/VR and (2) BIM collaboration with AR/VR.

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[1] Samsung Gear VR is a virtual reality device that allows exploring virtual worlds at the construction site or during meetings [34].

[2] Oculus Rift is a real-time viewer application with interactive capacities, developed by the Oculus Company, and can be implemented as a plugin in Revit [35]. These VR glasses are handling to visualize and experience 3D model, 360° panorama picture, and virtual mock-up over a BIM model [38].

- *BIM Interaction and Configuration with AR/VR***.** In an AR environment, building information can be generated and represented as 3D virtual models; those can then be viewed in 3D, performed virtual interactions with the real environment, or extracted and inserted into the multi-disciplinary users' views of a real-world scene (i.e. the . actual building site). AR devices (for examples, headset, smartphones or other mobile devices) can be used for interacting with the application to change the type of data to be visualized [20]. The AR can also support tangible interactions. Further, the coupling of BIM and AR can open up potential opportunities for exploring alternative approaches to data representation, organization and interaction for supporting seamless collaboration in BIM. VR offers to the user an interaction with the virtual building and its environment, which considers the virtual world, immersion, sensory feedback, and interactivity. The users must be able to change/move virtually some elements like doors, windows or walls. The transformation of objects in VR must be instantaneous; otherwise, the effect of immersion is heavily impaired. In this context, updates in the Revit[3] model can take from milliseconds to multiple seconds depending on database and geometry complexity. VR requires devices for interaction with the virtual environment of the building and the construction space. The interaction with the virtual environment of the building and the construction space required the use of head-mounted displays (HMDs) devices such as Oculus Rift, Samsung Gear VR, HTC Vive [39].
- *BIM Collaboration with AR/VR*. Collaboration in building design projects is very important, as they bring together a large number of diverse disciplines, supply chain stakeholders who have not worked together before. To establish clear and effective collaboration practices, it is imperative to manage a large amount of information and procedures involving complex tools and systems. As defined in [40], the collaborative environment in VR is “multiple users interacting within a virtual world that enables interaction among participants” where collaborative visualization is the most used. The collaborative visualization can be through Large Volume Displays (LVD), which allow the simultaneous collaboration of several individuals [41]. While for AR, as defined by Renevier and Nigay [42], a collaborative AR system is “one in which augmentation of the real environment of one user occurs through the actions of other users and no longer relies on information pre-stored by the computer”. In the building industry, it is still common for R&D teams to use 2D models and documents to explain and exchange with the project owner, client and stakeholders.
  However, the lack of knowledge in engineering or industrial design makes the exchange or understanding of plans difficult and may lead to misunderstandings.
  With the VR integration into the building field, these technologies support design applications, and used for collaborative visualization and construction processes improvement. The 3D visualization, provided for users by VR, allows a real time collaboration during different stages of the construction process. The collaboration platform BIM, through its server allows the interaction of different stakeholders by data

[3] Revit is building information modelling software for architects, landscape architects, structural engineers, mechanical, electrical, and plumbing (MEP) engineers, designers and contractors [35].

management. According to access rights, the platform allows building data storage, modification, export/import of different files, viewing and modifying. Thus, during the whole building life cycle, the augmented or virtual 3D model can be viewed and updated or modified.

During design phase, the AR offers to users (architect, engineers and contractors, etc.) a collaborative design review through usage of AR technologies with BIM. Engineers can work on augmented drawings or 3D models in real-time and can have an overview about samples or types of materials. In this case, the AR coupled to the VR allows the BIM design review, communicate, modify at distance or office in virtual world. During construction phase, the AR allows the construction information management through examining work process check and validate the working process. Thus, users (project manager, workers, engineers, architects and contractors, etc.) can interact, confirm, inspect, review, and add changes in a shared database in real time at job site, office or any place. During maintenance phase, AR can be used for tasks and process efficiency according to the fact that information can be available in real time and in the real context. Using AR enables maintenance teams to reduce errors and be guided during their maintenance actions. The usage of HMD gives to technician the possibility to focus in the task, visualize and interact with the related information at the same time [43].

