E-ISSN 2980-2563

Volume: 2 Issue: 2 Year: 2024

JOURNAL OF

TECHNOLOGY IN ARCHITECTURE, DESIGN, AND PLANNING

JTADP

İSTANBUL UNIVERSITY PRESS

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PUBLISHER
Istanbul University Press
Istanbul University Central Campus,
34452 Beyazit, Fatih, Istanbul, Turkiye
Phone: +90 (212) 440 00 00

Authors bear responsibility for the content of their published articles.

The publication language of the journal is English.

This is a scholarly, international, peer-reviewed and open-access journal published biannually in May and November.

Publication Type: Periodical

İSTANBUL UNIVERSITY PRESS

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Journal of Technology in Architecture, Design, and Planning
NOVEMBER 2024,
VOLUME 2 ISSUE 2

EDITORIAL

Dear Readers,

We are thrilled to present the fourth issue of the Journal of Technology in Architecture, Design, and Planning (JTADP), which has been dedicated to publishing research since May 2023. As JTADP nears the end of its second year, it has made remarkable progress. Notably, the journal is now indexed in DOAJ and ERIH PLUS. We are deeply encouraged by the support of our contributors and readers.

The preparation of this fourth issue was made possible through the collective efforts of many individuals. We extend our heartfelt gratitude to Istanbul University Press for their steadfast support. In particular, we thank Dr. Metin Tunç, General Operations Manager, as well as Operations Chief Esma Çavuşoğlu and Operation Assistant Gökhan Çimen for their invaluable contributions.

This issue includes five articles, each uniquely contributing to the academic discourse. Ezgi Özkoç and Şan Yalçın Sarabil analyze public spaces in the Metaverse, comparing platforms like Decentraland and Sandbox to highlight their unique features and user experiences. Nazire Papatya Seçkin explores the historical evolution of urban drainage systems and their future potential in addressing contemporary challenges such as climate change and urbanization. Ali İbiş investigates the use of steel fibre-reinforced concrete in urban furniture design, showcasing its potential for durability and aesthetic flexibility. M. Oytun Kasapgil and Kemal Kutgün Eyüpgiller document the architectural heritage of traditional Anatolian rural houses in Arapgir, examining their construction techniques and spatial formations. Finally, S. M. Amin Mostafavi Mousavi and Selahattin Ersoy delve into parametric architectural design, demonstrating how earthquake-resistant elements can balance structural performance with aesthetic appeal. These contributions collectively represent the breadth of innovative research we aim to showcase.

Despite being a relatively young journal, JTADP continues to grow with the contributions of dedicated researchers. It will serve as a platform for meaningful contributions to the academic community.

Sincerely,

Prof. Dr. Kemal Kutgün EYÜPGİLLER,
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Journal of Technology in Architecture, Design, and Planning
JTADP 2024, 2 (2), 64–76
DOI: 10.26650/JTADP.24.008

RESEARCH ARTICLE

Models for Positioning Public Spaces in the Metaverse

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ABSTRACT
The Metaverse plane constitutes an ever-evolving virtual universe that encompasses various digital platforms. These platforms allow users to engage in diverse experiences and create virtual environments using technologies such as virtual reality, augmented reality, and artificial intelligence. Within the Metaverse, public spaces serve as virtual arenas where users gather, share ideas, collaborate, and enjoy themselves. These spaces include environments where political, cultural, and social matters are discussed, catering to users with diverse characteristics. The objective of this study is to examine the significance of public spaces within the Metaverse and explore user experiences. To this end, the study compares public spaces in virtual reality platforms such as Decentraland and Sandbox, analysing different features, preferences, and experiences. The study uses literature review and quantitative data collection methods. Statistical data related to public spaces in the Decentraland and Sandbox platforms were gathered and assessed based on various criteria. These analyses highlight similarities and differences between public spaces on both platforms. This study aims to understand the diversity, functions, and user experiences within public spaces in the Metaverse. By emphasising the distinct features and user preferences offered by platforms like Decentraland and Sandbox, the research aims to contribute to the evaluation of public spaces within the Metaverse. It has been determined that Decentraland stands out with its DAO and contributions to public welfare, while Sandbox contributes to technology and innovation by supporting developers. It is concluded that both platforms can expand their user base and increase engagement.

Keywords: Metaverse, Public Spaces, Decentraland, Sandbox, Metaverse and Public Spaces

Introduction

The Metaverse is a constantly evolving and changing digital universe that encompasses many diverse Metaverse platforms. These platforms enable users to participate in various activities and subjects through technologies such as virtual reality, augmented reality, and artificial intelligence. Users can interact with others, create their own virtual environments, or enter existing ones. Metaverse platforms offer experiences in virtual art, culture, entertainment, education, business, sports, and gaming. They empower users to establish their own virtual communities or join existing ones (Şenkardeş, 2023).

Public spaces in the Metaverse are virtual environments where users gather to meet, chat, share ideas, debate, collaborate, compete, have fun, or learn (Şenkardeş, 2023). Public spaces are defined as areas that enable citizens to come together and discuss political, economic, and social issues. The opportunity for interaction provided by a public space, allowing for the exchange of ideas and information, enables individuals to evolve from passive listeners to potential participants (Şenkardeş, 2023). Public spaces in the Metaverse, in line with this definition, provide an environment for users to discuss political and cultural topics (Şenkardeş, 2021).

The characteristics, functions, benefits, and activities of public spaces in the Metaverse vary depending on the specific features, rules, objectives, and users of each Metaverse platform. Therefore, to compare public spaces within the Metaverse, it is necessary to identify and evaluate criteria such as the qualities, functionalities, access conditions, levels of participation, degrees of freedom, security and privacy policies, censorship and moderation practises, social and cultural interactions, and economic and educational benefits provided by these platforms.

The aim of this study was to investigate public space selection models in the Metaverse. This study examines the characteristics, functions, benefits, and activities of different public spaces across Metaverse platforms, exploring why users choose these spaces, how they experience them, and their assessments.

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Submitted: 25.04.2024 • **Revision Requested:** 30.05.2024 • **Last Revision Received:** 31.05.2024 • **Accepted:** 13.06.2024 • **Published Online:** 04.11.2024

The scope of this study includes conducting a literature review on the Metaverse and public spaces, examining their development processes and applications, and comparatively analysing public spaces in platforms like Decentraland and Sandbox. While both platforms are compatible with VR headsets, their public space selection models differ based on their unique features, rules, objectives, and user bases. By comparing these two platforms, this study aims to understand public space selection models in the Metaverse.

The methodology involves a literature review, quantitative data collection, and analysis. As part of the quantitative data collection, statistical data related to public spaces in Decentraland and Sandbox will be gathered. This data includes visitor numbers, durations, levels of participation, economic values, social interactions, and other metrics to illustrate the functions, benefits, and activities of these spaces. The collected data will be evaluated and compared using appropriate analytical methods to highlight the differences and similarities in public spaces across Decentraland and Sandbox platforms.

1. The Metaverse and the Public

The term "Metaverse" is a compound word derived from two components: "Meta" (a prefix in Greek meaning ’after’, ’beyond’, or ’transcending’) and "universe". In other words, the Metaverse can be described as universes that transcend reality, representing a continuous and permanent multi-user environment that merges physical reality with digital virtuality (Mystakidis, 2021).

Public spaces refer to urban areas that are open to everyone. This concept is organised around the idea of being "open to the public" or "accessible to all." Public spaces are a crucial part of urban areas because of their role in supporting urban activities. Public areas such as urban squares, streets, and parks are among the most frequently used spaces in cities because they facilitate interactions among city residents. Well-designed and clearly defined public spaces can enhance the image of a city and support the creation of more harmonious spaces. Consequently, the way people perceive and define a city varies according to the characteristics and environmental quality of its public spaces (Özkoç, 2020). Public spaces in the Metaverse platform are environments where users gather in a virtual space to discuss political, economic, entertainment, and social topics. These spaces are part of a decentralised and participatory virtual universe, where various digital environments coexist and transitions between reality and virtuality are possible. These platforms are typically blockchain-based and open-source. In the Metaverse, public spaces recreate spatiality in a virtual form, enabling individuals to move beyond the constraints they face in physical environments and to take advantage of new communication opportunities.

Public space ownership in the metaverse is a complex and multifaceted issue that encompasses various forms of ownership such as private, collective, and shared ownership. Research highlights the challenges in managing the ownership of virtual objects and metaverse assets, particularly in the context of distributed systems with complex ownership forms (Wang et al., 2023).

Moreover, the metaverse’s decentralised nature and the existence of various ownership forms raise important considerations for intellectual property rights, content licencing, and ownership within the metaverse (Mitrushchenkova, 2023). This underscores the need to address issues related to ownership, creation, and use of intellectual property rights in metaverse space (Kim, 2022).

In conclusion, the metaverse presents a paradigm shift in public space ownership, offering new opportunities for democratisation, recognition of digital works, and reimagining the concept of public spaces. However, it also brings forth challenges related to intellectual property, regulatory concerns, and data hegemony that need to be addressed to ensure responsible and equitable public space ownership within the metaverse.

1.1. Metaverse and the Development Process

The Metaverse is defined as a digital universe created through the combination of virtual reality, augmented reality, and other technologies, where users can experience, participate, and socialise from a first-person perspective. The concept of this new reality was first exemplified in William Gibson’s 1984 science fiction novel "Neuromancer". The book can be described as an early and influential representation of modern cyberculture and cyberspace concepts. In the novel, a virtual reality space called the "Matrix" is introduced. This matrix, which later became a frequently encountered theme in popular culture, is a network-connected virtual reality world. "Neuromancer" stands as one of the first and most influential representations of cyberspace and virtual reality in literature, leaving a profound impact on technology and culture. It is particularly significant for exploring visions of how people could interact in digital environments and examining the potential impacts of such technologies on society. Subsequently, the term “metaverse” was first coined in Neal Stephenson’s 1992 science fiction novel "Snow Crash" (Stephenson, 2003).

The process began with the use of puzzle theory and artificial intelligence, with the first examples appearing in gaming platforms. One of the earliest applications of artificial intelligence in the gaming world is "Spacewar!", developed in 1962 by Steve Russell and others (Bellis, 2019).

In "Spacewar!", players control spacecraft, and computers also control the ships. These computer-controlled ships display simple movement and combat strategies, representing an early example of artificial intelligence in gaming. Moving forward to 1993, "Doom" is acknowledged as one of the first popular online and multiplayer games (The Ultimate DOOM, 2021). Indeed, "Doom" served as a milestone by enabling players to interact within the same in-game world. This innovation paved the way for Massively Multiplayer Online Role-Playing Games (MMORPGs) like "EverQuest" and "Ultima Online." These MMORPGs offer gaming experiences that combine virtual worlds with social interaction, significantly enhancing the depth and engagement of online gaming (EVERQUEST, 2023). In 2003, "Second Life" emerged as a platform that stood out for offering social interaction, economic aspects, and freedom of personal expression in virtual worlds, attracting a broad user base (Galov, 2023). In the mid to the late 2000s, MMORPGs like "World of Warcraft" significantly increased the popularity of social interaction and community-building in virtual worlds. "World of Warcraft" especially became a cultural phenomenon, drawing millions of players into its expansive fantasy universe (Jones, 2021). In 2016, "Pokémon Go" became the first major mobile game to use augmented reality technology and became a global phenomenon. During the 2010s, the launch of VR headsets like the Oculus Rift and HTC Vive, brought virtual reality experiences into the mainstream.

