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An Integrated Framework for Engaging Stakeholders in the Circular Economy Processes Using Building Information Modeling and Virtual Reality

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***Abstract*—**Global climate change has become increasingly problematic over the past few decades. The construction industry has contributed to greenhouse gas emissions in recent decades. Considering these issues and the high demand for materials in the construction industry, Circular Economy (CE) is considered necessary to keep materials in the loop and extend their useful lives. By providing tangible benefits, Construction 4.0 facilitates the adoption of CE by reducing waste, updating standard work, sharing knowledge, and increasing transparency and stability. This study aims to present a framework for integrating CE and digital tools like Building Information Modeling (BIM) and Virtual Reality (VR) to examine the impact on the construction industry based on stakeholders' perspectives.

***Keywords*—**Circular Economy, Building Information Modeling, Virtual Reality, stakeholder engagement.

I. Introduction

OVER the past few decades, global climate change has become increasingly problematic. Despite this, the construction industry has contributed 40% of total greenhouse gas emissions in the past few decades and is the largest contributor to global waste generation [1]. Considering these issues and the high demand for materials in the construction industry, Circular Economy (CE), a model of production and consumption which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products, is considered to be beneficial for keeping materials in the loop and extending their useful lives [2]. To implement the principles of CE effectively, stakeholders need to be engaged in the process from the initial design phase to post-construction facility management. BIM and VR technologies have the potential to facilitate stakeholder engagement in CE processes.

BIM technology has been used in the construction industry to improve communication and collaboration between stakeholders by providing a shared digital platform for project information [3]. Additionally, VR technology can enhance stakeholder engagement by providing an interactive and immersive experience, improving communication channels, and enhancing understanding of the design intent [4]. Combining the advantages of BIM and VR can enable stakeholders to better visualize, communicate, and actively participate in the decision-making process throughout the life cycle of a building project. Although BIM and VR can potentially benefit CE processes, challenges still exist.

II. Literature Review

A. Circular Construction

Circular construction is the result of applying CE principles in the construction sector. CE allows to mitigate waste generation and material toxicity. To properly design a circular building, it must be traceable, designed for disassembly, and healthy in terms of material configuration. Furthermore, the whole lifecycle of the building must be assessed, and all the stakeholders since its inception should be involved in collaboration spirit and transparency. In order to transition from a linear economy to a CE, information is one of the most important elements. For example, indicators help determine a building's circularity, enabling designers to optimize their design to achieve more circular buildings [5].

Life Cycle Analysis (LCA) is the most commonly used CE methodology [6]. In LCA, the entire life cycle of a product is considered, from raw material extraction, manufacturing, and transport to the site, construction, operation, and maintenance, until the end of the product's life cycle, for recycling and demolition or recycling of the product. There are four phases in the LCA process: the goal and scope definition; the inventory analysis; the impact assessment; and the interpretation. The goal and scope of the project, including the functional unit, system boundary, and building materials, are established in the first phase based on the purpose and application of the study. The Life Cycle Inventory (LCI) is analyzed in the second phase of LCA. This phase consists of writing a list of input/output data based on the system's boundaries and purpose. The Life Cycle Impact Assessment (LCIA) is the third phase. This phase primarily provides additional information to assist in evaluating the system and better understanding the environmental perspective from which the quantities of materials, energy consumption, and resulting emissions are clustered with the aid of sustainability indicators. The final phase of the work involves discussing the results of the life cycle interpretation around the results of the previous two stages and finally making

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appropriate conclusions, suggestions, and decisions according to the scope and purpose of the project [7].

B. BIM and LCA Integration

Considering the CE approach, BIM is a useful tool for designing buildings. In addition to supporting information management and cooperation between stakeholders throughout the entire lifecycle of construction projects, BIM models produce an integrated design [8]. Throughout the facility's life cycle, BIM provides reliable information that can be used for decisions from conception to commissioning and beyond [9]. During the early stages of construction project design, this gives the opportunity to provide design alternatives within all possible variations and design parameters.