The solution needs the deployment of technologies such as mobile devices (mobile, tablets), mixed environment (MRCVE), identification systems (barre code, RFID) and geo tracking solutions (GPS, WPS) [44].

3.3 Level 3: BIM Full Collaboration, Full Immersion, Detection Problems and Suggestion Solutions with AR/VR

This level presents the highest level of AR/VR maturity of applications for BIM. It is the result of a mapping between BIM/ AR and BIM/VR maturity levels as illustrated in Fig.2. It includes two sub-levels: the first concerns the use of VR and BIM. We called it BIM full collaboration, full immersion, detection problems and suggestion solutions with VR. The second concerns the use of AR and BIM; we named it BIM full collaboration, detection problems and suggestion solutions with AR. These two sub-levels are the results of a mapping between BIM/ AR and BIM/VR maturity levels.

In this level three, different functionalities characterize each sub-level. They can be summarized as follows:

- *BIM Full Collaboration, Full Immersion, Detection Problems and Suggestion Solutions with VR.* The VR brings together the actors of the construction around a single BIM model hosted in a full collaborative platform, which allows ensuring a full collaboration. This Platform allows different collaborators to fully immerse themselves in real time, to meet together in virtual and to navigate inside the digital model, learn about all of its data and interact with its components. In addition, the use of the VR is much more useful in the design phase because it can detect and report upstream anomalies and catch up before starting the construction. This technology can be considered as a mean that allows proposing solutions and recommendations to the team workers in order to resolve the construction problems detected. Thus, in order to facilitate their collaborative work, the project actors must be equipped with VR tools with the same performance (resolution, sound, interaction, haptic, etc.).

– *BIM Full Collaboration, Detection Problems and Suggestion Solutions with AR.* During the works phase, when using the AR, the site team uses the BIM model, which is in the collaborative platform to display it in the real environment of the site. This technology will help field teams to carry out precise monitoring of the site in real time. The augmented elements give the impression of an almost natural presence of the building in the real environment. Therefore, the full collaboration will help the site team, in interaction with the BIM model in real time, to follow and simply enter the progress of the site, annotate and share the added information, report and detect problems, as well as offer a way to repair these anomalies.
  The collaboration process allows a more fluid flow of exchanges between the different project stakeholders throughout the building life cycle (from design to exploitation).

The AR/VR allow access to the database of the digital model via mobile devices remotely or on site. The workers will have the same level of information (geotagged photos, text or audio notes, showing a design flaw or any unforeseen event, etc.) and can handle heterogeneous data.

In addition, this level allows access to the BIM on site and the management, in real time, of the differences between the work as planned and the actual construction: the coherence between the "As built" object and the virtual model "as planned".

4 Conclusion & Perspectives

This paper presents the first step towards the specification of an AR/VR maturity model for BIM. The proposed model has been conceived based on the most known existing maturity models according to BIM and AR/VR technologies. Three main maturity levels have been identified based on a mapping between the selected existing maturity models. This preliminary study gives us some relevant findings. First, we can say that the specification of this model can benefit the construction industry; both in the design, construction and maintenance phases to evaluate identify their maturity levels and therefore enhance their systems. Thanks to the three maturity levels proposed, this model allows us identifying the main aspects characterizing the AR/VR systems for BIM, which are the visualization, interaction and configuration, collaboration, full collaboration, full immersion and detection problems and suggestion solutions.

However, this subject is only in its infancy. The proposed maturity model should be, firstly, tested to be validated. To that end, we envisage performing a theoretical evaluation of the proposed conceptual model with experts and then performing a case study with companies specializing in BIM, AR/VR. Secondly, a reflexion about the model implementation within company is needed in order to facilitate its integration. Eventually, this conceptual model did not deal with the transition from one maturity level to another. For this, we plan to integrate the transition mechanisms for moving from one maturity level to another in order to allow companies to develop their maturities.

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