Throughout the process, there have been several other key milestones. Pong, in 1972, symbolised the start of the video game industry. As one of the first popular arcade games, it introduced video games to a broad audience (Pong Game, 2023). Space Invaders, in 1978, solidified the place of video games in popular culture and introduced the first high score table, thus encouraging competition among players. Pac-Man, in 1980, became one of the first major arcade games to appeal to a wide audience, showing that video games were not just for children and teenagers (Namco, 2023). In 1985, Super Mario Bros significantly influenced the development of platform games and increased the popularity of games featuring complex worlds, characters, and storeys. The Legend of Zelda, released in 1986, was known for its open-world design and complex puzzles, influencing the evolution of adventure games. Pokémon, released in 1996, became a global phenomenon with its cross-platform experience and trading mechanics, emphasising the importance of player communities and interaction. In 2000, the Sims, as the first major game to simulate daily life, targeted a different type of player, expanding the boundaries of video games. In 2011, Minecraft, as an open-world survival game offering unlimited creativity, set new standards in game design and player interaction. Fortnite, in 2017, popularised the Battle Royale genre and introduced a new approach to the industry with in-game events, cross-platform play, and continuously updated content.

When examining the development of the Metaverse concept and realm, the earliest examples of virtual worlds in the 1980s and 1990s, like "Second Life" and "World of Warcraft," laid the initial foundations for the Metaverse concept. These games highlight the importance of social interaction and digital identities. The widespread use of the internet in the 1990s opened up possibilities for interaction and community building in digital worlds. In the 2000s and 2010s, the development of augmented and virtual reality technologies and the release of devices such as Oculus Rift, HTC Vive, and PlayStation VR provided users with more immersive and realistic virtual experiences, bringing the concept of the Metaverse closer to being a part of the near future. From 2010 onwards, the proliferation of smartphones and the rise of mobile technology have made virtual and AR experiences accessible to a broader audience. Games like "Pokémon Go" popularised augmented reality experiences through mobile devices. In 2010, Blockchain technology and cryptocurrencies began providing the necessary infrastructure for the Metaverse with innovations in digital asset ownership, security, and identity verification. In 2020, the COVID-19 pandemic increased the necessity for socialising and working in digital environments, further highlighting the importance and potential of the Metaverse. In 2021, Facebook’s branding as a Metaverse-focussed company, adopting the name Meta, marked the recognition of the Metaverse concept as a serious investment area in mainstream media and the technology sector. Investments and project developments by major technology companies like Microsoft, Google, and Apple in the Metaverse have increased interest in this field and its potential future.

Today, with the use of augmented reality (AR) technology, the Metaverse can integrate virtual and physical worlds. This immersive environment is designed to offer users an interaction and experience that is reminiscent of the real world. The continuous and interoperable nature of Metaverses enables user avatars to transition seamlessly between different virtual worlds. These transitions imply that avatars should retain their value, even as they move between worlds created by different entities (Xu et al., 2022).

The main goal now is to be a part of these experiences rather than just looking at a screen. It can be assumed that everything done online, from socialising to entertainment, gaming, and work, will be more natural and vivid. Screens, which are unable to fully transmit human emotions and interactions, lack that profound sense of presence. While avatars are used to represent people in the Metaverse, it can be thought that their use will become as common as today’s WhatsApp profile pictures, but they will be accompanied by live 3D representations instead of static images. These avatars could mimic human postures and gestures, possibly enabling richer interactions than those currently available online (Abbate et al., 2022).

This indicates that the Metaverse is too vast and inclusive to be owned by a single company or entity. The shared structure of the Metaverse allows thousands of users to be simultaneously present in a single server session. Users can access this environment anytime, anywhere, and their interactions are globally shared, connecting to the same environment with an equitable approach, regardless of borders or barriers. This means that an action by one user can affect not only users on a specific server but also all other users (Xu et al., 2022).

1.2. Public in the Metaverse: Decentralised Autonomous Organisations (DAO)

In the Metaverse, the spaces and platforms provided are important as they enable users to communicate with each other, collaborate, share, and come together for a common purpose. These areas and platforms bring together people from different cultures, ages, abilities, and perspectives, forming communities that, in the context of the Metaverse, are considered equivalent to the public. Location choices within the Metaverse are made according to user preferences. Users can explore, compare, try, and select the areas and platforms that suit them in the Metaverse, but they also have the freedom to convert their own lands into public spaces. This is exemplified by social responsibility activities, particularly in the Ed-Tech sector, on the Metaverse, like those undertaken by Open-Campus, which focuses on educational technologies and universal education rights.

Regarding the Metaverse and society, or the public, the recent interest in Metaverses based on blockchain technology has increased, leading to a rapid growth in user numbers. This growing community can be considered public. This increase necessitates a governance structure. In this context, DAOs (Decentralised Autonomous Organisations) are ideal candidates for democratic decision-making and collective resource management. DAOs taking on this role ensure that the Metaverse is managed more democratically and effectively. They adopt a community-centred approach, promoting community participation and empowerment. Within the Metaverse, DAOs virtually represent the interests of users and stakeholders, guiding the development and evolution of digital spaces. This approach makes the Metaverse a more participatory and user-focussed environment. Furthermore, smart contracts used in DAOs automate the governance processes of the Metaverse. This makes processes like digital asset management, access rights, and conflict resolution more efficient and transparent. Smart contracts facilitate transactions within the Metaverse, making it a more orderly and manageable digital world. Lastly, DAOs use tokens to encourage participation and governance. In the Metaverse, these tokens are used to reward contributions, manage digital property rights, and facilitate transactions. This enriches the economic dynamics of the Metaverse, encouraging users to play a more active and effective role in the virtual world. In summary, DAOs play a significant role in the democratic governance, community participation, automation processes, and economic interactions of the Metaverse. These features ensure that the Metaverse is a more participatory, efficient, and dynamic digital environment (Wang et al., 2022).

1.3. Metaverse Usage Areas and Preference Criteria

In 2021, Facebook reinforced its commitment to developing the Metaverse by transforming itself from a "social media company" into a "Metaverse company," branding as "Meta" (Xu et al., 2022). This branding increased attention to this area, particularly affecting its recognition. According to Zuckerberg, Meta's focus is to give people, wherever they are, the ability to feel like they are with another person. Additionally, in the long term, enabling people to interact not only with other humans but also with artificial intelligence, businesses, or places is a secondary point emphasised by Zuckerberg as part of the future of making the world more connected. The mentioned interaction can be parallel to reality through virtual twins (Krietzberg, 2023). Meta, one of the first modern steps towards the Metaverse, was described by Zuckerberg in his 2022 presentation as a network of 3D virtual worlds focussed on social connexion. This definition implies that in addition to the existence of a virtual environment, the component of social interaction is also essential. Moreover, the Metaverse will be more than just a virtual environment for entertainment; it will also be a virtual twin of the real world where individuals can work, learn, and trade. The Metaverse can transport people to distant locations through holograms or virtual rooms. Whether working or learning, virtual models can help delve deeper into a subject and better understand it (Abbate et al., 2022).

Virtual twins and new ecosystems promise a future where users can access 3D virtual or augmented reality environments using devices like virtual reality headsets, digital glasses, and smartphones. In these environments, users can work, communicate with friends, engage in commercial activities, travel to distant places, and benefit from educational opportunities (Abu-Salih, 2022). The virtual nature of this interaction will create an infrastructure for seamless interaction without borders or barriers.

The Metaverse contains various areas and platforms, each with different themes, functions, features, and communities. People can choose areas and platforms in the Metaverse based on their interests, needs, budgets, expectations, and values. Users may consider certain criteria when choosing a platform. Content quality and diversity are crucial; the content offered in the Metaverse should attract, inform, entertain, and satisfy users. Various contents in different categories, formats, languages, and qualities makes it easier for users to choose. User experience and accessibility are important; areas and platforms in the Metaverse should be easily accessible, navigable, interactive, and function smoothly. Compatibility with different devices, connexions, and conditions enhances the user experience. Security and privacy are key; areas and platforms in the Metaverse should protect users' personal data, private information, financial transactions, and digital assets. A secure infrastructure, transparent policy, ethical behaviour, and legal compliance gain users' trust.

In this context, metaverses can revolutionize service delivery ecosystems in every aspect of life, such as health, education, entertainment, e-commerce, and smart industries. In recent years, more proof-of-concept work has been developed on the metaverse. These prototypes rely on blockchain technology, which allows the archiving, mapping, sharing, and reuse of virtual spaces across different applications (Abbate et al., 2022).

Finally, Metaverses offer end-to-end services such as content creation, social entertainment, and in-world value transfer by providing users with digital identities (DIDs). These services, which transcend the boundaries between physical and virtual worlds, are offered regardless of users' nationalities or countries. Supported by the decentralised structure of blockchain technology, the Metaverse ecosystem continues its path as an independent economic system with transparent operating rules, ensuring sustainability.

1.4. Metaverse Platforms and Purposes of Use

Metaverse gaming platforms have emerged from the desire of users to experience different places and universes, successfully increasing interest and bringing various investment and venture opportunities. In particular, the visual and qualitative superiority of the virtual world over real life makes the metaverse a competing centre of interest and investment with the real world. Following the rapid development of the gaming industry after the 2000s, it reached a size of 252.52 billion dollars in 2018, increased to 406 billion dollars in 2023, and is expected to reach 626 billion dollars by 2028 (Clement, 2023). Especially with these increasing investments, the emergence of popular metaverse universes is expected.

Examples of popular metaverse gaming platforms include World of Warcraft, Pokemon Go, Minecraft, and DragonSB. World of Warcraft offers a sandbox-style experience across different universes, while Pokemon Go presents a unique metaverse adaptation that integrates the game with real-world maps. These games show that there are multiple ways for decentralised metaverses that exist. The aim of these platforms is not just to play a specific game but to offer more liberating experiences. However, the limitation of users with little content in these semi-metaverses drives the search for more free universes and spaces, and metaverse platforms begin to develop and diversify with the motto of decentralisation. For instance, the fact that virtual gold in "World of Warcraft" became seven times more valuable than real money in economically troubled Venezuela shows the power of game mechanics and a loyal community. This led to the emergence of games like New World, developed by Amazon, and Destiny, developed by Bungie. In World of Warcraft, there are public spaces designed for players to have fun, fight, trade, or engage in other activities, which enhance the social, economic, aesthetic, and financial aspects of the game and encourage player interaction.

Each metaverse platform offers unique experiences to its users. For example, while Upload offers virtual property trading based on blockchain, Roblox allows users to create their own games. Sandbox enables users to interact as avatars, and Decentraland allows users to buy and develop virtual lands (Garrett, 2023).

Upland is a blockchain-powered virtual world in which users can trade and interact with virtual properties based on real-world locations. In this digital environment, users can explore and acquire "lands" in various cities, blending the real and virtual realms. The Upland platform, available through iOS and Android apps as well as a web version, enables users to participate in virtual property dealings from any device with internet access. It operates as a simulated real estate marketplace. In Upland, properties are symbolised as non-fungible tokens (NFTs), offering users a chance to invest in and possess digital land. Participants can purchase, sell, and exchange digital assets like virtual properties. They can also earn UPX, the platform's native cryptocurrency by finding new properties, completing tasks, or joining events. This engaging model motivates users to actively contribute to the platform's expansion. Upland supports user-generated content, allowing players to create and customise their own properties, businesses, and artworks. This approach builds a dynamic and diverse community in which users can showcase their creativity and build their virtual identities. Since Upland is created with references to the real world, even though existing public spaces are represented in the virtual world, they are not fully functional as public spaces due to their nature of being subject to purchase and sale.