Additionally, LCA is an appropriate method for assessing environmental impacts. To maintain sustainability standards in the construction sector and protect the environment, it is important to integrate BIM and LCA, which could offer significant sustainability benefits [10]. Building data are gathered more efficiently and provide comprehensive project feedback [11]. BIM provides the opportunity to calculate energy consumption and environmental impacts. It, therefore, increases the ability to make informed decisions before making decisions concerning very low-energy buildings and the protection of the surrounding environment [12].

There are some studies that focus on the integration of BIM and LCA. According to Morsi et al., BIM techniques are capable of facilitating the performance of LCA. It provides information about how concrete residential construction materials and elements can be reduced throughout the life cycle of a building. The study utilized local materials databases, Revit modeling, and One-Click LCA plugins. The results indicate that the most significant environmental impact occurs during the manufacturing and operating stages. In this regard, it becomes imperative to integrate BIM techniques to ensure the assessment's transparency, coherence, and consistency and promote its endorsement by the construction industry [13].

Nilsen and Bohne investigate how BIM-based LCAs can be used early in the design process to establish an environmental perspective during the decision-making process. These results indicate that automating LCAs by using BIM and conducting ongoing assessments will contribute to a more effective decision-making process [14]. A framework was proposed by Xue et al. that integrates CE into whole-building lifecycle assessments using BIM as a basis. They demonstrated that integrating BIM with LCA greatly enhances the effectiveness of whole-building lifecycle assessments [15].

C. BIM and VR Integration

VR is becoming increasingly popular in the construction industry. The development of these tools, based on BIM, has generated significant interest in improving communication during the design, construction, and maintenance of buildings in recent years [16]. BIM-based VR has demonstrated great potential for allowing project teams to visualize and understand a project's complexity, facilitating activities such as effective construction process planning and equipment operations [17].

Balali et al. developed a framework for estimating construction costs utilizing VR technology. Using a real-time VR model, stakeholders and users could change materials in walls, floors, and other parts of a building and see the corresponding price impacts immediately. In the AEC industry, the results indicated that integrating VR into cost estimation can provide significant benefits for estimators [18]. Du et al. developed CoVR, a VR platform for improving stakeholder communication. Using this platform, users can view BIM data in multiuser interactive virtual environments, allowing remote stakeholders to interact with one another. The researchers determined that CoVR could improve communication based on a survey they conducted [19].

D. BIM and VR Integration in CE

Some studies have been conducted to utilize BIM and VR in CE to improve the CE processes. Kamari et al. used BIM-enabled VR technology for LCA and discovered respondents emphasized economic factors more than sustainability factors when making decisions [20]. The importance of educating stakeholders in this regard cannot be overstated. Another study found that the use of game design methods and digital twins of a CE prototype building improved learning for participants. A VR environment was developed to facilitate the reintroduction of materials and components to supply chains as well as some information regarding the removal procedures and the provenance of materials. The research identified three pillars for reducing construction waste: education, documentation, and visualization [21].

Rezvani et al. examined how VR and gaming can engage end users during the early stages of interior material selection processes, developing a BIM-VR platform where end users can choose materials for wall finishing. They provided information regarding scenario costs, environmental impacts, and visual representations of design scenarios. The findings of this study indicate that a sustainable design must involve end users in the design process [4].

E. Knowledge Gaps

As mentioned above, CE, BIM, VR, and their combinations have been examined in several studies. According to some of them [4], [21], BIM and VR can improve stakeholder engagement in CE processes. In spite of the potential benefits of BIM and VR, there are still several obstacles to overcome before they can be successfully incorporated into CE processes. BIM and VR implementation requires a standardized approach that all stakeholders can use [22]. This challenge can be addressed by developing an integrated framework that outlines the BIM and VR requirements for CE processes.

