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ORIGINAL RESEARCH ARTICLE

Proposed Model for Training Building Information Modeling (BIM) in Metaverse Technology Using a Mixed Method

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ABSTRACT

The Fourth Industrial Revolution and the advancement of technology necessitate all industries integrate their operations with cutting-edge technology to grow and stay ahead of global changes. Considering AEC (architecture, engineering, and construction) industry, this research focuses on integrating building information modeling (BIM) training using Metaverse, the world's leading technology, because education is crucial for the growth of individuals in all fields.

A mix-method approach was employed, which entails qualitative meta-synthesis and quantitative methods, such as questionnaires and structural equation modeling (SEM) using SmartPLS. Through various databases, 181 relevant studies were identified, and 30 were selected for further analysis. The selected studies were thoroughly analyzed qualitatively using the MAXQDA 2020 software. The process involved initial coding, axial coding and pattern coding to identify overall patterns and trends within the data. The extracted codes, comprising nine categories and 82 indicators, were validated by a panel of experts using the Fuzzy Delphi method in two rounds of feedback and discussion among the experts to reach consensus on the validity and appropriateness of the codes. Following these results, a comprehensive questionnaire was conducted to assess the factors that influenced BIM training in metaverse. A carefully designed questionnaire was distributed to 300 participants. The quantitative data was analyzed with the aid of descriptive statistics and structural equation modeling (SEM). Both qualitative and quantitative phases resulted in the division of findings into nine categories: technology data and information, education technology infrastructure, team capacity, socio-cultural factors, behavioral factors, applied technologies, functional results, practical features, and environmental configuration. ©**authors**

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1. Introduction

Education plays a crucial role in integrating technology with various industries. It serves as the foundation for growth, learning, and the advancement of humanity. Researchers are examining different aspects of utilizing metaverse technology to leverage this emerging space as a pioneering tool in educating AEC students.

The term "Metaverse" was first introduced in Neal Stephenson's novel "Snow Crash," where digital avatars were depicted (Lee et al., 2021). The word consists of two components: 'Meta,' meaning beyond, and 'verse,' relating to the universe (Mystakidis, 2022).

There are various definitions of the Metaverse, though no single, universally accepted definition exists. The Metaverse is commonly described as a universe that exists beyond reality, where multiple users can interact in a perpetual and persistent environment that merges the physical world with the digital realm (Mystakidis, 2022). This space represents a novel iteration of the Internet, characterized by the fusion of diverse technologies, and is continuously expanding in scope (Sriram, 2022).

A robust technological and economic infrastructure is essential for the development of the Metaverse. The establishment of Metaverse-related technologies relies on eight pillars: network, edge/cloud computing, artificial intelligence, computer vision, blockchain, robotics/IoT, user interactivity, and extended reality (a combination of VR, AR, and MR). However, creating a Metaverse ecosystem requires six fundamental pillars: avatars, content creation, virtual economy, social acceptability, security and privacy, and trust and accountability. (Lee et al., 2021).

Architecture, engineering, and construction industries, just like other industries, are moving towards the use of new technologies. In modern construction, building information modeling is a new technology that acts as a digital information management system and is highly informative in the industry (Volk, Stengel, & Schultmann, 2014). BIM is described as a process rather than a physical entity or software application. It is referred to as an intelligent emulation of architectural structures, which involves creating a 3D modeling representation of a building with accurate geometry and relevant information to assist in construction, fabrication, and procurement tasks. BIM covers 5D modeling of a building's entire lifecycle, which enables a more cohesive design and construction approach, which results in superior quality structures at a reduced expense and shorter project timeline (Eastman et al., 2011), (Khosrowshahi & Arayici, 2012) and (Zaker & Coloma, 2018).

2. Literature Review

Wang et. al (Wang et al., 2018) reviewed Virtual Reality (VR) studies from 1997 to 2017 in construction engineering training and education (CEET) and categorized these technologies in CEET into five major types: desktop-based VR, immersive VR, 3D game-based VR, BIM-enabled VR and Augmented Reality (AR). The findings indicated that immersive VR, 3D game-based VR, and AR could enhance student participation, interaction, and motivation. Building elements and spatial concepts were efficiently learned and comprehended by students in immersive visual environments using BIM-enabled VR. Le et. al (Le et al., 2015) studied the use of mobile-based VR and AR for construction safety education and developed a framework consisting of three modules: Safety Knowledge Dissemination (SKD), Safety Knowledge Reflection (SKR), and Safety Knowledge Assessment (SKA). The results suggest that this system can effectively improve construction safety and health education. Additionally, students found it easy to use and effective for enhancing construction safety education. Zaker & Coloma (Zaker & Coloma, 2018) presented a case study on the use of VR in a BIM-enabled project collaboration and design review. Simulating on-site tasks has the potential to significantly help the AEC industry. VR has additional benefits such as enhanced visualization, improved collaboration, clash detection, and client engagement. Despite this, there were still challenges that needed to be addressed like software and hardware costs, resistance to change, performance and compatibility issues, and physiological concerns. Wong et al (Wong et al., 2020) developed a BIM-VR framework to enhance engineering education. In a survey conducted by undergraduate civil engineering students, most students felt that their learning experiences were positive and interactive, and they found the use of augmented reality and virtual reality to be advantageous. Yan et al (Yan et al., 2020) in their research created a process that merges computational fluid dynamics (CFD) simulation, BIM, and VR visualization to aid in building design. The potential of combining these technologies to enhance building design and analysis is demonstrated in this study. Alizadehsalehi et al. (Alizadehsalehi, Hadavi, & Huang, 2020) discussed the integration of BIM and Extended Reality (XR) technologies in the AEC industry. The study showed how XR technologies, such as VR, AR, and Mixed Reality (MR), can improve efficiency and productivity in the AEC industry. A case study is provided by the authors to convert a 3D BIM model to VR and MR models for the NASA-Mars habitat project. Alizadehsalehi et al. (Alizadehsalehi, Hadavi, & Huang, 2021) analyzed how AEC students utilized BIM-into-VR technology by analyzing their learning performance, interoperability, visualization, real-world application, interaction, creativity, motivation, and comfort. A model was proposed by them to use BIM-into-VR in design and construction projects, which is based on an integrated definition function model. According to the findings, authentic and interactive educational environments and the use of BIM in real-world projects can enhance students' learning outcomes. Rossado Espinoza et al discussed using VR and BIM as teaching tools in engineering courses compared to traditional teaching methods. The VR-BIM method helped students visualize and analyze plumbing system designs in a creative and innovative manner, according to the results. The suggestion is that integrating VR and BIM in teaching can enhance their learning experience and help create highly skilled future engineers and architects (Rossado Espinoza et al., 2021). Tayeh et al. examined the possible advantages of incorporating BIM and Geographic Information Systems (GIS) MR applications to enhance the online learning process for students studying construction management. It was determined that MR on HoloLens had the most potent effects on enhancing students' spatiotemporal understanding, remote learning experience, communication, and collaboration among teams (Tayeh, Bademosi, & Issa, 2021). In the realm of architecture engineering and construction, Kim et al. presented a framework for evaluating VR applications based on BIM during the project design phase. An educational building project in Hong Kong tested the framework (Kim et al., 2021). Khan et al. carried out a thorough examination of how Immersive Technologies (ImTs) can be integrated BIM in the AEC industry. The use of ImTs was identified in various domains within the AEC industry by this study. The AEC industry has been aided by ImTs with valuable support in design decision-making, analysis of design outcomes, construction planning, monitoring, resource utilization, communications, and training (Khan et al., 2021).

The purpose of this study was to determine the primary parameters required to teach building information modeling using metaverse technology through qualitative meta-synthesis and quantitative methods, based on the literature reviewed.

3. Method

The research method employed in this study is a combination of the meta-synthesis method and a Fuzzy Delphi panel, which is utilized to extract parameters and generate a questionnaire for quantitative analysis.

The qualitative part involved obtaining articles using the meta-synthesis method to extract code from papers and develop a conceptual framework. Then, these identified categories and indicators were prepared in the form of a checklist and submitted to the fuzzy Delphi panel. The group of experts included 15 academic faculty members who were either associate professors or full professors specializing in construction (civil engineering) or IT engineering. Following the implementation of the fuzzy Delphi panel in three rounds, a research questionnaire was designed.