Roblox Metaverse: Founded in 2004 by David Baszucki and Erik Cassel and launched in 2006, Roblox has established itself as a large-scale game development and online gaming platform. By allowing users to both create and play games produced by other players, Roblox has become one of the largest Metaverse platforms, boasting over 56 million daily active users. The lockdowns during the COVID-19 pandemic significantly boosted the company's growth in game-based content creation and active user base. Roblox offers various products, including the creation and sale of virtual clothing, accessories, and avatar animations. Its virtual currency, Robux, is used for purchasing virtual items, accessing premium features, and game passes. Roblox provides a powerful and intuitive development environment that enables content creators to design, build, and script their 3D games or experiences. Roblox, which is compatible with multiple platforms including PC, Mac, iOS, Android, and Xbox One, enables users to engage with friends across these devices in shared gamelan experiences. Its virtual economy is centred around Robux, which is used to buy in-game items, avatar customisations, and support game developers through a profit-sharing model. The platform encourages player interaction with features like in-game chat, private messaging, and friend lists, thus nurturing a community-centric environment. Users have the freedom to customise their avatars with various clothing, accessories, and animations, allowing for unique self-expression within the digital world. Additionally, Roblox provides educational content such as coding courses, tutorials, and interactive projects, aiming to enhance learning and creative skills among its users. Currently, Roblox's database contains over 40 million games, each offering unique experiences. Roblox's Robux pricing is as follows: 450 Robux for $4.99 per month, 1,000 Robux for $9.99 per month, and 2,200 Robux for $19.99 per month, offering users various options to purchase Robux for acquiring virtual items and other premium features. The market data for Roblox are as follows: 24-Hour Trading Volume USD $97,533,902 and Market Cap USD $830,434,410. These figures clearly demonstrate Roblox's overall economic size and the intensity of financial activities on the platform. Regarding system size: Roblox maintains its presence with more than 18,000 servers (cloud systems hosting the universes) and over 170,000 devices (G2A, 2023).

The Sandbox Metaverse: Sandbox stands out as a community-focussed and decentralised gaming platform and virtual environment. Utilising blockchain technology, this metaverse platform offers players the opportunity to create, share, and monetise game experiences. Although Sandbox does not offer VR support, the potential look of VR is hinted at through Snoop Dogg's music video "House I Build." Sandbox Metaverse includes the Sandbox Game, where players explore, develop, and play games; the Sandbox Builder, enabling the creation of their own games and experiences; and the Sandbox Marketplace, where content creators can buy and sell virtual assets using the site's native cryptocurrency, SAND. The Sandbox platform is currently engaged in various projects, including a partnership with AXA Hong Kong in Mega City 2, where they aim to create a distinctive interactive space. AXA Hong Kong's acquisition of a 3x3 LAND parcel in The Sandbox is part of their strategy to offer innovative digital experiences to their customers. Within The Sandbox, users and developers can find several games and experiences, from simple puzzles to elaborate multiplayer adventures. For instance, The Sandbox Evolution, a notable platform game, allows players to craft their own pixel art worlds. The Sandbox harnesses blockchain technology for the management and exchange of virtual assets, where users can trade these assets using the SAND currency. It features unique virtual assets, such as virtual lands and in-game items, represented as non-fungible tokens (NFTs). The Sandbox Metaverse includes LAND ownership, a blockchain-driven economy, VoxEdit, and Game Maker, which enable users to build their own virtual environments and monetise their creations. Additionally, The Sandbox offers a secure Marketplace for the exchange of distinct digital assets like NFTs. The $SAND Token Economy is as follows: Market Cap $928,808,327, 24-Hour Trading Volume $184,715,000, Total Supply 3,000,000,000 SAND, and Circulating Supply 2,101,731,926 SAND. These figures indicate the current state of the Sandbox in the crypto market and the general economic size of the SAND token. The market cap and trading volume reflect the platform's financial stability and popularity among users, while the total and circulating supply indicate the token's ($SAND) market presence and accessibility (EOS, 2023).

Decentraland Metaverse: Decentraland is a blockchain-based virtual reality platform that allows users to produce content and applications, use them, and earn money from the process. This innovative platform offers LANDs, virtual land parcels that users can buy and develop. In Decentraland, each LAND parcel serves as a foundation for creating distinctive scenes, games, and apps, supported by the platform's provision of Software Development Kits (SDKs) for developers to craft their own content and applications. Players are also empowered to design their own NFTs for sale in the Decentraland marketplace. The platform hosts various projects, such as virtual casinos, art galleries, and gaming experiences. Noteworthy among these are the Decentraland Art Museum, which displays digital art in a virtual setting, and the Decentraland Conference Centre, a venue for virtual events and conferences. The platform features a diverse range of games, including RPGs, racing games, and first-person shooters. A popular game, Battle Racers, invites players to customise and race cars, while Golf Craft offers wearables that can be exchanged for points, diamonds, or tickets earned within the Metaverse. These wearables are tradable in Decentraland's Marketplace, OpenSea, and other virtual marketplaces. Utilising blockchain technology, Decentraland ensures secure and reliable financial transactions. Transactions within the Metaverse are conducted on the Ethereum blockchain network, with smart contracts overseeing the development and execution of applications as well as the ownership and transfer of LAND. Key features of the Decentraland Metaverse include virtual LAND ownership, VR compatibility, SDKs and tools, a Marketplace, and decentralised governance, enabling users to purchase LAND for various purposes, create content, and engage in social activities within the Metaverse. $MANA, Decentraland's native cryptocurrency, is used for financial transactions on the platform. The market data for $MANA are as follows: Market Cap $911,388,683, 24-Hour Trading Volume $163,287,621, Circulating Supply 1,893,095,371 MANA, and Total Supply 2,193,179,327 MANA. These figures show Decentraland's current status in the cryptomarket and the overall economic size of the $MANA token (Miller, 2022).

The Sandbox and Decentraland were chosen as example platforms because of their typical features of owning a virtual settlement and allowing owners to create their own metaverses on these settlements.

2. Structural and Public Comparison of Decentraland and Sandbox Platforms

Decentraland and Sandbox are two distinct Metaverse platforms, each with its own features and emphases. Decentraland offers several content creation and gaming experiences, allowing users to purchase and develop unique virtual land parcels known as LANDs. It is notable for hosting various game types and facilitating the creation and trading of customised NFTs (Non-fungible tokens). In contrast, Sandbox adopts a community-focussed approach, offering users the opportunity to create and share their games, as well as to generate characters or DIDs (Decentralised Identifiers). It also allows users to trade assets (a set of products usable within the Metaverse) created by them with other users. In this context, Decentraland and Sandbox provide users with rich experiences aimed at different purposes, offering various options in the world of the Metaverse. The diversity and adaptability of these two platforms are reflected in their user numbers, indicating proportional differences.

2.1. Comparative Analysis of Structures

Comparing the number of parcels between Decentraland and The Sandbox, Decentraland, launched in 2017, has 90,000 parcels, while The Sandbox, launched in 2018, has 166,464 parcels. Decentraland, which does not require a cryptowallet, recommends software wallets integrated with browsers and applies a 2.5% MANA fee. In contrast, The Sandbox uses supported cryptowallets like MetaMask, Bitski, and Venly for security and stability, applying a 5% fee on all transactions. This percentage difference in buying and selling implies that Decentraland is more community- or public-oriented, as it provides a direct resource to the company's coffers. Decentraland's monthly user count reaches 300,000, while on the other hand, Sandbox's user base will reach 4.5 million in 2022. The Sandbox was launched in 2018 and currently has 1.06 billion SAND tokens in circulation. There are 1.86 billion $Mana tokens, Decentraland's token, in circulation. This indicates that the Sandbox has a stronger stance on the token side.

As seen in Table 1, using current information on market volumes, the 24-hour trading volumes of Decentraland's ($MANA) and Sandbox's ($SAND) cryptocurrencies can be examined. Decentraland's 24-hour trading volume is $163,287,621, while Sandbox's 24-hour trading volume is $184,715,000. In a comparative analysis, Sandbox's 24-hour trading volume is higher than that of Decentraland. This indicates that Sandbox experiences more intensive trading in the cryptocurrency market and more active trading among its users. However, when considering other factors and long-term trends, this is only a short-term snapshot. However, when considering other factors and long-term trends, this is only a short-term snapshot. Users should determine their preferences by evaluating a range of factors such as market conditions, platform features, and projects (Coin Market Cap, 2023).

Table 1. . Comparison of Sandbox and Decentraland Based ao Specific Criteria (The author has created this figure)

COMPARISON PARAMETER	SANDBOX	DECENTRALAND
Platform Type	Based virtual world platform + game	Blockchain-based virtual world platform + social
Token	$SAND	$MANA
Earnings	Earnings Participating in in-game activities, creating assets, participating in investment programmes Leasing land, organising events, selling assets	Land Ownership Possibility to create your own games and experiences on land Possibility to create your own content on land
Land Ownership	Opportunity to create your own games and experiences on land	Opportunity to create your own content on the land
Management and Stakeholder Involvement: DAO	Token holders and participation to the extent allowed by the Sandbox.	Full participation via DAO.
Token Economy	A total of $3 billion in SAND, decreasing in circulation through investment programmes	Total amount of 3.8 billion $MANA, with a buyback and burn mechanism in place.
Starting Year	2018	2017
Amount of Land	166,464	90,000
Requirements for a Cryptocurrency Wallet	Yes	No, but a software wallet is required to store digital assets.
Supported Wallets	MetaMask, Bitski, and Venly	Browser-integrated software wallets, MetaMask
Marketplace fees	A fee of 5% is applied to all transactions	A 2.5% MANA cost is applied to all transactions.
VR Compatibility	No	No
Aim	Creating, owning, and monetising gaming experiences	Creating, experiencing, and monetising applications and content

Decentraland and Sandbox are Metaverse platforms with distinct management structures and community participation features. MANA and LAND owners control Decentraland through the Decentraland DAO, a decentralized autonomous organization. Decentraland, established earlier than Sandbox, offers fewer lands but has a clear governance structure through its DAO system. Sandbox, on the other hand, provides a more robust gaming experience and has a detailed roadmap for future development.

Both platforms value community participation and the involvement of users in decision-making processes. While Decentraland focuses on decentralised governance and open-source contributions, Sandbox adopts a community-centric approach, encouraging interaction through collaborations and projects. The choice of platform for users depends on individual priorities, levels of participation, and the governance model.

In this arena where the features promised to users create a sharp distinction, Sandbox's commitment, especially in its 2023 plans, to assist in business development by providing specialised resources, teams, and support to more than 300 agencies and studios attracts not only users but also developers.

Decentraland and The Sandbox are two significant virtual world platforms based on blockchain. Each offers unique experiences with its own gaming and social interaction features.

The Sandbox allows participation in in-game activities, asset creation, and investment programmes using the $SAND token. Users can create their own games and experiences on their lands. In its DAO structure, token holders can be active to the extent defined by the Sandbox. It is a platform governed by a token economy of 3 billion $SAND (Coin Market Cap, 2023).

