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Analyzing Barriers to Metaverse Application In Smart Cities: A DEMATEL-Based Approach

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Abstract. The concept of the metaverse has the potential to bring about revolutionary changes in several dimensions of smart cities, including the utilization of energy, supply chain, and operations. However, for it to become a reality, several inhibitors need to be analyzed and addressed. Hence, this study identifies the barriers to Metaverse applications in building smart cities and analyzes the causal relationships among them using the Decision Making Trial and Evaluation Laboratory (DEMATEL) approach. The results obtained by analyzing the responses from fifteen domain experts reveal that the security and privacy concerns as well as the digital addiction of users are the most significant barriers to the metaverse applications.

1 Introduction

Recently, the emergence of the metaverse has captivated the realms of technology, innovation, and urban development, promising a paradigm shift in the way we interact with our urban environments. A metaverse constitutes an immersive and three-dimensional virtual realm where individuals can engage via avatars to conduct their routine activities, thereby unlocking the capacity to communicate, engage in transactions, and explore novel prospects on a worldwide scope [1], [2]. The metaverse encompasses the merging of numerous state-of-the-art technologies, such as artificial intelligence (AI), virtual reality (VR), augmented reality (AR), extended reality (XR), and cloud computing [3]–[5]. As the metaverse gains prominence, its potential to reshape urban landscapes and infrastructures is garnering increasing attention.

A smart city encompasses an urban locality employing a diverse range of digital technologies to enhance the well-being of its inhabitants, upgrade infrastructure, modernize governmental services, facilitate accessibility, promote sustainability, and expedite economic growth [6]. Smart cities, characterized by their integration of digital technologies to enhance people's quality of life, are poised to be major beneficiaries of the metaverse's capabilities. The metaverse can redefine how cities operate, communicate, and deliver services across a multitude of sectors.

However, while the prospects are promising, the integration of the metaverse into smart cities is not without challenges. A comprehensive understanding of the barriers that may impede the seamless implementation of metaverse applications in smart cities is imperative and forms the basis of the present research. This article delves into the critical task of identifying the barriers that impede the application of Metaverse for building smart cities by reviewing the extant literature. Second, the causal relationships among the identified barriers are analyzed using a multi-criteria decision-making approach, DEMATEL (Decision-Making Trial and Evaluation Laboratory). We aim to uncover the interdependencies and causal relationships among these barriers through a structured methodology, shedding light on potential solutions and strategies for effective metaverse integration within smart cities.

In the following sections, we will delve into the context of the metaverse and smart cities, highlighting the potential benefits they offer individually. Subsequently, we will discuss the rationale for focusing on barriers and the importance of adopting the DEMATEL approach to comprehensively address these challenges. Through our research, we seek to contribute to the existing body of knowledge by offering insights that can guide policymakers, urban planners, and technology developers in navigating the intricacies of metaverse integration within the smart city landscape.

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2 Literature Background

The metaverse has many potential applications, including education, entertainment, commerce, and remote collaboration. Several studies have attempted to investigate the topic of Metaverse. The study by [1] explores the challenges of computing and offers framework for building the Metaverse on-edge devices with resource limitations. Another study discusses the Metaverse, its essence, technical framework, and challenges from a technical standpoint [7]. The review by [8] comprehensively examines articles about the Metaverse and its evolution, offering an overview of the sequential phases across its historical development and also enumerating contemporary technological progressions that facilitate the realization of the Metaverse. A similar study categorizes the fundamental concepts and vital techniques essential for achieving the Metaverse into three core elements and three methodologies (implementation, application, and user interaction), in contrast to a marketing or hardware-centric approach [9]. Another study explores the applicability of Metaverse in healthcare and the key challenges to its adoption in the domain [10].

Another study explores the potential of utilizing the metaverse to catalyze innovation and drive significant enhancements in the context of smart cities. The authors report the pivotal technologies that empower the metaverse, highlighting the foremost advantages and challenges tied to its adoption [11]. An additional research investigation charts the evolving range of Metaverse products and services, investigating their possible contributions to smart cities by considering their virtual representation. It places special emphasis on the sustainability objectives encompassing environmental, economic, and social aspects [12].

It can be seen from the review that there have been recent surveys to explore the applicability of Metaverse in various domains. While existing literature acknowledges the potential of the metaverse in smart cities, there is a dearth of comprehensive studies that systematically analyze the barriers hindering its effective application. The present research aims to bridge this gap in the existing body of research on Metaverse applications in smart cities. The challenges to the seamless integration of Metaverse into smart cities are reported in the sub-section below

2.1 Identified barriers

In the article, a comprehensive review was conducted to identify eight major challenges that Metaverse technologies may encounter when being applied in smart cities [11]. These challenges cover a wide range of areas and highlight the need for careful consideration and planning when implementing such technologies in urban environments.