III. Methodology

A. Overview

This paper presents a BIM-VR framework to improve CE processes by increasing the interoperability of stakeholders and systems during the design stage. Fig. 1 illustrates the overall architecture of the framework. The first step involves creating a basic BIM model. After that, more detailed information can be added, such as materials, textures, and components. It is then possible to create different scenarios of a building by changing the elements of the BIM model, such as the materials, textures, components, and even the layout of the building (Fig. 2). This allows designers to simulate and analyze different design configurations before construction begins. Each scenario is based on different materials and products that differ in terms of cost, aesthetics, and environmental impact. For example, a designer may choose to use sustainable materials to reduce the environmental impact of the building or more expensive materials to improve the aesthetics of the building. With a BIM model, designers can easily compare and analyze the different scenarios to choose the best one for the project. This allows them to make an informed decision that balances cost, aesthetics, and sustainability.

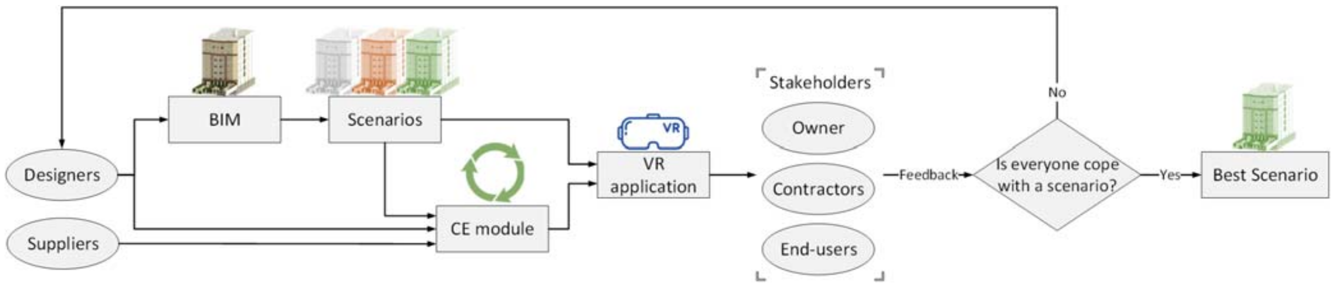


Fig. 1 The overall architecture of the framework

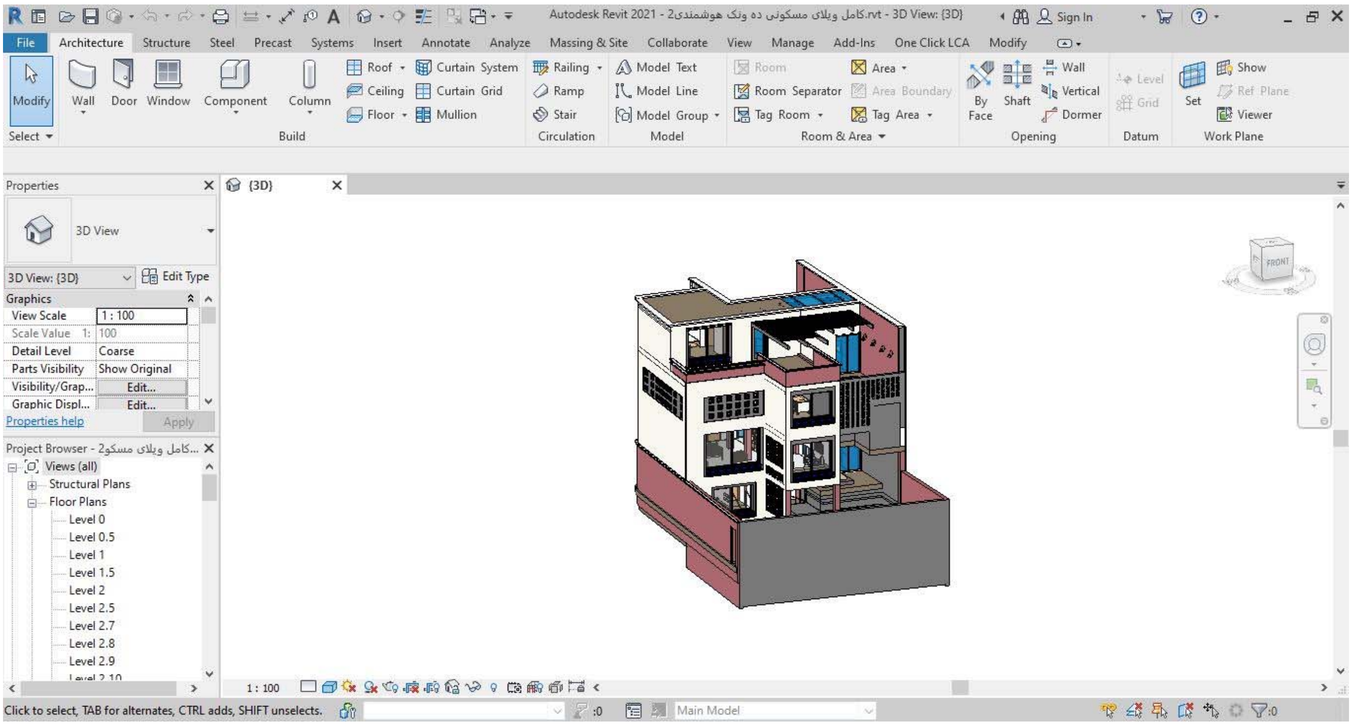


Fig. 2 Creating a basic BIM model and changing the elements within the model, including the materials, textures, components, and even the layout of the building to create different scenarios

With the detailed information provided by the supplier about each material and product, designers can evaluate metrics and indicators based on CE principles. This information can include environmental impact, sustainability, energy efficiency, and cost [23]. These data allow them to accurately compare the different materials and products and choose the one that best meets their needs.