Conversely, Decentraland offers users the opportunity to earn through leasing land, organising events, and selling assets using the $MANA token. Users can create content on their lands. Full participation and governance are facilitated through the DAO structure, and there is a total of 3.8 billion $MANA in its buyback and burn mechanism.

Neither platform offers VR compatibility; instead, they provide opportunities to create experiences through gaming and social interactions and to monetise them. In Decentraland, the price of a land parcel in some areas exceeds $10,000, and owners use these virtual villas for various purposes. The land parcels in Decentraland adhere to design restrictions that allow various artworks to be created quickly, independent of browser speed. These rules function as a set of zoning regulations, determining everything from building heights to how close neighbouring structures should be.

Both platforms offer perspectives on why their land systems are designed on a grid basis. While The Sandbox provides a structure for users to develop creative content, Decentraland prefers a structure that facilitates interactions between users and content. Both systems offer a structural order that regulates and facilitates ownership and interaction in the virtual world.

2.2. Comparative Assessment in the Public Domain

Decentraland is a decentralised and open-source platform. It features a web application that provides a dynamic bird's-eye view of its virtual city map. The map, using Decentraland's open protocols, displays the city's various districts, lands, roads, buildings, and activities (Waldorf, 2018). These areas are constantly changing and evolving because they are being bought and sold by users.

The Decentraland map consists of 90 districts, each with a different theme and function for public space settlement. These districts are connected to a main square located in the centre of the virtual city, known as Genesis Plaza. Genesis Plaza serves as the heart of the public space, facilitating socialisation, entertainment, and learning. Figure 1 shows the social centre of the platform located in the centre, the social area of Decentraland plaza, and the park.

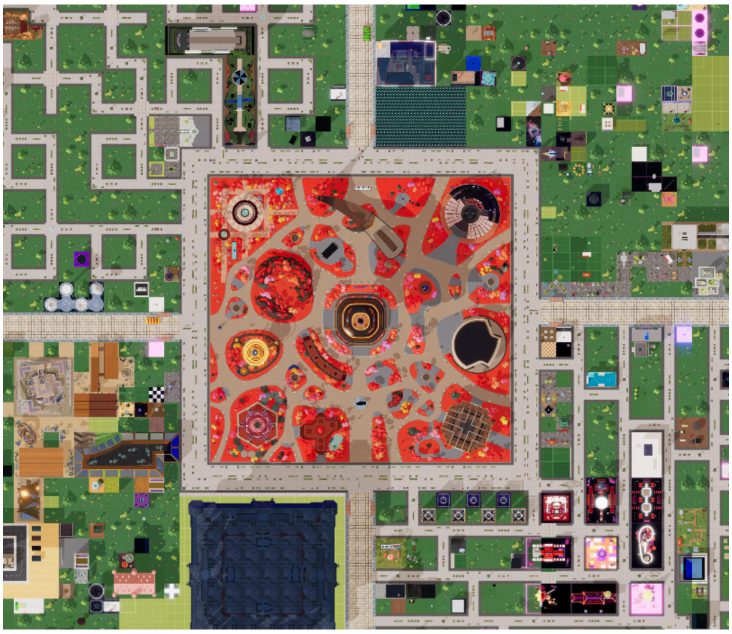

Figure 1. Decentraland's Map (Genesis City Map, 2023)

In terms of public space usage, Decentraland allows individuals to create their virtual identities and interact in public spaces. Individuals can play both consumer and producer roles in these areas. Consumers can navigate the public space, visit different districts, participate in events, and purchase or rent virtual goods. Producers can create, display, sell, or share their own lands, buildings, artworks, games, events, services, or other virtual goods in public spaces. Individuals can make or receive payments in MANA, their own cryptocurrency, for any transaction conducted in the public area (Coin Market Cap, 2023).

Other districts cover a variety of themes such as art, education, sports, gaming, shopping, music, culture, nature, history, science, technology, politics, religion, and philosophy. These areas allow individuals to participate in public spaces according to their interests. Figure 2 shows TMA World, an example of such a concept, in which a landowner has created a public space for experiencing a different form of life.

Decentraland's paradigm places land ownership firmly in the hands of the community, thereby endowing its members with absolute control over their virtual creations. Through a blockchain-based parcel ledger, users assert unequivocal ownership of virtual land, ensuring transparency and immutability in ownership records. Landowners wield authority over the content published on their allocated parcels, delineated by precise cartesian coordinates (x,y). Ownership of land within Decentraland confers not only governance rights but also facilitates the monetisation of virtual properties, underscoring the platform's commitment to decentralised governance and economic empowerment within the virtual realm.

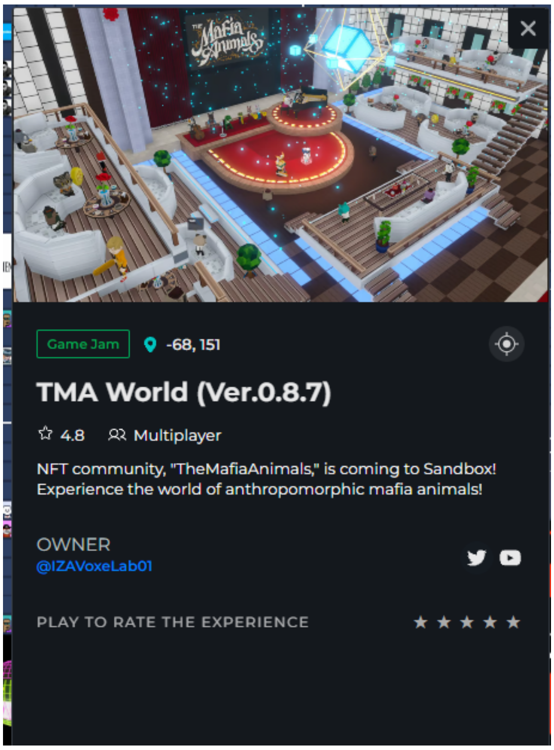

Figure 2. TMA World (Genesis City Map, 2023))

The Sandbox map is a web application that displays the different districts, lands, creators, and games of a virtual city. The Sandbox map has the following features in terms of public space settlement, usage, and urban planning: In terms of public space settlement, it consists of 166 districts with different themes and functions. These districts are connected to a main square located in the centre of the virtual city, known as the Elrond City Hub, as shown in Figure 3. Inside Elrond Hub, there are various centres such as the headquarters, metro, park, museum, hotel, casino, restaurant, airport, gaming centre, stadium, and rocket station. It has a decentralised system based on NFTs for participation (ElrondCityWhitePaper, 2023).

Figure 3. Elrond City Hub: Public Space Example (ElrondCityWhitePaper, 2023).

In Figure 4, the areas labelled "The Sandbox" on the map function as public spaces, facilitating socialisation, entertainment, and learning opportunities for individuals. On the map, the monkey icons represent NFTs (from the Bored Ape Yacht Club NFT collection), while areas marked "For Sale" are intended for advertising purposes. Additionally, MEDIECS and QuarkChain are represented as companies on the map.

Figure 4. The Sandbox Map (The Sandbox, 2023).

Similar to the Decentraland map, the other regions on the Sandbox map also encompass a variety of themes such as art, education, sports, gaming, shopping, music, culture, nature, history, science, technology, politics, religion, and philosophy. These areas provide individuals with the opportunity to participate in public spaces according to their interests. In addition, unlike the Sandbox, the Decentraland map features active public spaces. It is also noticeable that some areas on the Sandbox map are used for advertising.

In The Sandbox ecosystem, creators maintain full ownership rights over their assets, encompassing a comprehensive 100% control. All assets within The Sandbox adhere to copyright regulations, safeguarding the intellectual property of creators, provided that they do not infringe upon existing copyrights. Upon uploading content to The Sandbox, creators grant the platform an expansive licence, permitting the utilisation, reproduction, public display, distribution, and adaptation of the shared assets and games globally. This licence, devoid of royalty obligations, persists perpetually and irrevocably, empowering The Sandbox to foster the development, distribution, enhancement, and promotion of its services, activities, and assets and games publicly shared by creators.

The primary differences between The Sandbox and Decentraland lie in their approaches to ownership, governance, and control. In The Sandbox, creators retain 100% ownership rights over the assets they create, emphasising individual control over creative content. Conversely, Decentraland adopts a community-centric ownership model in which virtual land is permanently owned by the community as a whole. Users claim ownership of parcels on a blockchain-based ledger, ensuring decentralised ownership and governance. Creators in The Sandbox have complete control over their creations, dictating how assets are used and distributed within the platform. In contrast, landowners in Decentraland exercise control over the content published on their parcels of virtual land, allowing users to curate and manage their virtual environments. While creators in The Sandbox own their assets outright, the platform retains certain rights to utilise and promote these assets for development and service promotion. Monetisation opportunities vary on the basis of agreements between creators and the platform. In Decentraland, ownership of land grants users governance rights and the ability to monetise virtual properties through leasing, selling, hosting events, and participating in the platform's decentralised economy. In summary, The Sandbox emphasises individual ownership and control over creative assets, while Decentraland prioritises community ownership and decentralised governance. Each platform offers unique opportunities for engagement with virtual environments, characterised by distinct approaches to ownership, control, and monetisation (Blockchain Industry Group, 2023; Decentraland, 2023; The Sandbox, 2023).

The use of public spaces in Sandbox has characteristics similar to those of Decentraland. On the Sandbox platform, individuals can make or receive payments in SAND, their own cryptocurrency, for any transaction conducted in the public area.

In the context of Metaverse platforms, there is a heavy user base, and these users have participatory governance systems through Decentralised Autonomous Organisations (DAOs), especially in the context of decentralised management mechanisms. As mentioned earlier, the percentage of project shares taken from transactions again highlights Decentraland's emphasis on public welfare. On the other hand, considering the support and funding Sandbox provides to developers, it is evident that community creators, or the public, are the primary focus.

3. Conclusion

This study explores the concepts of the metaverse and public, analyzing the strengths and weaknesses of two prominent Metaverse platforms: Decentraland and Sandbox. Decentraland distinguishes itself with its well-established and older infrastructure, resulting in a wider user base and increased interaction and transaction volume. Its use of a DAO contributes to its decentralised nature, affording users greater control and freedom within the platform. However, the absence of a comprehensive roadmap for Decentraland introduces uncertainty regarding its future development, and exposure to competition may impact its user base and engagement.

In contrast, Sandbox benefits from a detailed roadmap and backing from prominent financial institutions, providing a clear direction for future development and fostering user trust. Nevertheless, its centralised nature limits user autonomy and freedom, and as an evolving project with potential competitors, it may face challenges in retaining its user base and engagement.

In terms of a public-oriented focus, Decentraland stands out due to its DAO and its contributions to public welfare, such as organising the Metaverse Music Festival and developing a Mental Health First Aid experience. This demonstrates that the platform extends beyond mere entertainment and can serve the community. Meanwhile, Sandbox's support for developers and development activities highlights its significant role in technology and innovation, indicating that it transcends being solely a gaming platform and can actively contribute to technological advancements and innovation.

Considering preferences for public spaces, both platforms have distinct advantages and disadvantages. Consequently, the choice between them hinges on individual user needs and expectations. Users are encouraged to select the platform that aligns best with their requirements when deciding among Metaverse platforms, as this can enhance their experience and contribute to the sustainable growth of these platforms. This study aims to aid users in identifying critical factors to consider when making choices among Metaverse platforms, serving as a valuable resource for comprehending the relationship between the Metaverse and the public, the prospective development of Metaverse platforms, and strategies for maximising user benefits within these platforms.