In the qualitative step, questionnaires were distributed and comparison between 300 faculty members and students of construction fields (architecture and civil engineering) to carry out structural equations and determine the relationships between variables by analyzing with SMART PLS. By approving these data, it was possible to propose a model for teaching BIM in Metaverse.

Qualitative Method

A meta-synthesis methodology was applied to synthesize and integrate findings from various studies. The meta-synthesis method was chosen for its ability to yield reliable results and ensure the alignment of high-quality data. This approach was developed by integrating findings from multiple studies and resulting in comprehensive results that would significantly contribute to the parameters that are important in teaching BIM through Metaverse technology.

The meta-synthesis process was structured according to Sandelowski and Barroso's framework, and it consisted of seven steps, as depicted in Figure 1 (Sandelowski & Barroso, 2006). Then the MAXQDA software was utilized for the analysis of the data derived from the meta-synthesis method.

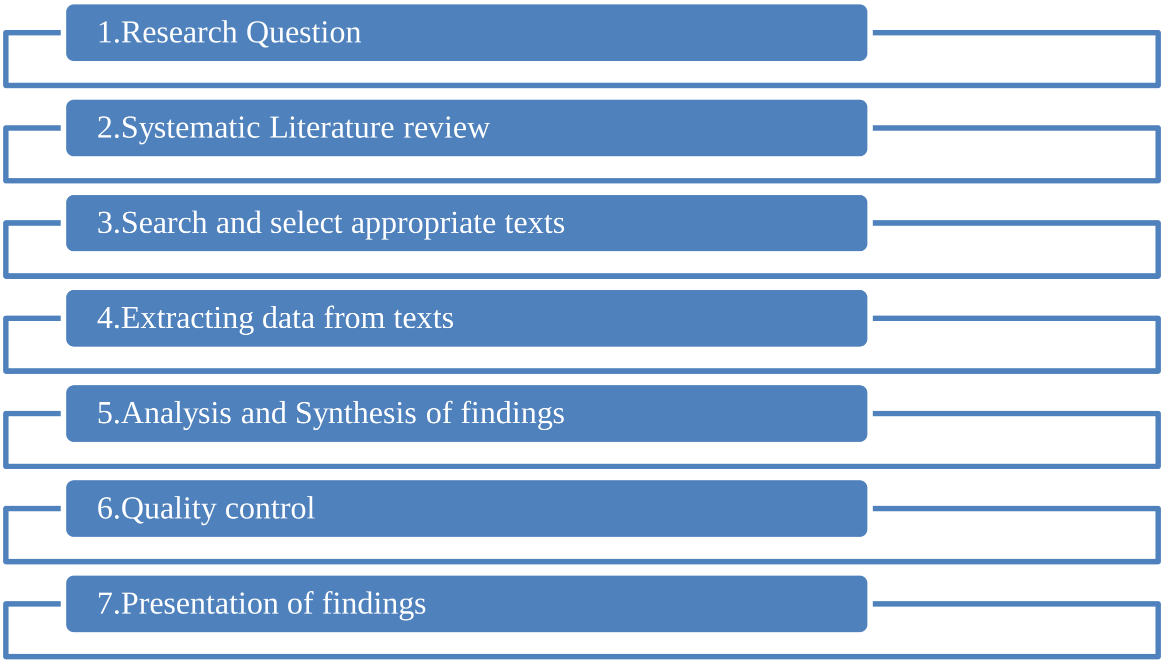

Figure 1. *Seven steps of meta synthesis method*

Research Questions

At this stage, the researchers have addressed the four initial fundamental questions:

What?	Dimensions and influential elements for teaching building information modeling using Metaverse technology.
Who?	Databases, journals, conferences, and diverse search engines.
When?	Between 2013 and 2023.
How?	Document analysis

4. Findings

Systematic Literature Review

Keywords which were used to systematically search for the materials published in different databases with the aim of determining valid and related documents in the appropriate time frame were: Metaverse, Metaverse & Education, Metaverse & BIM & Education, Building information modeling & Education, Virtual reality (VR) & Education, Virtual reality (VR) & Building, Building Information Modeling (BIM), Augmented Reality (AR) & education and Augmented reality (AR) & Building Information Modeling (BIM).

Search and Select Appropriate Texts

In this step, text analysis is conducted, guided by specific criteria for inclusion or exclusion (Yahyapour, Shamizanjani, & Mosakhani, 2015)(Weed, 2006). Utilizing keywords from Building Information Modeling (BIM) and Augmented Reality (AR), articles were collected, followed by a review of titles, abstracts, and content. The Critical Appraisal Skills Program (CASP) was employed to divide the sources into quality categories according to a score range of 0 to 50. Cases that scored less than 21 were excluded from further analysis.

Acceptance criteria for meta-synthesis included using English or Persian as the research language, publishing from 2013 to 2023, and the method of study (qualitative, quantitative-qualitative, and case studies). Different types of studies, including articles, books, thesis, organizational and institutional studies, as well as master's and doctoral dissertations, were taken into consideration. The meticulous process of searching for and selecting relevant articles is depicted in Figure 2 in a visual manner.

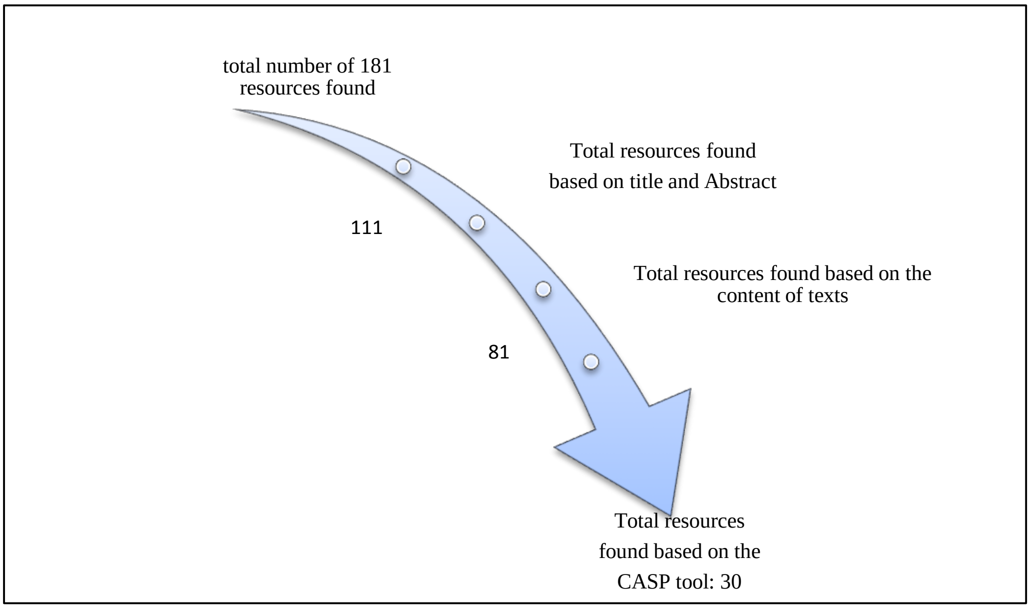

Figure 2. *Process of finding appropriate articles*

Extracting Data from Texts

The concepts and coding were obtained by continuously studying those 30 selected articles throughout the meta-synthesis several times. Context analysis has been employed in this research to analyze and present the final findings of the synthesis.

Analysis and Synthesis of Findings

Context analysis is a method to determine, analyze and express the patterns (contexts) in the data that organizes and describes the data in detail and can even go beyond this and interpret different aspects of the research topic (Thomas, 2003). Descriptive coding was assigned to each data code through contextual analysis. MAXQDA software was utilized to perform these steps. In step 7, the outcomes are displayed.

Quality Control

The meta-synthesis approach emphasizes the importance of quality control in ensuring the success of the process. This study relied on reliable databases to select sources, and any items that did not satisfy the required quality and validity standards were removed from the analysis. Finally, the reliability of the designed model was measured by using the Kappa index. The codes and concepts created by the researcher have been classified into concepts by another expert (who is blind of the of how to integrate them). Subsequently, the concepts offered by the researcher were compared with those offered by this expert. Then, the Kappa index has been determined by the number of concepts that are similar and different. The Kappa index was determined to be 0.696, which is equivalent to the level of valid agreement (Odibat & Eyadah, 2023).