By using a VR environment, other stakeholders, such as owners, contractors, and end-users, can visualize the project in 3D and interact with the different scenarios. This allows them to compare the different scenarios and decide which one to go with. For example, they can evaluate each scenario's cost, aesthetics, and environmental impact to choose the best one for the project. This gives stakeholders an immersive experience that helps them make an informed decision and gives them a better understanding of the project. Fig. 3 illustrates the VR application environment; stakeholders select a scenario, walk through the building, and view the information provided for each scenario, such as embodied carbon benchmarks. After examining the aesthetics of the building, the participants have the choice of viewing two panels of information, one containing information regarding the building's costs and the other providing information regarding its CE status. Then, stakeholders compare scenarios and provide feedback, and the designer redesigns the building to achieve the optimal scenario. These cycles can be repeated several times to ensure the best possible outcome. Through this iterative process, the designer can ensure that the final design achieves the best balance between cost, aesthetics, and environmental considerations.

IV. Development of VR Application

The purpose of this section is to explain the development process for VR applications. Based on Fig. 4, the first step is to create a basic 3D model of the project using Autodesk Revit software. The model includes architectural, structural, mechanical, and electrical information. By modifying the basic BIM model, several scenarios are created to be assessed by stakeholders. Additionally, using the energy simulation add-in in Revit software, the energy performance of each scenario is determined.