2.1.1 Interoperability Issues (IOP)

Establishing a smooth interaction between Metaverse elements and smart city technologies necessitates the creation of shared protocols, standardized data formats, and interfaces. In the absence of adequate interoperability, incorporating the Metaverse into the smart city framework might result in segregated data repositories, disruptions in communication, and operational inefficiencies. Further, balancing interoperability with security and safety is also critical and poses barriers [13].

2.1.2 Security & Privacy Concerns (SP)

Integrating the Metaverse into smart cities raises significant security and privacy concerns due to the sharing of personal data, virtual interactions, and immersive experiences. The convergence of virtual and physical realms exacerbates these issues. Some of the key issues include data breaches, identity theft, credential theft, denial of service, and user privacy breach by virtual surveillance [14], [15].

2.1.3 Ethical considerations (ETH)

Blurring the lines between reality and virtuality in the Metaverse raises ethical concerns regarding the portrayal and potential manipulation of individuals, as well as the consequences of such actions. Further, the use of the Metaverse in smart cities raises concerns about user consent and data ownership.

2.1.4 Network Infrastructure (NI)

Metaverse relies heavily on robust and high-speed network connectivity to deliver immersive experiences, real-time interactions, and data exchanges between virtual and physical environments. Several network-related challenges that can impact the successful incorporation of the Metaverse include limited bandwidth, network congestion, coverage, and scalability issues [16].

2.1.5 Data Management (DM)

Integrating data from Metaverse interactions with existing urban data sources can be challenging due to differences in formats, structures, and platforms. Robust and scalable storage solutions are necessary to manage this influx of data. Additionally, ensuring secure and controlled cross-domain data sharing while maintaining privacy poses a complex challenge.

2.1.6 Digital Addiction & Mental Health Issues (DMH)

The Metaverse provides immersive virtual experiences that may be addictive, leading to worries about overuse and potential effects on mental health. Overuse may lead to addictive behaviors, escapism, isolation, and detachment from real-life responsibilities [11].

2.1.7 Legal Barriers (LB)

As digital environments become more intertwined with urban life, legal complexities arise regarding intellectual property rights. Additionally, the borderless nature of the Metaverse can lead to conflicts related to jurisdiction, taxation, and regulatory frameworks. In the event of harm, damage, or disputes arising from Metaverse interactions, defining liability and responsibility can be complex [11]. As Metaverse applications involve transactions and consumer interactions, ensuring fair practices, dispute resolution mechanisms, and protection against fraud becomes important.

2.1.8 Environmental Pollution (ENV)

Emerging Metaverse technologies consume significant computing power and contribute to greenhouse gas emissions and increased energy consumption. End-Of-Life devices may also be a source of increased e-waste that needs proper management.

3 Approach

This study employs a multi-criteria decision-making (MCDM) approach to address the intricate nature of interrelated factors. From the available MCDM tools available, the Decision Making Trial and Evaluation Laboratory (DEMATEL) methodology is chosen as the most suitable solution due to its capability to analyze interdependencies while bypassing limitations related to sample size constraints [17]. DEMATEL offers a thorough system for constructing and assessing a structural model that encompasses causal relationships between complex factors [18]. Its introduction aimed to analyze interconnected cluster issues using an influence map [19]. Additionally, it assists decision-makers in pinpointing the central driving factors of a problem by considering causal relationships and scrutinizing interaction influences.
Given its effectiveness in thoroughly exploring relationships among factors, DEMATEL has found extensive application across various fields such as operations research [20], e-waste management decision-making [21], supply chain resilience [22], and so forth. Consequently, the decision to employ DEMATEL in this study stems from its aptitude for exploring causal relationships among the barriers to Metaverse applications in smart city contexts.
The steps of DEMATEL are given below:
Step 1: Experts were requested to participate in the data gathering by highlighting the impact of each element i on every other element j, indicated by b_{ij} on a scale from 0 (No influence) to 4 (very high influence). A direct relations matrix $\boldsymbol{B}$, is created based on these scores. This matrix $\boldsymbol{B}$ is used to display a pair-wise comparison of causal association. For n variables that affect the system, the association matrix $\boldsymbol{B}$ is illustrated in Eq. (1).