Presentation of Findings

Table 1 displays a total of 82 indicators that were categorized into 9 categories, representing the results of all 6 previous steps.

Table 1. *Codes that were derived from the meta-synthesis method.*

Categories	Indicators	References
1.Environmental configuration	Business environment	(Valipour, 2021)
	The dynamics of the environment	(Le et al., 2015), (Khudhair et al., 2021)
	Unexpected situations	(Shahmoradi, 2023)
	Visualization of complex 3D models	(Yan et al., 2020), (Shore et al., 2023)
	Transformation in space and expectations	(Khudhair et al., 2021), (Goodarzi, 2022)
	The post-reality world	(Awlian & Esmaeili, 2022), (Shafie, 2022)
	The existence of an integrated management approach	(Alizadehsalehi, Hadavi, & Huang, 2020), (Khan et al., 2021), (Khudhair et al., 2021)
2. Technology data and information	Data and information sharing	(Khudhair et al., 2021)
	Entry risks	(Sanjana, 2023)
	Graphical and non-graphical data	(Khan et al., 2021)
3.Education technology infrastructures	Solving technological challenges	(Valipour, 2021)
	Network communications	(Valipour, 2021)
	Development of capacity and resources	(Valipour, 2021)
	Development of knowledge network	(Valipour, 2021)
	Learning process and content	(Valipour, 2021), (Alizadehsalehi, Hadavi, & Huang, 2021)
	Cost and investment required	(Goodarzi, 2022), (Zaker & Coloma, 2018)
	Development of technological learning	(Chamorro-Atalaya et al., 2023), (Valipour, 2021)
	Removing the limitation of web-based education	(Tan et al., 2022), (Shafie, 2022), (Pourmohammadbagher & Safarabadi, 2023)
	Removing the limitation of physical presence in the class	(Siyaev & Jo, 2021), (Koo, 2021), (Shafie, 2022)
	Removing the limitations of the boundaries of social communication and learning	(Abi Aufa & Anisah, 2023), (Shafie, 2022), (Dahan et al., 2022)
	Hardware and software limitations	(Tan et al., 2022), (Shahmoradi, 2023)
	The need for an advanced electronic structure	(Le et al., 2015), (Choi et al., 2022), (Valipour, 2021), (Goodarzi, 2022)
	The need for technological infrastructure in education	(Koo, 2021), (Odibat & Eyadah, 2023), (Abi Aufa & Anisah, 2023), (Goodarzi, 2022)
4. The team capacity	Behavioral conflicts	(Asiksoy, 2023)
	Interoperability	(Alizadehsalehi et al., 2021)
	Personality traits	(Sanjana, 2023)
	Performance of inspectors	(Shahmoradi, 2023)
	Professional development of teachers at all levels	(Valipour, 2021), (Awlian & Esmaeili, 2022)
	Informed decision making	(Kim et al., 2021)
	Attitude and understanding	(Alizadehsalehi et al., 2021), (Khudhair et al., 2021), (Yang et al., 2022a)
	The need to develop human skills	(Alizadehsalehi et al., 2021), (Chamorro-Atalaya et al., 2023), (Shahmoradi, 2023), (Goodarzi, 2022), (Odibat & Eyadah, 2023)
5. Socio-cultural factors	Resolving institutional conflicts	(Valipour, 2021)
	Resolving cultural conflicts	(Valipour, 2021)
	Social influence	(Shahmoradi, 2023)
	Cultural necessities	(Valipour, 2021)
	Necessities of governance	(Valipour, 2021)
	Cultural growth	(Valipour, 2021)
	Development of intercultural strategies	(Valipour, 2021)
	Strategies for monitoring the learning environment	(Valipour, 2021)
	Control and supervision	(Khan et al., 2021), (Siyaev & Jo, 2021), (Shahmoradi, 2023)
	Development of education strategies	(Wong et al., 2020), (Valipour, 2021), (Odibat & Eyadah, 2023)

	The need for extensive learning of new technologies	(Asiksoy, 2023), (Khan et al., 2021), (Abi Aufa & Anisah, 2023), (Zaker & Coloma, 2018), (Goodarzi, 2022)
6. Behavioral factors	Participation	(Shahmoradi, 2023)
	Resistance to acceptance	(Zaker & Coloma, 2018)
	Habit	(Yang, Ren, & Gu, 2022)
	Gender	(Yang, Ren, & Gu, 2022)
	User sentiments	(Shahmoradi, 2023)
7. Applied Technologies	Avatars	(Valipour, 2021), (Asiksoy, 2023)
	Mixed reality	(Valipour, 2021), (Asiksoy, 2023)
	Virtual reality	(Yan et al., 2020), (Chamorro-Atalaya et al., 2023), (Goodarzi, 2022)
	Metaverse technology	(Asiksoy, 2023), (Dahan et al., 2022), (Pourmohammadbagher & Safarabadi, 2023), (Shafie, 2022)
	Using different media	(Asiksoy, 2023), (Zaker & Coloma, 2018), (Sanjana, 2023)
	Augmented reality technology	(Tan et al., 2022), (Asiksoy, 2023), (Shore et al., 2023), (Siyaev & Jo, 2021), (Goodarzi, 2022), (Awlian & Esmaeili, 2022)
	Digital technological tools	(Le et al., 2015), (Fernandes, 2023), (Yan et al., 2020), (Asiksoy, 2023), (Liu et al., 2023),(Pourmohammadbagher & Safarabadi, 2023), (Shafie, 2022)
8. Functional results	High scalability	(Choi et al., 2022)
	Quality of education	(Kim et al., 2021)
	Improving design quality	(Kim et al., 2021)
	Correspondence training	(Yang, Ren, & Gu, 2022)
	Remote vision	(Shahmoradi, 2023)
	The possibility of online distance learning	(Shahmoradi, 2023)
	Profit	(Sanjana, 2023), (Shahmoradi, 2023)
	Combined active training	(Shahmoradi, 2023), (Wong et al., 2020), (Goodarzi, 2022)
	Improve real-world experience	(Alizadehsalehi, Hadavi, & Huang, 2021), (Wong et al., 2020), (Choi et al., 2022), (Asiksoy, 2023),(Pourmohammadbagher & Safarabadi, 2023) ,(Chamorro-Atalaya et al., 2023), (Awlian & Esmaeili, 2022)
9. Practical features	Access	(Choi et al., 2022)
	Convenience	(Alizadehsalehi, Hadavi, & Huang, 2021)
	Motivation	(Alizadehsalehi, Hadavi, & Huang, 2021)
	Design exploration	(Khan et al., 2021)
	Design speed	(Shore et al., 2023)
	Confidence in design	(Shore et al., 2023)
	Accuracy of design	(Shore et al., 2023)
	Building design	(Shore et al., 2023)
	Feasibility of implementation	(Shahmoradi, 2023)
	Creativity	(Ayiter, 2012), (Alizadehsalehi, Hadavi, & Huang, 2021)
	Design analysis	(Kim et al., 2021), (Khan et al., 2021)
	Safety	(Le et al., 2015), (Kim et al., 2021)
	Building information modeling	(Yan et al., 2020), (Zaker & Coloma, 2018)
	Activity in any place and time	(Pourmohammadbagher & Safarabadi, 2023), (Shahmoradi, 2023)
	Maintaining security	(Shahmoradi, 2023)
	Flexibility	(Ayiter, 2012), (Kim et al., 2021)
	Planning	(Wong et al., 2020), (Alizadehsalehi, Hadavi, & Huang, 2021), (Khan et al., 2021)
	Improving links and communications	(Siyaev & Jo, 2021), (Abi Aufa & Anisah, 2023), (Awlian & Esmaeili, 2022)
	Ease of visualization	(Alizadehsalehi, Hadavi, & Huang, 2021), (Yan et al., 2020), (Alizadehsalehi, Hadavi, & Huang, 2020), (Shore et al., 2023)

Fuzzy Delphi Method:

While experts employ their mental skills and abilities to compare, it should be noted that the traditional method of quantifying people's views cannot completely capture the human thinking style. To put it differently, fuzzy sets are a better match for linguistic and sometimes unclear human explanations. Therefore, fuzzy sets (using fuzzy numbers) are the preferred method for making long-term predictions and making decisions in the real world.