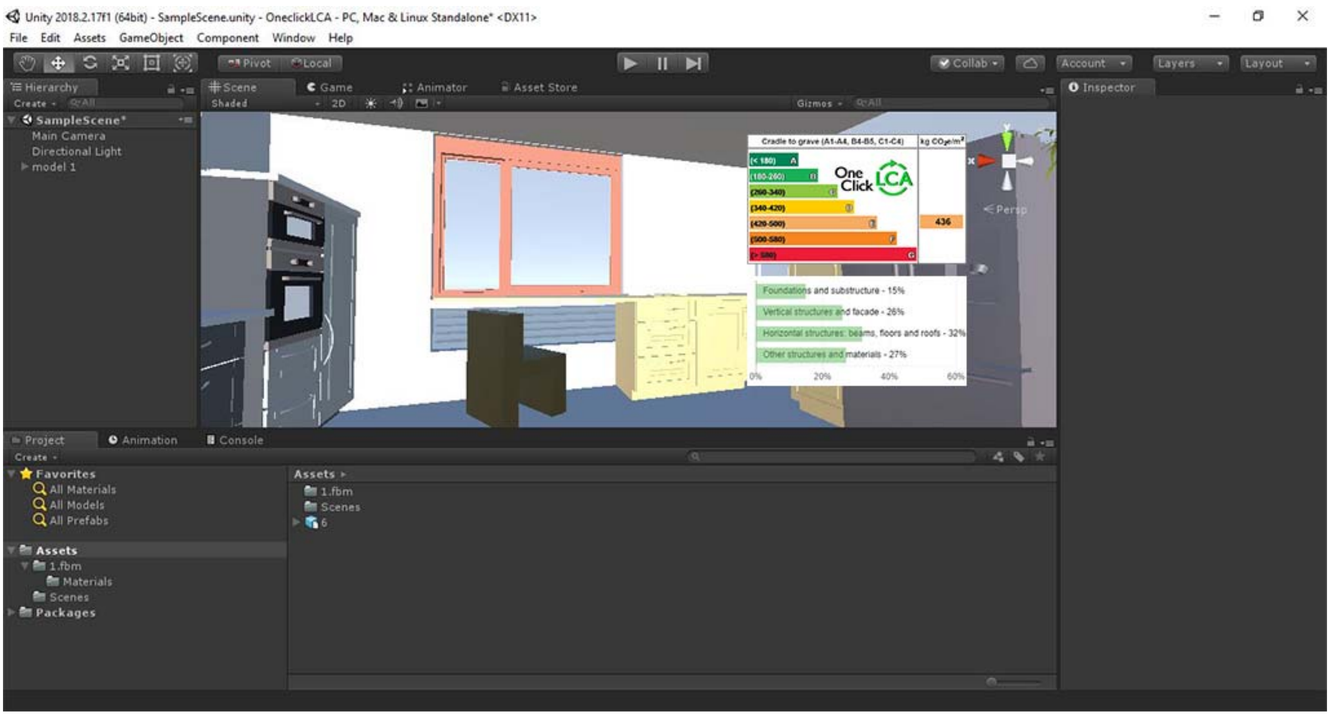
The next step is to prepare a 3D model for use in a VR environment. The direct import from Revit to Unity 3D eliminates some textures and lighting. In order to optimize and control texture and lighting, a 3D model must first be exported in FBX format from Revit and imported into 3DMax, then exported in FBX format from 3DMax and imported into Unity 3D.

The next step is the import of BIM data into OneClickLCA. OneClickLCA has a plugin for Revit that allows BIM data to be exported to OneClickLCA. OneClickLCA provides access to its database for generic construction materials and a comprehensive list of available databases. The metrics and indicators of CE can be calculated and analyzed by mapping these databases to elements in the BIM model. Lastly, OneClickLCA provides a comprehensive report of CE information for each scenario, which can be exported to a database for import into VR applications.