Peer Review: Externally peer-reviewed.
Author Contributions: Conception / Design of Study – E.Ö., Ş.Y.S.; Data Acquisition - E.Ö., Ş.Y.S.; Data Analysis / Interpretation - E.Ö., Ş.Y.S.; Drafting Manuscript - E.Ö., Ş.Y.S.; Critical Revision of Manuscript – E.Ö., Ş.Y.S.; Final Approval and Accountability - E.Ö., Ş.Y.S.; Technical or Material Support - E.Ö., Ş.Y.S.; Supervision - E.Ö., Ş.Y.S.
Conflict of Interest: The authors have no conflict of interest to declare.
Grant Support: The authors declared that this study have received no financial support.

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How cite this article

Özkoç, E., & Yalçın Sarabil, Ş. (2024). Models for Positioning Public Spaces in the Metaverse. *Journal of Technology in Architecture Design and Planning, 2*(2), 64–76. https://doi.org/10.26650/JTADP.24.008

İSTANBUL UNIVERSITY PRESS

Journal of Technology in Architecture, Design, and Planning
JTADP 2024, 2 (2), 77–84
DOI: 10.26650/JTADP.24.010

RESEARCH ARTICLE

The Approach and Importance of Urban Drainage from The Past to The Present

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ABSTRACT

Urban drainage and basic infrastructure systems, including the collection and controlled management of rainwater and wastewater, have been important throughout history. The origin of well-designed systematic drainage systems dates back to the Bronze Age. This systematic drainage design has continued to evolve over time. The common denominator of these systems is the efficient use of natural resources and the creation of liveable and resilient living spaces, which form the basis of the urban drainage technologies used today. It is clear that sewerage and drainage systems in cities are very important and will be an important part of future urban planning. Today, urban drainage and water management has to meet expectations beyond its historical importance due to concepts such as urbanisation, climate change, and energy conservation. Therefore, sustainable drainage systems are gaining attention for their ability to reduce carbon footprints, improve surface water runoff, and control flood risk. This article discusses the basic principles of drainage and assesses how important it has been for settlements throughout history and how it should be dealt with in the future using new concepts.

Keywords: Drainage, water management, sustainable drainage systems

Introduction

Throughout history, all successful civilisations have focused on efficient drainage systems that facilitate land reclamation, separate wastewater from drinking water and allow rainwater to be used for agricultural irrigation. Many historic excavations have uncovered earthen reservoirs, cisterns, manhole covers, in situ drainage channels, and ditches dating back to ancient times. The wetlands irrigated by the Nile in ancient Egypt were drained and used for agricultural production 6,000 years ago (Whalen & Sampedro, 2010). In DeAgri Cultura, written by Marcus Porcius Cato in the 2nd century BC, the drainage methods used by Roman farmers were described in detail (Cato, 2010). There is no doubt that drainage is essential for human life.

Historical evidence shows that factors such as climate, topography, local conditions, and materials have influenced urban drainage techniques. The first applications, which began with trial and error, evolved over time with experience, leading to the current drainage systems and water management principles used today (Burian & Edwards, 2002). Throughout history, storm water and wastewater have been considered in urban drainage systems, and these water types have either been combined in a single channel or kept separate during collection and disposal.

Historical Background

Archaeological evidence shows that humans have needed drainage systems since the moment they began to control their environment, and that the collection of rainwater and storm water from urban areas was at the heart of this need. As Cun et al. (2019) stated in their article, the world's first urban hydraulic systems date back to the Bronze Age (ca. 2800–1100 BCE) (Mays et al., 2007), and urban storm water management systems have existed since 3500–1100 BCE (Angelakis, 2017).

Mesopotamian cities are characterised by well-designed drainage systems. In the ancient cities of Ur and Babylon, for example, rainwater was controlled by gutters and drainage systems, while domestic waste was controlled by vaulted sewers. It is noteworthy that bricks baked with asphalt sealants were used in these systems. Rainwater was also collected and used for irrigation and

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Submitted: 10.05.2024 • **Revision Requested:** 13.06.2024 • **Last Revision Received:** 29.08.2024 • **Accepted:** 31.08.2024 • **Published Online:** 13.11.2024

domestic purposes (Burian & Edwards, 2002). In Habuba, wastewater was collected through U-shaped terracotta pipes that ran under the streets and drains lined with stone slabs and transported outside the city walls (Angelakis, 2016).

The most striking examples of a drainage system coordinated with the layout of urban areas and organised according to a plan can be found in the Indus civilisation. For example, in Harappa and Mohenjo-Daro, most dwellings were connected to open channels built in the middle of the streets. The channels are known to have been constructed either by excavating earth or by using burnt bricks above ground and sealing them with mud mortar. The fact that sewage was not discharged directly into the street sewers indicates that urban drainage systems were used to convey waste and rainwater (Burian & Edwards, 2002; Possehl, 2002). These settlements used reservoirs to collect rainwater.

The remains of the Minoan civilisation in Crete show extensive drainage systems. This evidence suggests that advanced water management and sanitation techniques were used in Minoan settlements; therefore, the architectural and hydraulic functions of rainwater and sewage systems were of great importance (Angelakis & Spyridakis, 2010). The remains of Minoan civilisation show that rainwater was conveyed by terracotta pipes and that there were stone drainage systems for sanitary sewerage, roof drainage and surface drainage. Rainwater was collected via both roof and surface collection. Wide-branched stone channels and terracotta pipes were used to convey water to the cisterns (Charlesworth et al., 2016; Burian & Edwards, 2002; Gorokhovich, et al., 2011). As Yannopoulos et al. (2017) pointed out, in Hellas, as in other ancient civilisations, drainage and sewerage systems were combined. Figure 1 shows the drainage pipe used in Ephesus, Turkey.

Figure 1. Pipes used in Ephesus, Turkey (Photo by N.P.Seçkin).

The collection of rainwater for later use in urban drainage systems has been widely used in past civilisations. The use of cisterns dates back to the Neolithic period; rainwater and urban runoff are known to have been collected in cisterns in Persia, and surface water storage technology was developed and used for a long time in ancient Crete. In the Hellenistic period, most cisterns were fed by rainwater, while some were fed by spring water. In Roman times, water collected on roofs was transferred to a cistern inside the house (Burian et al., 2002; Mays et al., 2013).

Aqueducts, which transport water from the source to the main distribution point, were widely used by ancient civilisations to supply water to cities and agricultural areas. The first example is the Nineveh aqueduct built by the Assyrians at Jerwan to supply water to the city of Nineveh. Some of the aqueducts, the most spectacular examples of which can be seen in the Hellenistic and Roman periods, were fed by surface water; most of them were reinforced by springs. The aqueducts in the Roman city of Timgad in North Africa were known to have been fed by qanats, a kind of underground tunnel that carried water from a well to the surface. Wings are known to have appeared in the Middle East at the beginning of the first millennium BCE and are still used in arid regions (Britannica, 2022; 2024; Deming, 2020).

Herculaneum, a Roman city, had a systematic sewage system. The drainage of rainwater and sewage from the city through cobbled streets, the presence of drainage holes in the pavement, and a sewer system under the street indicate the existence of a system for the disposal of sewage and rainwater (De Feo et al., 2014). This observation has been confirmed in Pompeii. The street drainage system consisted of openings on the vertical surface of the kerbstones or openings in the pavement, channels, and manholes to which the drain was connected. Drainage followed the gradient of the road, and the collected water was discharged into the main street sewer, to which the water draining from the buildings was also connected (Mays, 2001). However, stepping stones were used to allow pedestrians to cross the streets without stepping on wet ground caused by rain, flooding, bath water, or fountains (Figure 2).

Figure 2. Stepping stones in Pompeii (Photo by H.Kayan).

The concept of the urban water cycle, first encountered in Roman times, became widespread in Europe and the United States in the late nineteenth century, with the construction of piped water supplies and water-carrying sewer systems. The installation of kerbs and gutters or the levelling of roadbeds to divert surface runoff from streets to drainage channels are important findings (Burian & Edwards, 2002).

Historically, the fact that settlements in ancient China were built near large rivers provided both a source of water and an opportunity to control storm water. The basic principle in the design of drainage systems is to utilise the natural terrain, reduce surface runoff from the site, and effectively recycle rainwater, in short, to integrate the urban and natural environment (Che et al., 2013). In addition to a sewerage system that forms a perfect network, structural solutions that prevent surface runoff, pavements that act as both aesthetic and infiltration can be given as examples. The courtyard complex of individual buildings represents traditional dwellings. As Cun et al. (2019) explains, 'Micro drainage systems in courtyard complexes collect rainwater and convey it via minor drainage systems to the architecture-community-level drainage system. Rainwater gathered in community sewers is then transported to the main urban sewers for discharge into the major drainage system. All of these rainwater management practises at different scales, including natural retention, natural infiltration, and natural treatment, are consistent with the Sponge City concept. Water cellars are also widely used, especially in areas with erratic rainfall and water shortages during dry periods. In this method, rainwater collected from the ground and roof is combined and stored in a settling tank (Zhou et al., 2021).

The rapid growth of urbanisation in the 18th and 19th centuries, coupled with serious public health problems, led to the search for solutions and the development of urban drainage practises. For example, the cholera epidemic in London in the 19th century was solved by the construction of a series of combined preventative sewers north and south of the Thames. However, in the absence of a treatment system, the Thames estuary and its banks were polluted. Since the introduction of biological treatment in the 1920s, urban drainage systems have evolved in line with technical requirements (Butler et al., 2018).

The most significant change in drainage from ancient times to this day has been the choice of materials used to make pipes. Initially made of earth, pipes have been made of lead, wood, stone, and even bamboo; in the present day, copper, brass, concrete, and plastic pipes have replaced the materials of the past to facilitate the flow of water (Seçkin et al., 2017).

Principles of urban drainage

As technology has progressed, drainage systems using high-pressure pumps have been developed alongside traditional systems based on the attraction of water. The aim is to make good use of water, control erosion, and remove water quickly and safely from the foundation, roof, and perimeter of buildings.

Rainwater, in particular, is the main cause of erosion. The aim of drainage is to collect, control and channel water to prevent flooding and erosion, to prevent stagnant water and frost damage to the soil, to maintain the bearing capacity of the soil and to ensure the sustainability of effective waterproofing in buildings. This can be achieved by using surface and subsurface drainage systems or a combination of these. Surface drainage is an open system, whereas subsurface drainage is a closed system. In storm water drainage systems, a number of system elements such as natural drainage beds, open ditches, channels or gutters, culverts, drains, above- and underground pipes, and manholes are used to control and render harmless surface runoff. For example, rainwater falling on the roof of a building flows from the roof surface to the gutters. Rainwater flows from the gutters into the downpipes. These pipes are either poured onto a terrace or concrete or grass surface for wall base protection. If the rainwater downpipes are connected to the underground drainage pipes, the water is drained away from the building site via the underground drainage system and is harmless. However, if there is no such connection, the water that falls from the downpipes onto the ground surface will flow down the slope and away from the wall if this surface slopes away from the building wall. Otherwise, it will collect at the base of the wall, be absorbed by the soil, raise the water table, and potentially damage the structure if there is no drainage system at the base of the building wall.