The indicators were monitored using the Fuzzy approach based on the opinion of 15 experts in AEC and IT fields. The Fuzzy Delphi method was used twice to approve all indicators, and the results are shown in Appendix. The significant parameters that are influencing the teaching of BIM in Metaverse can be seen in Figure 3.

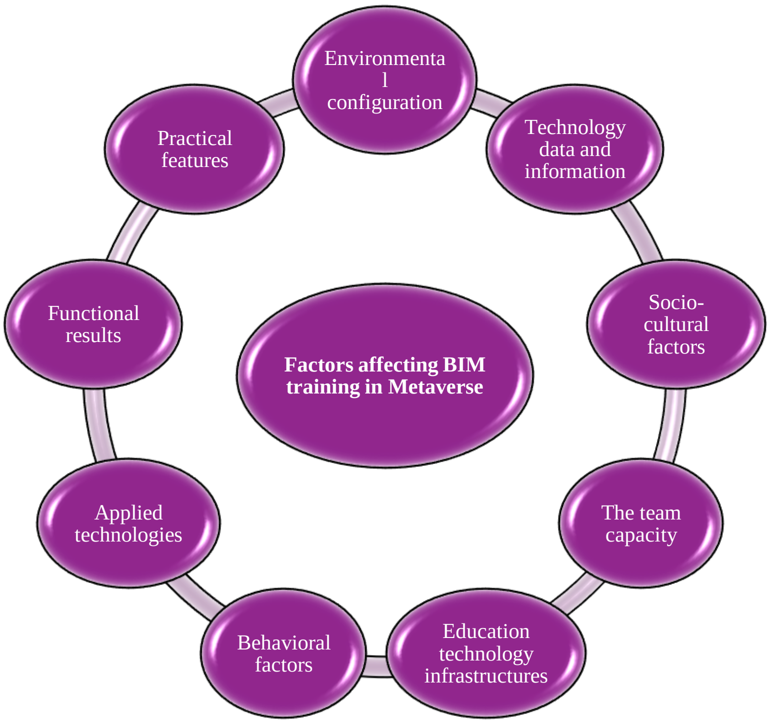

Figure 3. *Conceptual model of parameters for BIM, training in Metaverse*

Quantitative Section

Validation and analysis were performed on the questionnaire that was generated by categories and indicators and distributed to the statistical society during this period. There were 163 male and 137 female members in the statistical society, with 28% holding master's degrees and 72% holding PhD degrees, and there were diverse age groups.

The Kolmogorov-Smirnov normality test has been taken to check the normal distribution of data. The data showed a P-value below 0.05, indicating that our variables do not have a normal distribution in our population. Smart Pls is the most effective way to run our model in this situation.

The research model has been validated through the use of the partial least squares technique. Typically, structural equation modeling involves two components: the measurement model and the structural model, and the model variables are classified as latent and manifest variables.

Assessing Measurement Model Fit

In order to evaluate the suitability of the measurement model, the research utilized three parameters: reliability, convergent validity, and discriminant validity.

Reliability:

The model's internal consistency was measured by assessing its reliability, that was measured using factor loading coefficients (first order), Cronbach's Alpha, and composite reliability (CR). Factor loading coefficients should be greater than 0.4, and Cronbach's alpha and CR should be greater than 0.7 to indicate acceptable reliability. Table 2 shows that all dimensions of the model under study have composite reliability coefficient values and Cronbach's beta values greater than 0.7. It can be concluded that the questionnaire is reliable.

Table 2. *Reliability factors*

Variable	Cronbach's Alpha	CR
Technology data and information	0.955	0.971
Education technology infrastructures	0.919	0.932
The team capacity	0.913	0.931
Socio-cultural factors	0.932	0.942
Behavioral factors	0.817	0.873
Applied Technologies	0.857	0.893
Functional results	0.895	0.916
Practical features	0.964	0.968
Environmental configuration	0.851	0.887

Validity

Validity is achieved when test questions accurately measure their intended purpose. When one or more characteristics are measured by two or more methods, the correlation between these measurements provides two important indicators of validity: convergent validity and discriminant validity, which are used to validate the questionnaire study.

Convergent Validity:

High correlation between test scores that measure a single characteristic indicates that the questionnaire has convergent validity. For convergent validity, Average Variance Extraction (AVE) and Composite Reliability (CR) are calculated. If AVE is greater than 0.5 and CR is greater than 0.7, then there is convergent validity. Moreover, CR must surpass AVE. As can be seen in Table 3, the AVE value is always greater than 0.5, and the composite reliability (CR) value is also greater than 0.7 in all cases, which is also greater than the AVE value; therefore, convergent validity is confirmed.

Table 3. *Convergent Validity*

Variable	AVE	CR
Technology data and information	0.917	0.971
Education technology infrastructures	0.518	0.932
The team capacity	0.633	0.931
Socio-cultural factors	0.597	0.942
Behavioral factors	0.582	0.873
Applied Technologies	0.551	0.893
Functional results	0.551	0.916
Practical features	0.627	0.968
Environmental configuration	0.531	0.887

Discriminant Validity:

Discriminant validity is the measure's ability to distinguish between different concepts and avoid measuring irrelevant constructs. To evaluate discriminant validity, we utilized Fornell and Larcker and the Heterotrait-Monotrait Ratio (HTMT) Criteria.

Fornell and Larcker's criteria:

If the correlation between tests that measure different characteristics is low, the tests have diagnostic or discriminant validity. Discriminant validity involves comparing the differences between the indicators of one construct and the indicators of other constructs in the model. The square root of the AVE of each construct and the values of the correlation coefficients between the constructs are compared for this calculation. For this purpose, a matrix must be formed in which the diagonal elements of the matrix are the square roots of the AVE coefficients of each construct and the elements below the diagonal are the correlation coefficients between each construct and the other constructs. Table 4 displays this matrix.

Table 4. *Fornell and Larcker validity*

Variable	1	2	3	4	5	6	7	8	9
Technology data and information	0.958								
Education technology infrastructures	0.492	0.720							
The team capacity	0.515	0.571	0.796						
Socio-cultural factors	0.551	0.448	0.428	0.773					
Behavioral factors	0.562	0.635	0.577	0.459	0.763				
Applied Technologies	0.583	0.471	0.748	0.501	0.535	0.742			
Functional results	0.327	0.237	0.405	0.316	0.482	0.304	0.742		
Practical features	0.668	0.555	0.565	0.523	0.637	0.675	0.380	0.792	
Environmental configuration	0.613	0.497	0.453	0.546	0.634	0.529	0.315	0.718	0.728

In Table 4, each column displays the square root of the AVE of each construct greater than the correlation coefficients of the other constructs. This implies that the construct discriminant validity is acceptable.

Heterotrait-Monotrait Ratio (HTMT) Criterion:

The Heterotrait-Monotrait Ratio (HTMT) is a new method for assessing discriminant validity in partial least squares (PLS) structural equation modeling. The HTMT criterion is the ratio of the geometric mean to the average of the correlations of the indicators within the same construct. The HTMT calculation begins by estimating the average correlation between the indicators (observed variables) in every construct. Next, the geometric mean of these correlations is computed. The geometric mean is then divided by the average correlation among all indicators in the model. The HTMT criterion clearly outperforms classical approaches to assessing discriminant validity, such as the Fornell-Larcker criterion. The HTMT criterion is a valuable tool for assessing discriminant validity in PLS-SEM. It is a more robust and reliable measure than traditional methods, and it can help researchers ensure that their measures are distinct from each other and adequately capture the intended constructs. If the HTMT value is less than 0.90, discriminant validity between two reflective constructs is confirmed. This matrix is shown in Table 5.

Table 5. *HTMT Criterion*

Variable	1	2	3	4	5	6	7	8	9
Technology data and information									
Education technology infrastructures	0.524								
The team capacity	0.550	0.626							
Socio-cultural factors	0.584	0.479	0.463						
Behavioral factors	0.636	0.735	0.672	0.524					
Applied Technologies	0.643	0.526	0.843	0.558	0.642				
Functional results	0.342	0.252	0.441	0.349	0.554	0.339			
Practical features	0.698	0.592	0.602	0.553	0.720	0.743	0.408		
Environmental configuration	0.677	0.567	0.509	0.612	0.756	0.611	0.351	0.797	

As can be seen in Table 5, this criterion is below 0.90 for all constructs in the model, which is confirmed.