$$\boldsymbol{B} = \begin{bmatrix} 0 & b_{12} & \cdots & b_{1n} \\ b_{21} & 0 & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & 0 \end{bmatrix} \tag{1}$$

Step 2: The normalization is carried out using equations (2) & (3).

$$\boldsymbol{F} = \boldsymbol{B}/q \tag{2}$$

$$q = max_{1 \le i \le n}\left\{\sum_{j=1}^{n} b_{ij}\right\} \tag{3}$$

Step 3: The total relation matrix $\boldsymbol{TRM}$ is obtained from $\boldsymbol{F}$, using eq. (4) where $\boldsymbol{I}$ represents the identity matrix.

$$\boldsymbol{TRM} = \boldsymbol{F}(\boldsymbol{I} - \boldsymbol{F})^{-1} \quad (4)$$

Step 4: Matrices R and S are obtained from the row and column sums.

$$\boldsymbol{R} = \left[\sum_{j=1}^{n} m_{ij}\right]_{n\times 1}' = (r_1, r_2, \dots, r_i, \dots, r_n) \quad (5)$$

$$\boldsymbol{S} = \left[\sum_{i=1}^{n} m_{ij}\right]_{1\times n} = (s_1, s_2, \dots, s_i, \dots, s_n) \quad (6)$$

$$\boldsymbol{TRM} = m_{ij} \quad i, j = 1,2,3, . . n$$

Step 5: The data set of $\{r_i + s_i, r_i - s_i\}$ are plotted using $(r_i + s_i)$ as the horizontal axis and $(r_i - s_i)$ as the vertical axis.

4 Analysis

Fifteen subject matter experts, with an average of twelve years of experience, were engaged to capture their perspectives regarding the nature of causal connections among the identified eight factors. These experts were requested to provide their assessments using the scale outlined in Step 1. The direct relation matrix, resulting from the amalgamation of responses from all experts, is detailed in Table 1.

Table 1. Direct Relations Matrix

	SP	IOP	ETH	NI	DMH	LB	DMH	ENV
SP	0.000	1.133	2.000	1.200	1.667	0.333	0.867	1.467
IOP	0.000	0.000	0.533	1.867	0.333	0.333	0.733	1.400
ETH	0.000	0.067	0.000	2.067	0.600	0.600	0.333	1.667
NI	0.000	1.400	1.867	0.000	1.533	0.467	1.800	1.800
DMH	0.000	0.600	1.200	1.933	0.000	0.267	2.267	1.533
LB	0.000	1.333	1.800	1.933	1.200	0.000	1.467	2.067
DM	0.000	0.467	1.133	1.733	1.533	0.000	0.000	1.600
ENV	0.000	0.267	1.067	1.733	1.200	0.467	0.933	0.000

The normalization of direct relation matrix is done using equations (2) and (3) and is given in Table 2.

Table 2. Normalized Matrix

	SP	IOP	ETH	NI	DMH	LB	DMH	ENV
SP	0.000	0.116	0.204	0.122	0.170	0.034	0.088	0.150
IOP	0.000	0.000	0.054	0.190	0.034	0.034	0.075	0.143
ETH	0.000	0.007	0.000	0.211	0.061	0.061	0.034	0.170
NI	0.000	0.143	0.190	0.000	0.156	0.048	0.184	0.184
DMH	0.000	0.061	0.122	0.197	0.000	0.027	0.231	0.156

LB	0.000	0.136	0.184	0.197	0.122	0.000	0.150	0.211
DM	0.000	0.048	0.116	0.177	0.156	0.000	0.000	0.163
ENV	0.000	0.027	0.109	0.177	0.122	0.048	0.095	0.000

The Total relation matrix is shown in Table 3.

Table 3. Total Relations Matrix

	SP	**IOP**	**ETH**	**NI**	**DMH**	**LB**	**DMH**	**ENV**
SP	0.000	0.282	0.516	0.571	0.449	0.141	0.409	0.549
IOP	0.000	0.119	0.270	0.455	0.230	0.101	0.282	0.393
ETH	0.000	0.137	0.235	0.488	0.267	0.131	0.264	0.432
NI	0.000	0.298	0.494	0.463	0.434	0.149	0.485	0.574
DMH	0.000	0.220	0.417	0.587	0.282	0.121	0.502	0.518
LB	0.000	0.323	0.538	0.689	0.447	0.120	0.502	0.652
DM	0.000	0.182	0.364	0.507	0.372	0.085	0.262	0.463
ENV	0.000	0.158	0.341	0.477	0.326	0.120	0.328	0.298

The impacts given and taken by each factor were calculated using equations (5) and (6) and are explained in Table 4.