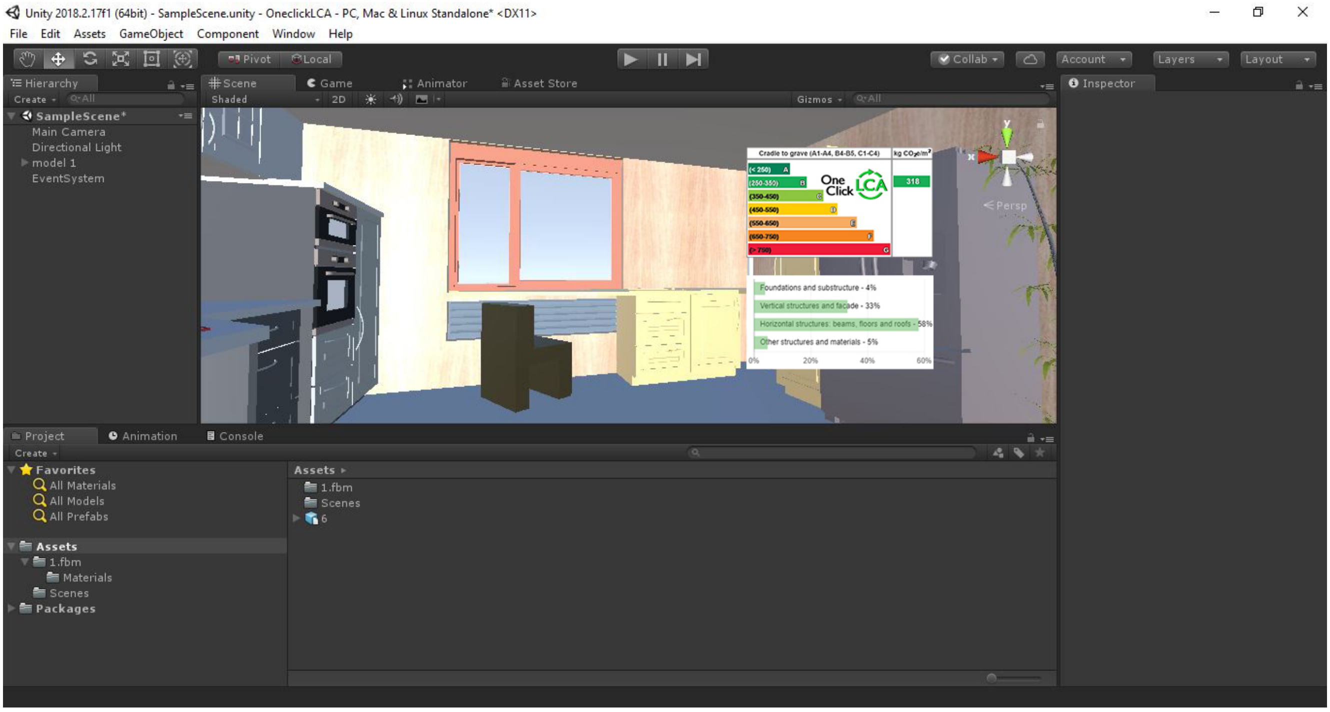
The next step after importing the 3D model and CE database into Unity 3D is to link the data of the databases to the elements of the 3D model. These data are added to each element of the 3D model by developing a C# script in Unity 3D. The final step involves creating a VR application and user interface (UI) that stakeholders can interact with and view relevant information.

V. Discussion & Conclusion

The paper reviews the literature on Circular Construction, BIM, and VR and how integrating them can benefit the CE. The benefits of BIM and VR, such as better visualization and communication, understanding of a project's complexity, and their potential to improve the sustainability of the CE, are highlighted. The paper proposes a framework for integrating CE with BIM and VR to leverage both technologies' benefits for sustainable development. The framework incorporates CE principles into BIM and VR processes, aiming to develop a more sustainable Circular Construction. This framework has several advantages and challenges, which are listed below.



(a)



(b)

Fig. 3 Different scenarios for a project, (a) A scenario with a Gypsum wall, (b) A scenario with a wooden wall