Based on the evidence presented, it can be concluded that the measurement model has both acceptable convergent and discriminant validity. This means that the questionnaire is a valid tool for measuring the concepts of interest. The results validated the measurement model and suggested that the constructs are adequately measured and represented by the observed variables.

Structural Equation Modelling (SEM)

After assessing the validity and reliability of the measurement model, the structural model was evaluated through the relationships between the latent variables. For this assessment, Variance Inflation Factor (VIF), R-Squared (R^2), Effect Size Measure (f^2), Predictive Power Measure (Q^2) and Second-Order Factor Loadings Test have been used. In order to evaluate the importance of the relationships, bootstrapping was utilized to calculate the t-statistic, which is shown in figure 4 along with Second-Order Factor Loadings. A significant correlation between the observed variables and the corresponding second-order latent variable can be seen if the bootstrapping value (t-statistic) exceeds the critical value of 1.96. Thus, it can be inferred that the latent variable has been adequately measured. According to the description, it appears that the second-order factor loadings in the PLS-SEM model were properly evaluated and found to be statistically significant. This supports the conclusion that the latent variables are adequately measured by the observed variables.

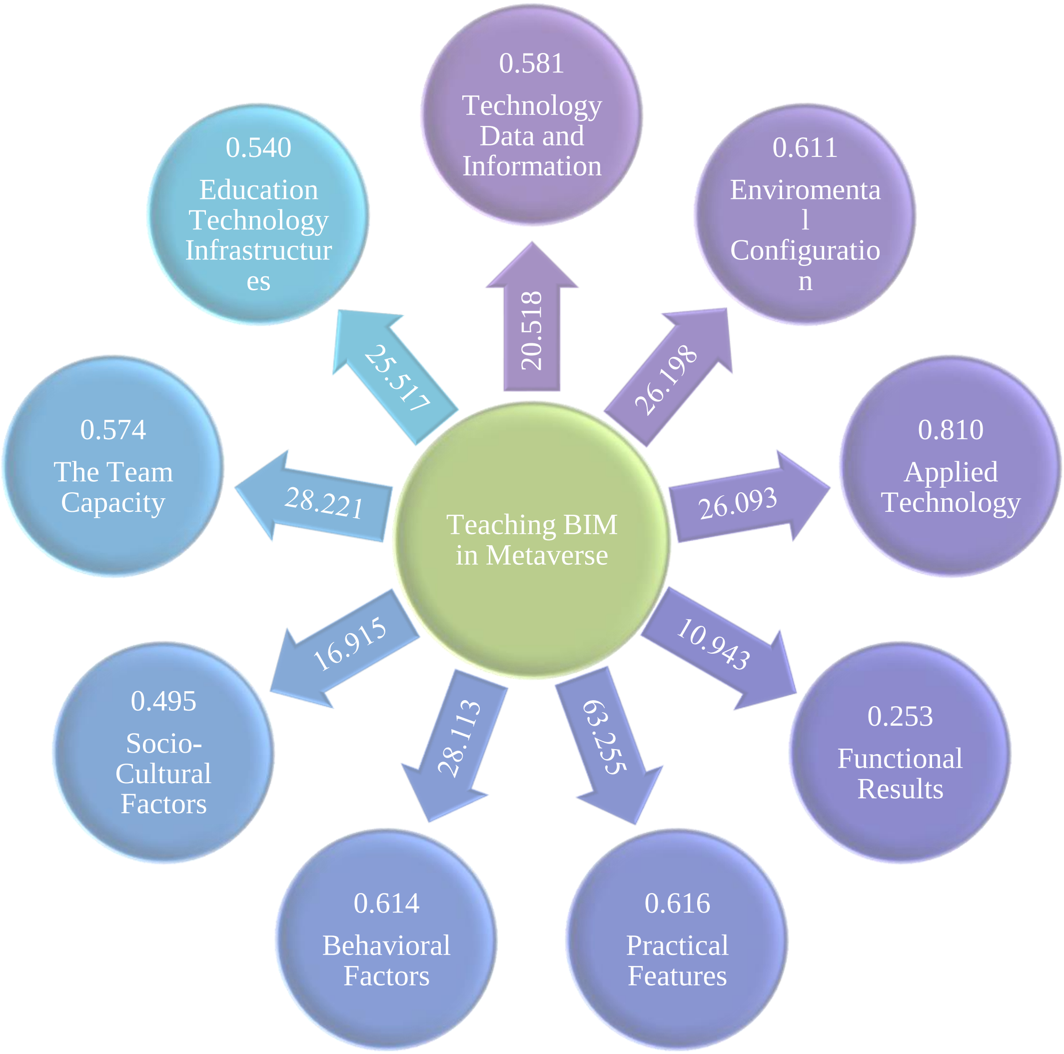

Figure 4. *t-statistic and second-order factor*

As it has been shown, there is a significant relationship between the latent and manifest variables of the research, and the initial conceptual model is fully supported based on coefficients such as second-order factor loadings, t-statistics, and other factors. Figure 5 shows the full relationship between all categories and indicators.

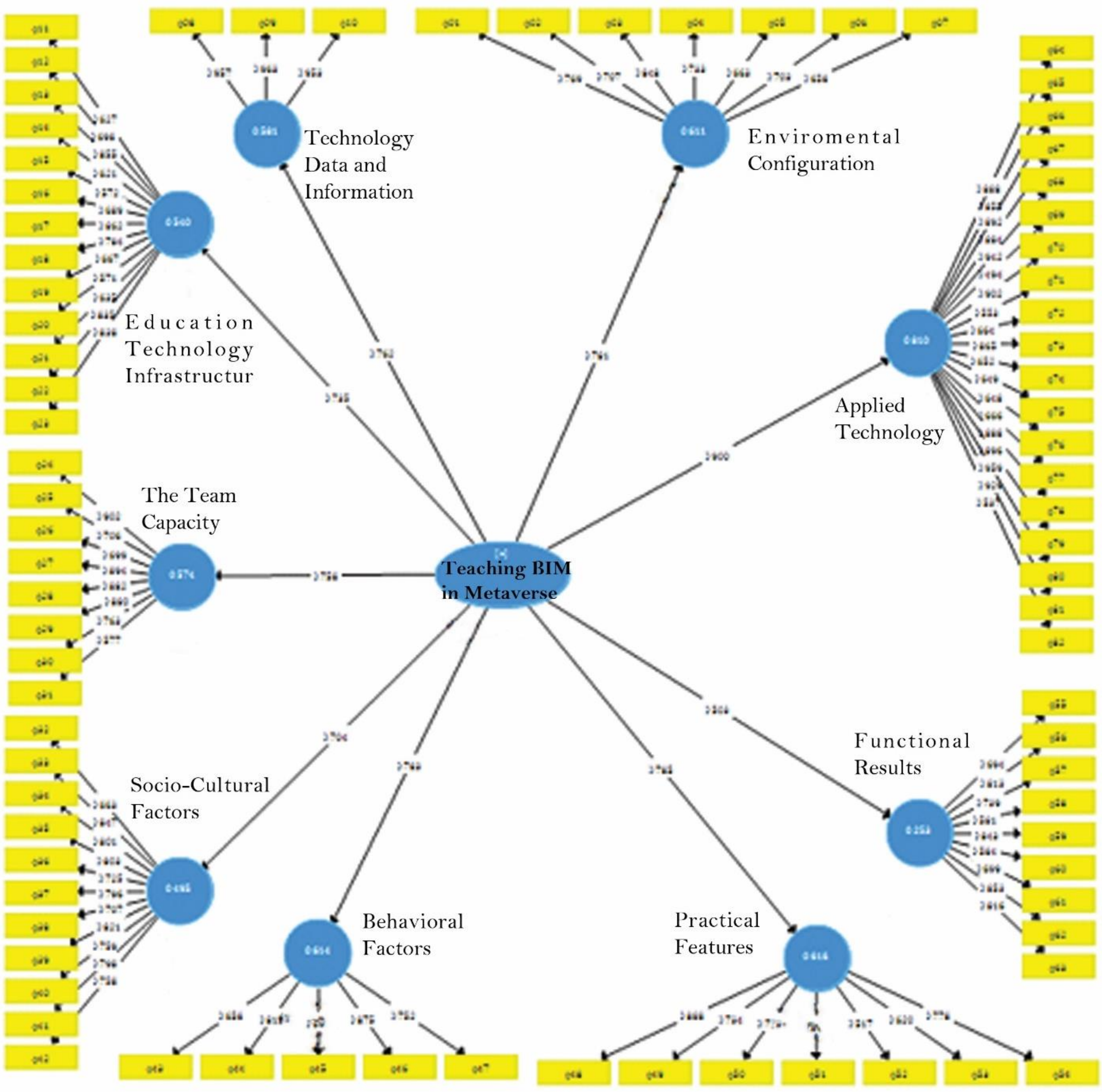

Figure 5. Full relationship between variables

Proposed Model:

Based on the findings in previous analysis, we have proposed a model for training BIM in the metaverse which is shown in Figure 6.