As mentioned earlier, two types of sewer systems can be conventionally defined: a combined system, in which wastewater and storm water flow together in the same pipe, and a separate system, in which wastewater and storm water are kept in separate pipes. The combined system carries wastewater when it is not raining. When it rains, storm water is added, and the flow of water in the sewer increases. This large volume of wastewater is minimally treated and discharged into the environment, thereby causing pollution. In a separate system, rainwater and wastewater do not mix and can be discharged at an appropriate time. However, rainwater can be polluted for several reasons, such as washing pollutants from the catchment surface, and is slightly more expensive than a combined system (Butler et al., 2018).

Storm water drainage systems are more important in areas where development or settlement is intensively intercepted by storm water runoff. In fact, while under natural conditions about 20-30 per cent of annual precipitation is surface runoff, in areas of high density development this proportion increases to 90-95 per cent (Untermann, 1973). Increased density means an increase in surfaces such as vehicular and/or pedestrian roads, car parks, roofs, and terraces, which causes rapid surface runoff immediately after rainfall. This situation increases the importance of drainage systems.

In a good drainage system, gravity is the main factor governing the formation of surface runoff. The slope of the surface plays an important role. Erosion is the main drainage problem. Both fast and slow movement of water on the ground is harmful. The former leads to erosion and unwanted potholes, while the latter causes formations such as wet soils and swamps. This creates risks that negatively affect the sustainability of waterproofing. In this context, the success of waterproofing in buildings depends on the selection of the appropriate waterproofing material, the correct and faultless application of the waterproofing, and, where necessary, the installation of an adequate drainage system (Seckin et al., 2017).

Land drainage, foundations, floor slabs, walls, wall cavities, wallvoids, ceiling slabs, roofs, plumbing, heating, ventilation, and cooling systems are very important in the design development process to remove water from buildings. These need to be analysed separately. The starting point is the site drainage. Topography, soil type and soil structure are important. Groundwater levels, average rainfall, existing infrastructure, and irrigation systems are also critical to the design of land drainage. All this is important for the correct design of the land drainage, as well as for determining the location of the structure on the site and the finished ground elevation.

Land drainage and levelling are inextricably linked. Grading is the most important solution for reducing runoff velocity and achieving a good infiltration rate, and it should be performed in accordance with the existing topography without disturbing the shape of the existing contour lines. The grading plan and implementation should take into account the collection and removal of water before it reaches the building, allow water to flow without ponding in specific areas, and ensure that perimeter elevations are at least 15 cm below the finished floor level of the building. This will control runoff water from buildings, which can be controlled by rapidly removing runoff from the project area using drainage structures such as channels, aggregate-filled infiltration trenches or tunnels, and detention and retention ponds (Seckin et al., 2017).

Sustainable Drainage Systems

Mays (2007) defined the sustainability of water resources as the ability to use water in sufficient quantity and quality, from the local to the global scale, to meet the needs of people and ecosystems for the present and the future, to sustain life, and to protect people from damage caused by natural and man-made disasters that affect the sustainability of life.

Urban drainage techniques and surface water management strategies can be traced through historical records and archaeological remains. Similar source control methods, such as infiltration, storage, and conveyance in sustainable drainage systems (SuDS), are well known and effectively used in old settlements (Charlesworth et al., 2016). However, similar examples of sustainable rainwater harvesting systems can be found in traditional settlements. The main source of urban water in ancient Egypt was rainwater, and it was associated with structures such as canals and aqueducts (Mays, 2008). As noted by Charlesworth et al. (2016), rainwater collected from roof basins is sometimes conveyed through terracotta pipes to underground cisterns where it is stored. The use of sand filters where water supply was dependent on rainfall, reservoirs to store retained surface and rainwater, and floating aquatic plants in areas where evaporation was likely to significantly reduce volume, such as the ancient Maya, are practises found in antiquity. The use of a coarse sand filter at Phaistos in Crete to remove silt and other pollutants before water was stored in cisterns; the use of infiltrating pavements, meandering swales, and water harvesting at Machu Picchu are good examples of a sustainable drainage strategy (Charlesworth et al., 2016). However, traditional methods such as steels, ponds, and agricultural land used for rainwater harvesting in India are remarkable.

The climate, topographical features, and natural resources of a region, density of urbanisation, the wealth of the communities, history, legislation, and policies determine the scope and quality of urban drainage systems (Butler et al., 2018). Looking at the information that has survived from the historical record to the present day, changes in the understanding of urban water management over time can be constructed as an evolution of the previous stages. Brown et al. (2009) explained this situation in terms of a network of relationships (Figure 3). Based on a historical analysis of technical and institutional arrangements in urban water management, this network identifies six different stages of urban development that cities have gone through in achieving water sensitivity.

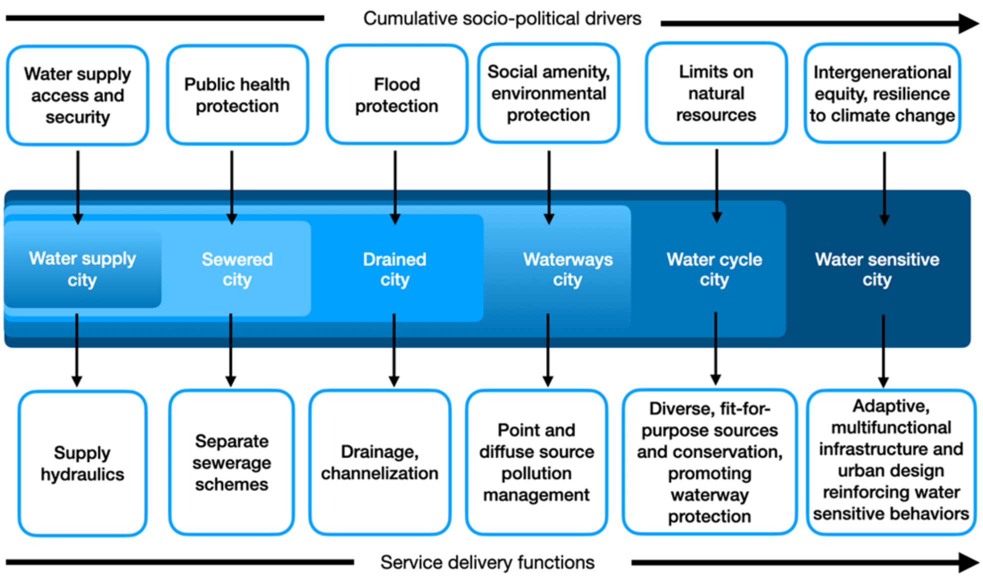

Figure 3. Urban water management transition states (Reproduced from Brown, et al., 2009).

Traditional urban water management is concerned with meeting water needs and removing surface runoff and wastewater from the city. Today, however, the recycling and reuse of rainwater and wastewater are gaining importance in line with cities' sustainability and development goals. Therefore, urban water management requires an integrated system that meets water demand, reuses wastewater, and controls storm water (Wen, 2019).

Due to climate change, the management of flood risk and extreme rainfall in urban areas is becoming increasingly important. Sustainable drainage systems (SuDS), includes 'technical solutions for transporting surface water, slowing down the runoff before it enters watercourses, storing or reusing water at the source, or allowing water to fall on permeable surfaces and soak into the ground' (EPOA, 2024). The systematic use of green roofs, permeable pavements, rain gardens, and canals as part of SuDS can help urban areas become more resilient to flooding and improve the quality of source water (Figure 4).

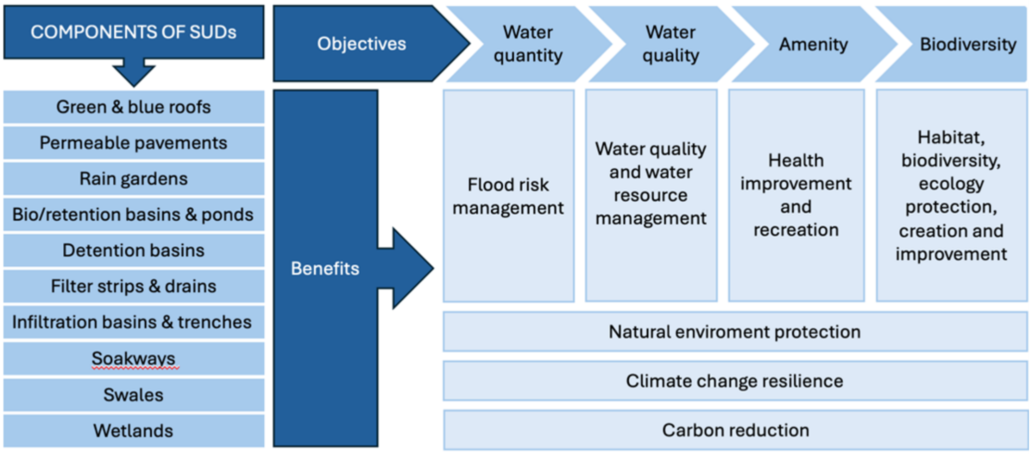

Figure 4. Components, objectives, and benefits of Sustainable drainage systems.

Rainwater harvesting should be the main principle for rainfall management in urban areas. This allows water collected from roofs and other surfaces to be reused. The SuDS network should take into account natural drainage paths, infiltration, and discharge rates. The best example of a sustainable urban drainage system that can filter pollutants through natural treatment is the use of vegetation. Water infiltrates through vegetation, and pollutants in the water decompose and are removed from the water. Vegetated water storage solutions include dry attenuation basins, balancing ponds (wet systems, and shallow vegetated or bio-swales.

Conclusion

The concept of drainage and road use dates back to the early Mesopotamian Empire. However, as we know from De Feo et al. (2014), well-organised and operated sewerage and drainage systems were first used in the Minoan and Harappan civilisations of Crete. The use of hydraulic systems for water supply, distribution, and the transfer of rainwater to the sewers was evident from Minoan remains. These drainage designs, which began with the Minoan and Indus Valley civilisations and were further developed during the Hellenistic and Roman periods, formed the basis of sewerage and drainage technologies in urban environments. The main purpose of these systems is to efficiently use natural resources, making civilisations more resilient to disasters and improving living standards (Angelakis, 2017; Angelakis & Spyridakis, 2013; De Feo et al., 2014).

There is no doubt that urban drainage and sanitation systems will be an important part of future urban planning. Urban drainage and water management must meet today's expectations far beyond its historical importance due to concepts such as urbanisation, climate change and energy saving, which have gained importance today. Population growth and urbanisation can lead to further depletion of already insufficient water resources, increased pollution and health risks in urban areas and negative impacts on wastewater infrastructure. The inadequacy and obsolescence of the infrastructure systems of existing buildings and facilities, combined with new growth and urbanisation rates and increasing environmental expectations, may require costly new investments (De Feo, et al., 2014).

Infrastructure systems that are renewed or built from scratch should be developed in a way that does not contribute to the carbon footprint and therefore does not contribute to climate change and that supports natural life. Sustainable drainage systems (SuDS), which provide a natural approach to rainfall management in urban areas, slow water runoff and improve water quality and storage capacity. The main principle of SuDS is the treatment and management of storm water, which helps to achieve sustainable development goals. This approach avoids the need for extensive surface water conveyance infrastructure, reduces capital costs and carbon footprint, and controls flood risk. In addition to these technical benefits, it provides an aesthetic appearance to the area where it is used by increasing green open space. The functional impact of a smart city building can be enhanced by integration with urban facilities. Some SuDS techniques, such as green roof rain gardens, support biodiversity and ecosystems while providing water management.