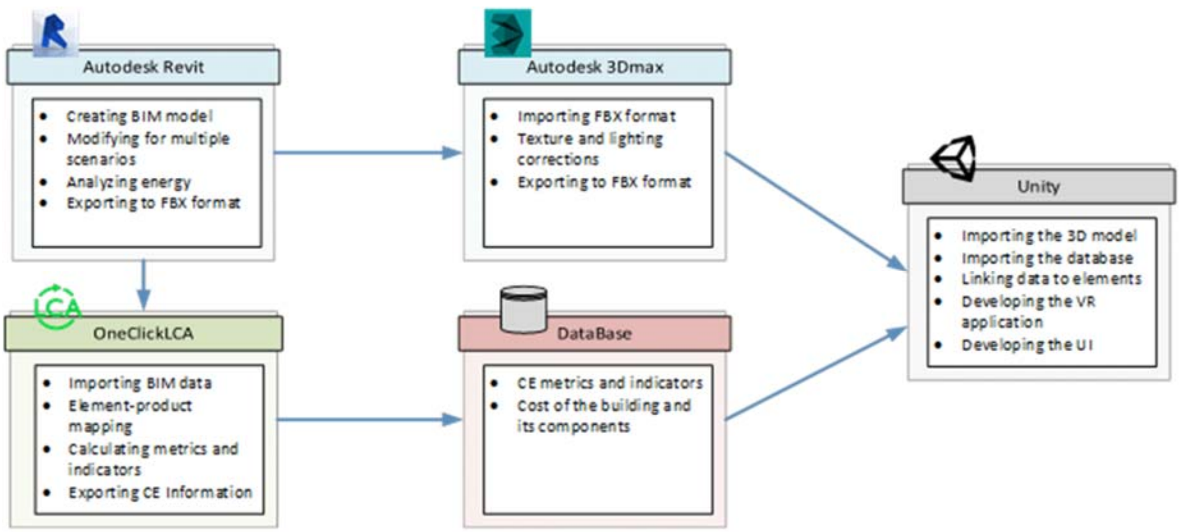


Fig. 4 VR application development process

A. Benefits

1. Improved communication and collaboration between stakeholders throughout the project life cycle by providing data exchange, interoperability, and compatibility.
2. Improved stakeholder engagement by providing a deeper understanding of the project, which enables stakeholders to make more informed decisions.
3. Increased efficiency in the design and construction process by enabling designers, contractors, and other stakeholders to easily access and share project data.
4. Increased transparency and stability in the entire process by providing accurate data and information exchange between stakeholders.

B. Challenges

1. Choosing the appropriate CE metrics and indicators to display in the VR environment is challenging. Stakeholders may have different needs and opinions, so selecting the right metrics and indicators to display can be difficult. Additionally, the information displayed in the VR environment should be relevant, easy to understand, and visually appealing. Careful consideration should be taken in how the data are presented to ensure that it effectively

conveys the desired message.

2. Stakeholder education and training are also challenging, as stakeholders need to understand how to use BIM and VR technologies to fully benefit from their advantages. Additionally, stakeholders must be adequately trained to interpret and act on the data presented in the VR environment to make informed decisions that align with the CE principles.
3. Preparing the VR environment for each scenario can be time-consuming and require a high level of expertise. This is due to the technical complexity of the process and the amount of data that are needed to create a VR environment. Additionally, the hardware and software requirements for creating the environment can be costly.
4. Interoperability between different software, databases, and systems is an important challenge. Material Passports, which store data about the origins and lifecycle of materials, are an integral part of circular construction. Therefore, the ability to share and access data between different software, databases, and systems is essential in order to effectively leverage the advantages of BIM and VR for Circular Construction.
5. There is also the challenge of identifying which information is required, when it is required, and who is authorized to access it.

REFERENCES

[1] E. Commission, "LEVEL (S): taking action on the total impact of the construction sector," ed: Publications Office of the European Union Luxembourg, 2019.

[2] S. Meža, A. Mauko Pranjić, R. Vezočnik, I. Osmokrović, and S. Lenart, "Digital twins and road construction using secondary raw materials," *Journal of Advanced Transportation,* vol. 2021, pp. 1-12, 2021.

[3] S. Alirezaei, H. Taghaddos, K. Ghorab, A. N. Tak, and S. Alirezaei, "BIM-augmented reality integrated approach to risk management," *Automation in Construction,* vol. 141, p. 104458, 2022.

[4] M. Rezvani, H. Taghaddos, S. Sobhkhiz, M. Noghabaei, and K. Ghorab, "User Engagement for Sustainable Development: How Can Virtual Reality Help?," in *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021: CSCE21 Construction Track Volume 1*, 2022: Springer, pp. 239-249.

[5] I.-N. Chumbiray Alonso, E. Sahebzamani, F. Lendinez, and N. Forcada Matheu, "Circular economy and digital twins in the construction sector," in *Proceedings from the 26 th International Congress on Project Management and Engineering (Terrassa, July 2022)= Comunicaciones presentadas al XXVI Congreso Internacional de Dirección e Ingeniería de Proyectos, celebrado del 5 al 8 de julio de 2022*, 2022: Asociación Española de Ingeniería de Proyectos (AEIPRO), pp. 444-456.

[6] R. Rocca, C. Sassanelli, P. Rosa, and S. Terzi, "Circular economy performance assessment," in *New business models for the reuse of secondary resources from WEEEs: the FENIX project*: Springer International Publishing Cham, 2021, pp. 17-33.