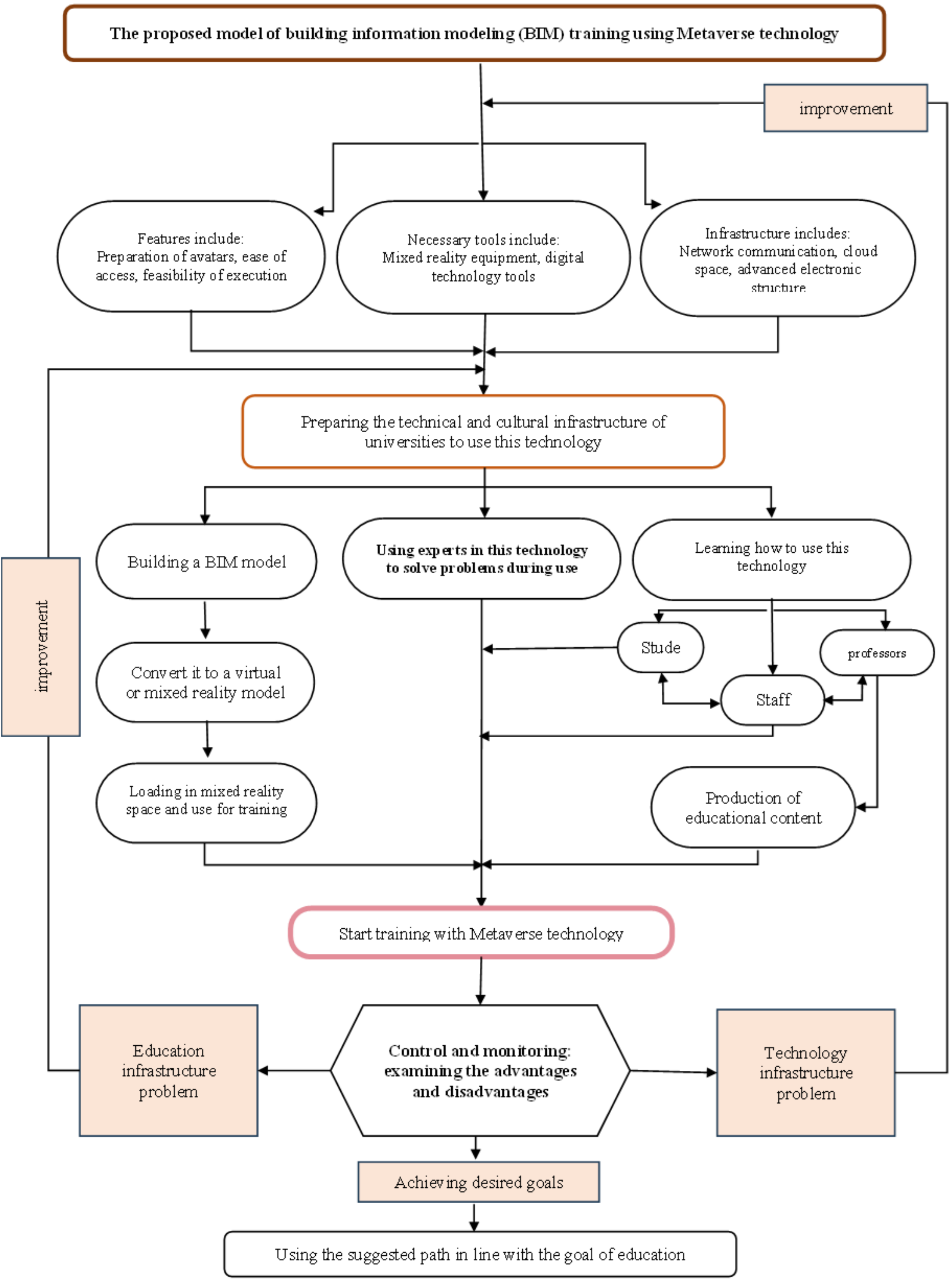

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Figure 6.*Sttudy proposed model*

As depicted in Figure 6, to apply the proposed model, there is a need to pass some steps:

Step 1: Technological Infrastructure

The initial step involves establishing the requisite technological infrastructure, which encompasses:

- Advanced electronic structures
- Network communication development
- A suitable metaverse cloud environment
- Robust internet connectivity
- Procurement of essential equipment, including VR & AR headsets and other necessary hardware
- Preparation of appropriate avatars

- Development of user-friendly and executable platforms

Step 2: Prepare Universities for Metaverse Adoption

The subsequent step entails preparing universities' technical and cultural infrastructures for the adoption of this technology. This preparation encompasses:

- Organizing workshops and classes to familiarize faculty, students and staff with the rationale behind employing this technology, its functionalities, operating within the metaverse environment, and utilization of the associated tools.
- Ensuring the availability of specialized personnel to address any technical issues that may arise during implementation.

Step 3: Prepare BIM Models for Metaverse Integration

Given the objective of teaching BIM within the metaverse, it is crucial to:

- Prepare BIM models using software such as Revit
- Convert these BIM models into virtual reality models using software like Unity
- Upload these converted models into the metaverse platform utilization

Step 4: Conduct Immersive Learning Sessions

Once the preceding steps have been completed, the following phase involves:

- Faculty and students accessing the established metaverse platform using the provided equipment, including augmented reality headsets and personalized avatars
- Engaging in active learning activities within the metaverse environment, utilizing the prepared educational content to effectively teach the desired subjects

Step 5: Evaluate and Refine the Metaverse Learning Experience

Following each learning session, it is recommended to:

- Critically evaluate the advantages and disadvantages of conducting classes within the metaverse environment
- Identify and address any technical or educational infrastructure-related issues
- Continuously refine and enhance the metaverse-based BIM education experience based on feedback and observed successes

By adhering to this structured approach, universities can effectively integrate BIM education into the metaverse, fostering an immersive and engaging learning experience for students while simultaneously advancing their technological capabilities.

5. Conclusion

Integrating metaverse technology into BIM training holds immense potential for transforming the learning experience. By addressing the various challenges and capitalizing on the numerous benefits, universities can create a more accessible, flexible, and engaging learning environment for future generations of BIM professionals. The metaverse provides a gateway to a world of possibilities, where students can collaborate, explore, and learn without limitations, shaping the future of BIM training and the construction industry as a whole.

According to the categories and indicators obtained from this research, it can be seen that there are many factors for training the metaverse world, and these factors can be reduced or increased by adding other studies. In relation to the practical features of Metaverse for teaching building information modeling, due to the easy access to the classroom space, the possibility of being present at any place and time, and creating personal planning, students will feel more comfortable, motivated and flexible. This can create discovery, speed, confidence and precision in students' construction designs. Along with increasing students' creativity, visualization and analysis. Designs with safety and feasibility of implementation is another advantage of this method.

Jumping into this 3D parallel world requires high-speed Internet along with series of applied technologies such as MR, VR and AR which all needs related glasses and gloves to enter their space. Having your own avatar is another requirement, so it is necessary to prepare or train how to create one of them via available technologies. In technological infrastructure aspect is important to investing to upgrade advanced electronic infrastructures for the development of network communications and technological learning. There should be no limitation in accessing education in the Metaverse. Furthermore, necessary training needs to be given to each individual before using it. Thus, they expand the boundaries of social communication and learning.

Creating special content is necessary to teach in this technology. These data can be graphical or non-graphical. For example, in order to teach BIM, it is necessary to create a 3D model with related software such as Revit, and then convert it by Unity engine to be able to use in Metaverse.