Urban drainage has evolved and progressed throughout history, but its basic purpose and principles have not changed. Today, urban drainage has become even more important because of global warming and climate change, which have become a threat to the whole world. By controlling water using methods that are in harmony with nature, it will meet environmental, climatic, and aesthetic requirements and allow cities to maintain their unique value.

Peer Review: Externally peer-reviewed.
Conflict of Interest: The author have no conflict of interest to declare.
Grant Support: The author declared that this study have received no financial support.

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How cite this article

Seçkin, N. P. (2024). The Approach and Importance of Urban Drainage from The Past to The Present. *Journal of Technology in Architecture Design and Planning, 2*(2), 77–84. https://doi.org/10.26650/JTADP.24.010

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Journal of Technology in Architecture, Design, and Planning
JTADP 2024, 2 (2), 85–93
DOI: 10.26650/JTADP.24.009

RESEARCH ARTICLE

Urban Furniture Design Using Steel Fibre Reinforced Concrete with Digital Design

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ABSTRACT

This research, conducted on the use of steel fibre reinforced concrete (SFRC) in urban furniture, investigates the performance of this material, which has the potential to offer more durable and aesthetic solutions than traditional concrete. In this study, both experimental and numerical methods were used to evaluate the mechanical properties of the SFRC and its applicability in urban furniture. As a result of the experiments conducted on concrete mixtures containing different ratios of steel fibres, it was observed that the ratio of steel fibres significantly affected the mechanical properties of concrete, such as compressive strength, flexural strength, and fracture energy. The obtained data show that steel fibres increase the strength of concrete and reduce the risk of cracking, thereby enabling the production of more durable structures. In addition, the stress distribution and crack formation in the concrete internal structure were examined using computer-aided analysis. In this way, we better understood how steel fibres affect the behaviour of concrete, and important data were obtained for the design of urban furniture with different geometries. As a result, this study shows that the use of steel fibre reinforced concrete in urban furniture offers many advantages. SFRC provides both aesthetically rich options and structurally more durable solutions. In this way, urban furniture should be both visually attractive and long-lasting.

Keywords: Steel fibre reinforced concrete, Urban furniture, Materials science, Grasshopper, Karamba3D

1. Introduction

In the 21st century, with the rapid development of urbanisation processes, cities have become not only areas where housing and infrastructure services are provided but also spaces that are constantly evolving in terms of aesthetics and functionality. This process requires cities to offer liveable spaces that appeal to users not only functionally but also aesthetically. Urban furniture is an important component of cities in this context. Used in parks, squares, roads, and other public areas, urban furniture must meet both aesthetic and functional expectations. The materials used in urban furniture design play a critical role in meeting these expectations. Although traditional concrete has been widely used in the construction sector for many years, it is insufficient for structures with thin sections and complex forms. Cracks, durability problems, and aesthetic limitations are some of the weaknesses of traditional concrete. These shortcomings have led to a search for more durable, flexible, and aesthetic solutions. In recent years, various new materials and technologies have been developed as a result of these searches. One such material is steel fibre reinforced concrete (SFRC). SFRC stands out because of its high strength and durability. Exhibiting superior mechanical properties compared to traditional concrete, this material is particularly prominent for its crack resistance, energy absorption capacity, and long-lasting structure (Gupta et al., 2023). The advantages of SFRC make it attractive, especially for use in urban furniture with thin and complex geometries. Research on the use of this material in urban furniture can offer new solutions that comply with fundamental design principles such as aesthetics and functionality. Urban furniture is an element that increases human interaction in the city, provides user comfort, and at the same time strengthens the city's identity aesthetically. While the widespread use of concrete offers a cost-effective solution in the production of urban furniture, it has certain limitations, especially in terms of aesthetics and durability (Nilimaa et al., 2023). In this context, SFRC symbolises the beginning of a new era in urban furniture. By offering both aesthetic variety and durability, this material goes beyond the traditional usage limits of concrete and supports innovative approaches to urban furniture design. Although traditional concrete is a widely used material in the construction sector, there is a need for new materials due to cracking and durability problems, especially in thin-section structures. SFRC is an innovative material developed to increase crack resistance and improve the mechanical performance of concrete. SFRC provides extra strength

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Submitted: 07.10.2024 • **Revision Requested:** 04.11.2024 • **Last Revision Received:** 06.11.2024 • **Accepted:** 07.11.2024 • **Published Online:** 14.11.2024

to concrete as a result of the homogeneous distribution of steel fibres within the concrete, and thus minimises the risk of cracking (Liew & Akbar, 2020). This characteristic renders SFRC an attractive material, especially in areas such as thin sections, complex geometric structures, and urban furniture with aesthetic concerns. The advantages of SFRC are not limited to increasing crack resistance but also go beyond the limitations of traditional concrete in terms of aesthetics (Singh, 2017). This material can make an aesthetic contribution to urban furniture with different colours, textures, and surface applications. At the same time, the SFRC, which offers significant advantages in terms of sustainability, emerges as a cost-effective solution because of its longer lifespan and reduced maintenance requirements. There have been many studies in the literature on steel fibre reinforced concrete. Studies on the use of SFRC in structural elements, in particular, have examined in detail the high strength and crack resistance of this material. Ossama et al. (2021) presented important findings on the use of this material in structural elements such as beams and slabs by examining the mechanical performance of SFRCs with different fibre types and ratios (Osama, ve diğerleri, 2021). Anbuchezian et al. (2023) experimentally evaluated the effect of different additives on the crack resistance of SFRC (Anbuchezian et al., 2023). In another study by Hosseinzadeh et al. (2023), the energy absorption capacity of SFRC was studied, and the performance of this material under harsh environmental conditions was detailed (Hosseinzadeh et al., 2023). However, the literature on the use of SFRCs in more specific and aesthetically oriented applications, such as urban furniture. Blazy et al. (2022) made a significant contribution in this area by evaluating the use of glass fibre reinforced concretes in smart cities (Blazy et al., 2022). Graur et al. (2023) investigated the effect of geometric forms on the aesthetic and functional designs of concrete furniture (Graur et al., 2023). Studies by Soulioti et al. (2015) and Ghosni et al. (2016) have shown how steel fibres improve the mechanical properties of concrete, revealing the potential of SFRC for use in urban furniture (Soulioti et al., 2011), (Ghosni et al., 2016). However, existing studies in the literature have generally focused on structural elements, and comprehensive studies detailing the applications of SFRC in urban furniture are rare. This situation increases the importance of this study, which aims to investigate the potential of SFRC in applications in which aesthetic and functional requirements are at the forefront, such as urban furniture. The main question of this research is whether steel fibre reinforced concrete can perform better than traditional concrete in urban furniture and whether this material can offer more durable and aesthetic solutions. The hypothesis of this research is as follows:

- Digital simulations can accurately predict the behaviour of SFRCs in different geometries and optimise design processes.

The main purpose of this study is to investigate the potential use of SFRC in urban furniture and to fill the gap in the literature on this topic. The aesthetic and mechanical advantages of the SFRC are evaluated both theoretically and experimentally. In addition, the behaviour of the SFRC in different geometries will be simulated using digital design tools, and the results of these simulations will be verified using physical tests. In this way, this study aims to obtain important findings on how SFRC can be used in the design and production processes of urban furniture. The use of SFRC in urban furniture can offer new solutions that meet the aesthetic and functional requirements of modern cities. The importance of this study stems from the fact that SFRC can be evaluated as a material that can contribute to the aesthetics and durability of urban furniture. Given the existing deficiencies in the literature, this study can be an important source of information on the use of SFRC in urban furniture. The structure of the study is organised as follows: In the first section, the research method related to the use of SFRC in urban furniture is explained. In the second section, the theoretical foundations of the SFRC are discussed by focusing on its mechanical properties and aesthetic advantages. Numerical analyses and simulations conducted using digital design tools are presented. The test results of the SFRC samples and their analyses are included. The fourth section contains the discussion section. In the last section, an evaluation of the findings obtained throughout the study is presented, and recommendations for the future are presented. In conclusion, this research investigates the potential use of steel fibre reinforced concrete in urban furniture both theoretically and experimentally. In thin and complex geometries where traditional concrete is weak, the high strength, flexibility, and aesthetic advantages of SFRC offer new possibilities for urban furniture design. This study examines in detail how SFRC can be integrated into architectural design processes, how it can be modelled with digital tools, and how it can meet both the aesthetic and functional requirements of urban furniture. The findings will contribute to the durable and aesthetic design of urban furniture and offer innovative solutions that will improve the quality of urban spaces.

2. Methodology

2.1. Research Model

A mixed-methods research model was used in this study. The mixed-methods approach combines quantitative and qualitative research methods and complements each other. Within the scope of the study, quantitative data were obtained through physical and digital testing of the mechanical properties of steel fibre reinforced concrete, while qualitative data were obtained from the literature to form a theoretical framework. This method aims to comprehensively analyse the performance of SFRC in urban furniture.

2.2. Research Design

Quantitative data were obtained from experimental studies conducted on SFRC mixtures with different material ratios and from analyses conducted in Rhino, Grasshopper, and Karamba3D. Through these experiments, numerical data on the mechanical properties of SFRC (strength, flexibility, etc.) were collected. Qualitative data were obtained by reviewing existing scientific publications. In this way, information about the use of the SFRC in previous studies and the results obtained was obtained. By evaluating both quantitative and qualitative data together, the advantages, disadvantages, and potential application areas of using SFRC in urban furniture were clarified. This approach provides a deeper and more comprehensive understanding of the use of SFRC in urban furniture.

2.3. Study Group and Universe

In this study, urban furniture prototypes were produced using steel fibre concrete mixtures with different material ratios were examined. The focus of this research is on small-scale structural elements used in urban areas such as city squares and parks; in other words, urban furniture. The experiments conducted on these prototypes provide important data on the structural and aesthetic performance of using steel fibre concrete in such structural elements.

2.4. Data Analysis

All data collected in the study was analysed carefully. Numerical data obtained from experimental studies were examined in detail to reveal the mechanical properties of concrete. In this way, a clearer understanding of important parameters such as the strength and flexibility of concrete was obtained. The data obtained from the computer simulations were visualised using graphs and tables, allowing for a better understanding of the behaviour of concrete in different regions. In this way, important details such as the stress distribution and crack formation in the concrete internal structure can be obtained. Finally, all the data obtained from both the experimental and computer-aided methods were combined, and a comprehensive evaluation was made of the use of steel fibre reinforced concrete in urban furniture. Thanks to this evaluation, the advantages, disadvantages, and usage limits of concrete in such applications were determined, and an important roadmap was created for future studies.

2.5. Reliability and Validity

The reliability and validity of the research were ensured through various methods, increasing the objectivity and generalizability of the results. Experimental studies were carried out using standard methods and measurement tools and were repeated on several samples with different steel fibre ratios. It can be concluded that the results obtained are generally valid. In addition, the material models used in the digital simulations were verified by comparing them with the real experimental results. This also increased the reliability of the simulations. Throughout this process, a systematic approach was adopted to minimise subjective effects.