Table 4. Separation Measures, Relative Closeness and Alternatives' Ranks

Dimension	$\boldsymbol{r_i}$	$\boldsymbol{s_i}$	$\boldsymbol{(r_i + s_i)}$	$\boldsymbol{(r_i - s_i)}$
SP	2.917	0	2.9170	2.9170
IOP	1.850	1.718	3.5674	1.8497
ETH	1.954	3.175	5.1288	1.9542
NI	2.897	4.236	7.1336	2.8973
DMH	2.646	2.807	5.4531	2.6461
LB	3.272	0.967	4.2394	2.3048
DM	2.234	3.035	5.2697	-0.8007
ENV	2.046	3.879	5.9253	-1.8326

Utilizing the impact of each dimension on the others, an influence map is formulated to elucidate the interplay among these dimensions. This map delineates the contribution of each dimension to the others. The diagram is illustrated in Figure 1.

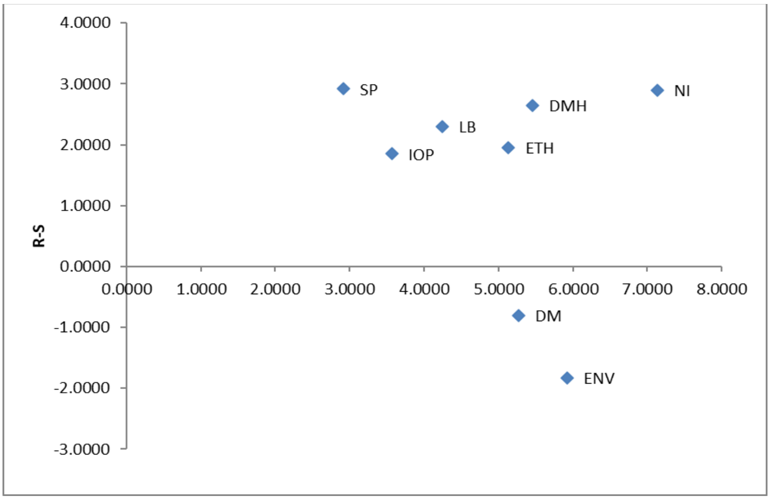

Fig.1. Relative Causal Strength of Barriers

The depicted figure highlights that Security and Privacy emerge as the most potent barrier, exerting a significantly robust influence on other factors. Subsequently, Network Infrastructure, and Digital Addiction, & Mental Health follow in strength. According to the insights provided by the experts, Environmental Pollution and Data Management are perceived as the relatively weaker factors within this relational context.

5 Concluding Remarks

This research article systematically explores the barriers impeding the successful integration of the Metaverse within smart cities, employing a DEMATEL-based approach. By analyzing the interrelationships among various factors, our study sought to shed light on the complex dynamics surrounding Metaverse application in urban contexts. The outcomes of our analysis unveiled compelling insights into the hierarchy of barriers. Security and Privacy emerged as the foremost influential barrier, exerting a robust impact on other factors. This underscores the critical significance of addressing data protection and user privacy concerns to ensure a harmonious fusion of the Metaverse within the fabric of smart cities. Network Infrastructure and Digital Addiction and Mental Health followed as substantial barriers, necessitating attention to ensure seamless experiences and mitigate potential adverse impacts on well-being. Conversely, our findings indicate that Environmental Pollution is perceived as the weakest barrier according to the experts' assessments. While this could potentially signal a lower priority, it is important to approach this result with caution. Sustainability remains a core concern in modern urban planning, and even though it ranks lower among the barriers, the environmental implications of Metaverse integration should not be disregarded.

Our study highlights the complexity and multidimensionality of challenges involved in Metaverse integration in smart cities. As urban environments evolve and digital technologies advance, policymakers, urban planners, and technology developers must consider a holistic approach that addresses the identified barriers. Recognizing the paramount importance of security and privacy while also maintaining a commitment to environmental sustainability is crucial for unlocking the full potential of the Metaverse while ensuring the well-being of citizens and the urban ecosystem.

Moving forward, further research and collaborative efforts are needed to address the identified barriers comprehensively, facilitating the seamless integration of the Metaverse within smart cities. With careful consideration of these insights, stakeholders can navigate the dynamic landscape of emerging technologies, creating a harmonious synergy between the virtual and physical realms for the benefit of urban societies and future generations.

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