Environmental configuration is another effective factor that helps students and professors to experience the post-reality world and different and unexpected situations, like, the virtual destruction of a building, based on wrong design. This dynamic environment with its integrated approach helps students understand complex 3D models, search in that space and meet their mental expectations.

Team capacity as another category determines that each person characteristics and their tendency to use this technology. For example, a large group of professors and students may not have much desire or sufficient knowledge regarding the use of new technologies in the field of education, so there is a need to increase human skills, attitudes and awareness in this regard. On the other hand, not only the professors should receive the necessary training to teach in this space, but also the students should be familiar with interacting in this space, learning, and cooperating with other students and professors in order to make informed decisions. In addition to this, behavioral factors state the requirement to prevent the resistance to acceptance and participate in this 3D virtual world. It can be said that the gender and emotions of users can also be effective in learning and how to interact with each other and teaching.

The category of socio-cultural factors generally refers to the factors of resolving institutional conflicts, resolving cultural conflicts, social influence, cultural necessities, governance necessities, cultural growth, development of cross-cultural strategies, strategies for the learning environment, control and supervision, development of education strategies and the need for extensive learning of technology. By familiarity with the world's up-to-date teaching patterns, students and professors can use the most up-to-date classes in the world, with students and universities, interact and benefit from their knowledge and even gain new cultural experiences.

Education in the metaverse has its own unique features. Students can watch, experience and learn closely the components of a building at a very high scale, which will result in high quality of education and also high quality of future designs and executive works of students. On the other hand, this non-attendance and distance education gives students the possibility to access the education from anywhere in the world. Also, this space will give professors the possibility of combined active training and the possibility of improving the real-world experience for students. Finally, in terms of cost, there are several dimensions, such as reducing the costs of forming face-to-face classes, travel costs for special educational learning to another city or country, or the cost and risk of high-risk training, such as the wrong design of a structure, checking the destruction of a structure, the effects of earthquakes, floods, etc., or the simulation of crisis conditions.

The findings of this research have important practical implications in civil industry. As BIM cause to facilitate design reviews with project stakeholders and also its simulation process helps to identify potential problems before construction begins, teaching this important method in metaverse world can make it easier for students and engineers to understand it. On the other hand, it can boost the construction industry in different aspects in all the countries through participating of constructors, architectures and all related engineers in various fields by sharing their ideas and minds besides training via this parallel 3D world.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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Here we attached the table of results of the two rounds of fuzzy Delphi method due to answer of the experts.

Table 6. *Fuzzy Delphi round 1 result*

Indicator	Mean	geomean	Max	Mean	Crisp	Result
Business environment	6	8.06	9	(6, 8.06, 9)	7.87	Accepted
The dynamics of the environment	6	7.73	9	(6, 7.73, 9)	7.65	Accepted
Unexpected situations	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Visualization of complex 3D models	6	7.45	9	(6, 7.45, 9)	7.48	Accepted
Transformation in space and expectations	6	7.32	9	(6, 7.32, 9)	7.44	Accepted
The post-reality world	6	8.26	9	(6, 8.26, 9)	8.01	Accepted
The existence of an integrated management approach	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Data and information sharing	6	7.71	9	(6, 7.71, 9)	7.64	Accepted
Entry risks	6	7.91	9	(6, 7.91, 9)	7.78	Accepted
Graphical and non-graphical data	6	8.48	9	(6, 8.48, 9)	8.15	Accepted
Solving technological challenges	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Network communications	6	7.71	9	(6, 7.71, 9)	7.64	Accepted
Development of capacity and resources	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Development of knowledge network	5	7.24	9	(5, 7.24, 9)	7.16	Accepted
Learning process and content	6	8.13	9	(6, 8.13, 9)	7.92	Accepted
Cost and investment required	6	8.12	9	(6, 8.12, 9)	7.91	Accepted
Development of technological learning	6	8.05	9	(6, 8.05, 9)	7.87	Accepted
Removing the limitation of web-based education	6	8.55	9	(6, 8.55, 9)	8.20	Accepted
Removing the limitation of physical presence in the class	6	8.19	9	(6, 8.19, 9)	7.96	Accepted
Removing the limitations of the boundaries of social communication and learning	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Hardware and software limitations	6	7.91	9	(6, 7.91, 9)	7.78	Accepted
The need for an advanced electronic structure	6	7.32	9	(6, 7.32, 9)	7.44	Accepted
The need for technological infrastructure in education	6	7.45	9	(6, 7.45, 9)	7.48	Accepted
Behavioral conflicts	4	8.29	9	(4, 8.29, 9)	7.69	Accepted
Interoperability	6	7.94	9	(6, 7.94, 9)	7.79	Accepted
Personality traits	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Performance of inspectors	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Professional development of teachers at all levels	6	7.20	9	(6, 7.2, 9)	7.40	Accepted
Informed decision making	6	7.32	9	(6, 7.32, 9)	7.44	Accepted
Attitude and understanding	6	7.39	9	(6, 7.39, 9)	7.46	Accepted
The need to develop human skills	6	7.14	9	(6, 7.14, 9)	7.38	Accepted
Resolving institutional conflicts	5	7.57	9	(5, 7.57, 9)	7.38	Accepted
Resolving cultural conflicts	5	7.19	9	(5, 7.19, 9)	7.12	Accepted
Social influence	6	8.12	9	(6, 8.12, 9)	7.91	Accepted
Cultural necessities	4	7.41	9	(4, 7.41, 9)	7.11	Accepted
Necessities of governance	6	7.45	9	(6, 7.45, 9)	7.48	Accepted
Cultural growth	6	7.71	9	(6, 7.71, 9)	7.64	Accepted

Development of intercultural strategies	6	7.32	9	(6, 7.32, 9)	7.44	Accepted
Strategies for monitoring the learning environment	6	7.92	9	(6, 7.92, 9)	7.78	Accepted
Control and supervision	6	7.51	9	(6, 7.51, 9)	7.51	Accepted
Development of education strategies	5	7.04	9	(5, 7.04, 9)	7.03	Accepted
The need for extensive learning of new technologies	6	7.91	9	(6, 7.91, 9)	7.78	Accepted
Participation	6	7.32	9	(6, 7.32, 9)	7.44	Accepted
Resistance to acceptance	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Habit	6	7.45	9	(6, 7.45, 9)	7.48	Accepted
Gender	6	7.39	9	(6, 7.39, 9)	7.46	Accepted
User sentiments	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Avatars	6	7.45	9	(6, 7.45, 9)	7.48	Accepted
Mixed reality	6	8.26	9	(6, 8.26, 9)	8.01	Accepted
Virtual reality	6	8.12	9	(6, 8.12, 9)	7.91	Accepted
Metaverse technology	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Using different media	6	7.85	9	(6, 7.85, 9)	7.73	Accepted
Augmented reality technology	6	7.71	9	(6, 7.71, 9)	7.64	Accepted
Digital technological tools	6	7.45	9	(6, 7.45, 9)	7.48	Accepted
High scalability	6	7.71	9	(6, 7.71, 9)	7.64	Accepted
Quality of education	6	7.78	9	(6, 7.78, 9)	7.69	Accepted
Improving design quality	3	8.23	9	(3, 8.23, 9)	7.48	Accepted
Correspondence training	6	7.98	9	(6, 7.98, 9)	7.82	Accepted
Remote vision	3	7.81	9	(3, 7.81, 9)	7.21	Accepted
The possibility of online distance learning	5	7.22	9	(5, 7.22, 9)	7.15	Accepted
Profit	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Combined active training	6	7.78	9	(6, 7.78, 9)	7.69	Accepted
Improve real-world experience	6	7.78	9	(6, 7.78, 9)	7.69	Accepted
Access	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Convenience	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Motivation	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Design exploration	6	8.00	9	(6, 8, 9)	7.84	Accepted
Design speed	6	8.06	9	(6, 8.06, 9)	7.87	Accepted
Confidence in design	7	8.57	9	(7, 8.57, 9)	8.38	Accepted
Accuracy of design	6	8.00	9	(6, 8, 9)	7.84	Accepted
Building design	6	8.28	9	(6, 8.28, 9)	8.02	Accepted
Feasibility of implementation	6	8.20	9	(6, 8.2, 9)	7.97	Accepted
Creativity	6	7.73	9	(6, 7.73, 9)	7.65	Accepted
Design analysis	6	8.28	9	(6, 8.28, 9)	8.02	Accepted
Safety	6	7.99	9	(6, 7.99, 9)	7.83	Accepted
Building information modeling	6	8.41	9	(6, 8.41, 9)	8.11	Accepted
Activity in any place and time	5	8.26	9	(5, 8.26, 9)	7.84	Accepted
Maintaining security	6	8.28	9	(6, 8.28, 9)	8.02	Accepted
Flexibility	4	7.93	9	(4, 7.93, 9)	7.46	Accepted
Planning	6	7.93	9	(6, 7.93, 9)	7.78	Accepted
Improving links and communications	4	7.43	9	(4, 7.43, 9)	7.12	Accepted
Ease of visualization	6	8.07	9	(6, 8.07, 9)	7.88	Accepted