[7] I. ISO, "International Standard ISO 14044, Environmental Management—Life Cycle Assessment—Requirements and guidelines," *The International Journal of Life Cycle Assessment,* pp. 652-668, 2006.

[8] A. Carlsén and O. Elfstrand, "Augmented Construction: Developing a framework for implementing Building Information Modeling through Augmented Reality at construction sites," ed, 2018.

[9] A. Shekargoftar, H. Taghaddos, A. Azodi, A. Nekouvaght Tak, and K. Ghorab, "An Integrated framework for operation and maintenance of gas utility pipeline using BIM, GIS, and AR," *Journal of Performance of Constructed Facilities,* vol. 36, no. 3, p. 04022023, 2022.

[10] J. Díaz and L. Á. Antön, "Sustainable construction approach through integration of LCA and BIM tools," in *Computing in civil and building engineering (2014)*, 2014, pp. 283-290.

[11] U. Bogenstätter, "Prediction and optimization of life-cycle costs in early design," *Building Research & Information,* vol. 28, no. 5-6, pp. 376-386, 2000.

[12] F. Shadram, T. D. Johansson, W. Lu, J. Schade, and T. Olofsson, "An integrated BIM-based framework for minimizing embodied energy during building design," *Energy and Buildings,* vol. 128, pp. 592-604, 2016.

[13] D. M. A. Morsi, W. S. Ismaeel, A. El Hamed, and A. A. E. Othman, "Applying LCA-BIM integration for a sustainable management process," in *ARCOM 2020-Assoc Res Constr Manag 36th Annu Conf 2020-Proc 2020*, 2020, pp. 416-24.

[14] M. Nilsen and R. A. Bohne, "Evaluation of BIM based LCA in early design phase (low LOD) of buildings," in *IOP Conference Series: Earth and Environmental Science*, 2019, vol. 323, no. 1: IOP Publishing, p. 012119.

[15] K. Xue *et al.*, "BIM integrated LCA for promoting circular economy towards sustainable construction: an analytical review," *Sustainability,* vol. 13, no. 3, p. 1310, 2021.

[16] D. Bryde, M. Broquetas, and J. M. Volm, "The project benefits of building information modelling (BIM)," *International journal of project management,* vol. 31, no. 7, pp. 971-980, 2013.

[17] X. Wang and P. S. Dunston, "Tangible mixed reality for remote design review: a study understanding user perception and acceptance," *Visualization in Engineering,* vol. 1, pp. 1-15, 2013.

[18] V. Balali, M. Noghabaei, A. Heydarian, and K. Han, "Improved stakeholder communication and visualizations: Real-time interaction and cost estimation within immersive virtual environments," in *Construction Research Congress 2018*, 2018, pp. 522-530.

[19] J. Du, Z. Zou, Y. Shi, and D. Zhao, "Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making," *Automation in Construction,* vol. 85, pp. 51-64, 2018.

[20] A. Kamari, A. Paari, and H. Ø. Torvund, "BIM-enabled virtual reality (VR) for sustainability life cycle and cost assessment," *Sustainability,* vol. 13, no. 1, p. 249, 2020.

[21] T. M. O'Grady, N. Brajkovich, R. Minunno, H.-Y. Chong, and G. M. Morrison, "Circular economy and virtual reality in advanced BIM-based prefabricated construction," *Energies,* vol. 14, no. 13, p. 4065, 2021.

[22] S. Safikhani, S. Keller, G. Schweiger, and J. Pirker, "Immersive virtual reality for extending the potential of building information modeling in architecture, engineering, and construction sector: systematic review," *International Journal of Digital Earth,* vol. 15, no. 1, pp. 503-526, 2022.

[23] B. Soust-Verdaguer, E. Palumbo, C. Llatas, A. Acevedo, E. Hoxha, and A. Passer, "Environmental Product Declarations (EPDs) of construction products in Spain: Current status and future challenges," in *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 1078, no. 1: IOP Publishing, p. 012128.