Table 7. *Fuzzy Delphi round 2 result*

Indicator	Mean	geomean	Max	Mean	Crisp	Result
Business environment	6	7.95	9	(6, 7.95, 9)	7.80	Accepted
The dynamics of the environment	6	7.71	9	(6, 7.71, 9)	7.64	Accepted
Unexpected situations	6	7.99	9	(6, 7.99, 9)	7.82	Accepted
Visualization of complex 3D models	7	8.55	9	(7, 8.55, 9)	8.36	Accepted
Transformation in space and expectations	7	8.55	9	(7, 8.55, 9)	8.36	Accepted
The post-reality world	7	8.76	9	(7, 8.76, 9)	8.51	Accepted
The existence of an integrated management approach	4	7.62	9	(4, 7.62, 9)	7.25	Accepted
Data and information sharing	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Entry risks	6	7.51	9	(6, 7.51, 9)	7.51	Accepted
Graphical and non-graphical data	6	7.24	9	(6, 7.24, 9)	7.41	Accepted
Solving technological challenges	6	7.67	9	(6, 7.67, 9)	7.61	Accepted
Network communications	6	7.80	9	(6, 7.8, 9)	7.70	Accepted
Development of capacity and resources	6	7.89	9	(6, 7.89, 9)	7.76	Accepted
Development of knowledge network	6	7.65	9	(6, 7.65, 9)	7.60	Accepted
Learning process and content	6	8.04	9	(6, 8.04, 9)	7.86	Accepted
Cost and investment required	6	7.93	9	(6, 7.93, 9)	7.79	Accepted
Development of technological learning	6	8.17	9	(6, 8.17, 9)	7.94	Accepted
Removing the limitation of web-based education	6	8.40	9	(6, 8.4, 9)	8.10	Accepted
Removing the limitation of physical presence in the class	6	8.01	9	(6, 8.01, 9)	7.84	Accepted

Removing the limitations of the boundaries of social communication and learning	6	7.63	9	(6, 7.63, 9)	7.58	Accepted
Hardware and software limitations	6	7.54	9	(6, 7.54, 9)	7.52	Accepted
The need for an advanced electronic structure	6	8.01	9	(6, 8.01, 9)	7.84	Accepted
The need for technological infrastructure in education	5	8.25	9	(5, 8.25, 9)	7.83	Accepted
Behavioral conflicts	6	8.65	9	(6, 8.65, 9)	8.26	Accepted
Interoperability	6	8.01	9	(6, 8.01, 9)	7.84	Accepted
Personality traits	5	7.50	9	(5, 7.5, 9)	7.34	Accepted
Performance of inspectors	6	7.93	9	(6, 7.93, 9)	7.79	Accepted
Professional development of teachers at all levels	6	7.80	9	(6, 7.8, 9)	7.70	Accepted
Informed decision making	4	8.06	9	(4, 8.06, 9)	7.54	Accepted
Attitude and understanding	6	8.02	9	(6, 8.02, 9)	7.84	Accepted
The need to develop human skills	6	8.44	9	(6, 8.44, 9)	8.13	Accepted
Resolving institutional conflicts	6	7.70	9	(6, 7.7, 9)	7.63	Accepted
Resolving cultural conflicts	6	7.70	9	(6, 7.7, 9)	7.63	Accepted
Social influence	4	7.86	9	(4, 7.86, 9)	7.41	Accepted
Cultural necessities	6	8.48	9	(6, 8.48, 9)	8.15	Accepted
Necessities of governance	6	7.94	9	(6, 7.94, 9)	7.79	Accepted
Cultural growth	6	8.21	9	(6, 8.21, 9)	7.97	Accepted
Development of intercultural strategies	6	8.18	9	(6, 8.18, 9)	7.95	Accepted
Strategies for monitoring the learning environment	6	7.61	9	(6, 7.61, 9)	7.57	Accepted
Control and supervision	6	8.35	9	(6, 8.35, 9)	8.06	Accepted
Development of education strategies	6	8.14	9	(6, 8.14, 9)	7.93	Accepted
The need for extensive learning of new technologies	6	8.06	9	(6, 8.06, 9)	7.87	Accepted
Participation	6	8.12	9	(6, 8.12, 9)	7.91	Accepted
Resistance to acceptance	6	7.84	9	(6, 7.84, 9)	7.73	Accepted
Habit	6	8.07	9	(6, 8.07, 9)	7.88	Accepted
Gender	6	7.59	9	(6, 7.59, 9)	7.56	Accepted
User sentiments	3	7.63	9	(3, 7.63, 9)	7.08	Accepted
Avatars	6	8.24	9	(6, 8.24, 9)	7.99	Accepted
Mixed reality	6	8.01	9	(6, 8.01, 9)	7.84	Accepted
Virtual reality	6	7.97	9	(6, 7.97, 9)	7.81	Accepted
Metaverse technology	6	8.36	9	(6, 8.36, 9)	8.07	Accepted
Using different media	6	8.53	9	(6, 8.53, 9)	8.19	Accepted
Augmented reality technology	6	8.03	9	(6, 8.03, 9)	7.86	Accepted
Digital technological tools	4	7.32	9	(4, 7.32, 9)	7.05	Accepted
High scalability	6	7.96	9	(6, 7.96, 9)	7.81	Accepted
Quality of education	6	8.36	9	(6, 8.36, 9)	8.07	Accepted
Improving design quality	6	8.28	9	(6, 8.28, 9)	8.02	Accepted
Correspondence training	6	8.37	9	(6, 8.37, 9)	8.08	Accepted
Remote vision	6	8.37	9	(6, 8.37, 9)	8.08	Accepted
The possibility of online distance learning	4	7.69	9	(4, 7.69, 9)	7.29	Accepted
Profit	6	7.92	9	(6, 7.92, 9)	7.78	Accepted
Combined active training	6	8.14	9	(6, 8.14, 9)	7.93	Accepted
Improve real-world experience	6	7.48	9	(6, 7.48, 9)	7.49	Accepted
Access	6	7.69	9	(6, 7.69, 9)	7.63	Accepted
Convenience	6	7.71	9	(6, 7.71, 9)	7.64	Accepted
Motivation	6	8.21	9	(6, 8.21, 9)	7.98	Accepted
Design exploration	6	8.06	9	(6, 8.06, 9)	7.87	Accepted
Design speed	6	8.12	9	(6, 8.12, 9)	7.92	Accepted
Confidence in design	6	8.33	9	(6, 8.33, 9)	8.06	Accepted
Accuracy of design	6	7.58	9	(6, 7.58, 9)	7.55	Accepted
Building design	6	7.67	9	(6, 7.67, 9)	7.61	Accepted
Feasibility of implementation	6	8.36	9	(6, 8.36, 9)	8.07	Accepted
Creativity	6	8.15	9	(6, 8.15, 9)	7.93	Accepted
Design analysis	6	8.67	9	(6, 8.67, 9)	8.28	Accepted
Safety	4	7.49	9	(4, 7.49, 9)	7.16	Accepted
Building information modeling	6	7.83	9	(6, 7.83, 9)	7.72	Accepted
Activity in any place and time	6	8.41	9	(6, 8.41, 9)	8.11	Accepted
Maintaining security	3	7.66	9	(3, 7.66, 9)	7.11	Accepted
Flexibility	4	7.58	9	(4, 7.58, 9)	7.22	Accepted
Planning	6	7.86	9	(6, 7.86, 9)	7.74	Accepted
Improving links and communications	6	8.31	9	(6, 8.31, 9)	8.04	Accepted
Ease of visualization	5	7.42	9	(5, 7.42, 9)	7.28	Accepted