3. Results

In this study, the mechanical behaviour and structural performance of steel fibre reinforced concrete were investigated using experimental and numerical methods. Concrete mixtures containing different ratios of steel fibres were prepared, and the important mechanical properties, such as compressive strength, flexural strength, and fracture energy, of these mixtures were determined. In addition, experimental studies were conducted on the prepared specimens, and the obtained data were supported by FEA. The obtained findings provide important design parameters for the use of SFRC in structural elements.

3.1. Mechanical Test Results

A comprehensive experimental study was carried out to improve the mechanical properties of reinforced steel concrete, which is gaining increasing importance in the construction sector. In this study, 14 different concrete mixtures with different material ratios were prepared. Important mechanical properties, such as compressive strength, flexural strength, and fracture energy, were evaluated on specimens obtained from the prepared mixtures. Because of the tests conducted on the specimens under standard conditions, the effects of the steel fibre ratio on the strength and other mechanical properties of concrete were investigated. In this way, it is aimed to contribute to the construction of safer and more durable urban furniture by determining the most suitable usage ratios of concrete with different material ratios.

Table 1. Concrete Components Table.

Mixture No.	Cement	Silica Sand (0.5 mm)	Silica Sand (0.52 mm))	Silica Fume	Mosaic Semolina (24 mm) Basalt Black	Steel wire tip 2 (3D30 mm)	PP Fibre (12 mm)	PP Fibre (30 mm)	Glass Fibre (12 mm)	Additive hyperplas ticizer	Water
N0	200	279	397	0	0	0	0	0	0	23	170
N1	200	154	151	96	0	35	3	0	0	91	200
N2	200	147	143	96	0	35	0	0	15	91	200
N3	200	147	143	96	0	35	0	0	10	109	200
N4	200	144	0	65	73	35	0	0	10	82	150
N5	200	173	170	74	0	35	0	0	10	91	190
N6	200	146	143	87	0	0	15	0	10	109	200
N7	200	173	170	87	0	0	0	0	0	91	150
N8	200	154	151	87	0	0	0	0	5	91	200
N9	200	154	151	87	0	0	0	10	5	91	170
N10	200	162	159	87	0	0	3	10	0	91	165
N11	200	146	125	65	94	35	3	0	0	26	180
N12	200	146	132	65	94	0	3	10	0	26	200
N13	200	135	121	65	94	35	3	0	0	26	200

Table 1, which lists the components of concrete mixtures mixed in different proportions, was prepared to produce concretes with different properties. In this way, it is aimed to determine the most suitable concrete mixture for a specific application by comparing the performances of different concrete mixtures. Such studies are important to understand how the properties of concrete, such as its strength, permeability, and workability, respond to different component ratios.

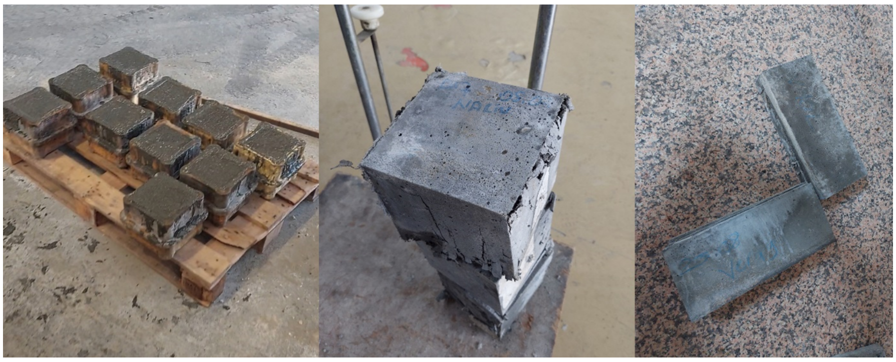

Figure 1. Concrete Mix Development Process.

The sample shown in Figure 1 was developed based on the information obtained from the test results of the previous sample. Thus, new samples with better performance were produced by eliminating the deficiencies and inadequacies observed in the previous samples. In particular, the aim was to obtain a concrete mixture with fluidity suitable for easy shaping in moulds for thin-section concrete urban furniture while also meeting the desired strength values. In this process, each sample was optimised according to the test results of the previous one, gradually approaching the concrete mixture most suitable for the desired properties.

Table 2. Properties of fresh and hardened concrete mixtures.

Mixture No.	Mixer Speed (rpm)	Depression (mm)	Decomposition	Other Observations
N0	11	No	No	Normal Consistency
N1	11.4	No	No	Very Fluent
N2	11.6	No	No	Less Fluent
N3	10	Yes	Decomposition	Very Strict
N4	11.5	No	No	Good Consistency
N5	12	Yes	Aggregate Settlement	Very Fluent Decomposition
N6	11	No	No	Very lightweight fluid
N7	11	Yes	No	Precipitation
N8	11	No	No	Good Consistency
N9	11	Yes	No	Good Consistency
N10	12	No	No	Very Fluent
N11	12	No	No	Less Sticky
N12	11	No	No	Thick Consistency
N13	11	No	No	Low Movement

The first table gives a detailed overview of the properties of the fresh concrete mixtures. In the evaluation of these properties, parameters such as mixer revolution, slump, and segregation (Table 2) were used. The mixer revolution is a factor that directly affects the homogeneity of the concrete mixture, while the slump and segregation parameters provide important information about the workability of the concrete and the homogeneity of the mixture. The segregation values indicated as "Yes" and "No" indicate whether undesirable segregation occurred in the concrete mixture. The rest of this section includes more subjective evaluations, such as the consistency of the concrete. The second table presents the mechanical properties of the samples after hardening, including their compressive strength, flexural strength, fracture energy, and peak load. By combining these two tables, the effects of different mixture parameters on the properties of concrete in both fresh and hardened states can be examined. Thus, concrete mixtures with the desired properties can be designed.

Table 3. Concrete mix performance evaluation table.

Mixture No.	Compressive Strength (MPa)	Flexural Strength (MPa)	Fracture Energy Gf (Joule/m²)	Peak Load (3 cm section) (kN)
N0	30	4	200	1.9
N1	105	18,02	6134	2.35
N2	95	21.12	6081	2.74
N3	107	24,5	8779	4.7
N4	120	25.46	8267	2.55
N5	110	24	8680	31
N6	65	7	1991	2.7
N7	102	5,08	36	16
N8	53	7,03	84	14
N9	77	5,67	735	9
N10	80	4.84	1335	9.47
N11	103	22	8482	12.39
N12	78	4.48	1218	3.865
N13	107	24.5	8654	14.4

Table 3 provides valuable insights into the structural performance of various concrete mixtures by comparing their mechanical properties. Parameters such as compressive strength, flexural strength, fracture energy, and peak load shed light on the behaviour of concrete under different loads. The compressive strength represents the concrete's resistance to compression, whereas the flexural strength indicates its resistance to bending. Fracture energy is a measure of concrete crack resistance, with higher values indicating more durable concrete. The peak load is the maximum load a concrete specimen can withstand. By analysing these parameters, the suitability of different concrete mixtures for structural applications can be assessed, and the most optimal mixture can be selected.

Figure 2. Wooden mould prepared for prototype casting.

The data obtained from the mechanical tests conducted on specimens produced with concrete mixtures prepared at different material ratios enabled us to design the wooden mould shown in Figure 2 for casting thin-section concrete urban furniture. Thanks to these tests, we determined the most suitable concrete mixture for the production of urban furniture by comparing the strength, flexibility, and other properties of different concrete mixtures. As a result of detailed examinations conducted on specimens produced with the most suitable concrete mixture determined, a mould was designed for a thin-section concrete urban furniture prototype, and prototype production was started.

Figure 3. Shows the prototype product extracted from the mould on the left, and the physical loads applied to it on the right.

The mould was filled with concrete at the determined optimal concrete-mixture ratios, and the product was removed from the mould. This process was carried out to evaluate the properties of the selected concrete mixture, such as fluidity, setting time, and ease of mould removal. The obtained product was then subjected to physical loading.

3.2. Digital Simulation Results

In this study, a comprehensive process was followed for the design, analysis, and optimisation of urban furniture produced using steel fibre reinforced concrete. In this process, which was carried out using Rhino 3D, Grasshopper, and Karamba3D software, both geometric modelling and structural analyses were combined.

Figure 4. Three designs for thin-section urban furniture.

Various urban furniture designs were modelled in 3D in a Rhino 3D environment. Among the designs shown in Figure 4 above, the design shown in Figure 5 below was selected as the most suitable for production and converted to Brep format to be subjected to a more detailed analysis due to Grasshopper's parametric design capabilities. The Brep object was converted into a mesh structure that was compatible with the Karamba3D add-on and prepared for finite element analysis.

Figure 5. Design selected for the production of a thin-section urban furniture prototype.

The material properties of the SFRC were defined in detail using Karamba3D software. Mechanical properties such as Young's modulus, shear modulus, specific weight, tensile strength, and compressive strength were added to the material library and used in the model. Considering that the urban furniture will exhibit shell behaviour, the cross-sectional properties of the model were defined with the "Shell Const" component in Figure 6 and converted into a shell element using the "Mesh to Shell" component to prepare it for analysis.

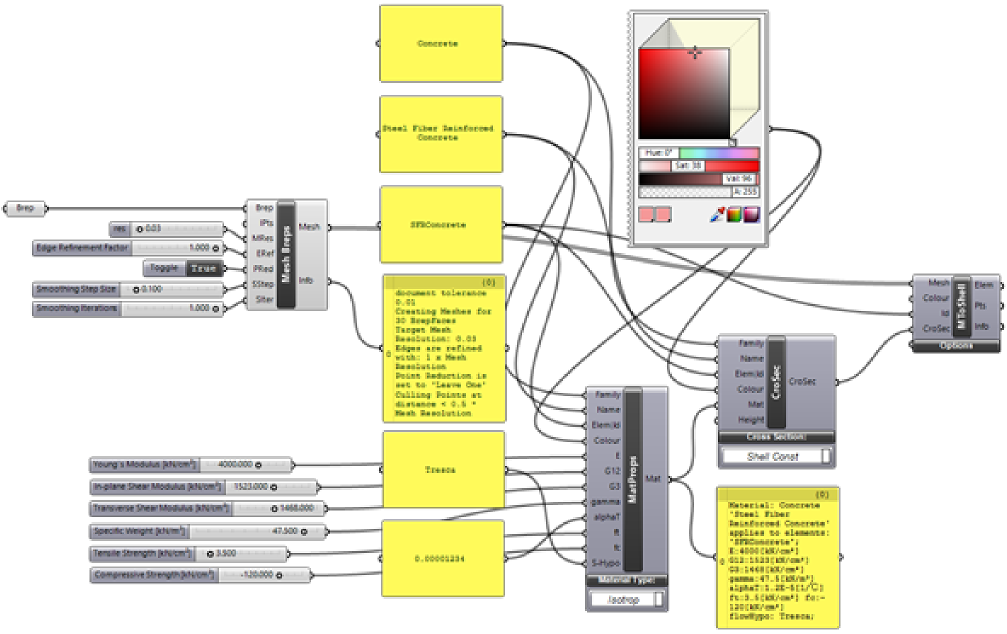

Figure 6. Three designs for thin-section urban furniture are presented below.

Thanks to the "Assemble" component in Karamba3D, the geometric model was transformed into a structural system, considering the loads, boundary conditions, and material properties. The AnalyseThII component processed this numerical model to determine the static and dynamic behaviours of the structure. In this analysis, the engineering results, such as the stress, deformation, and displacement caused by the loads on the model, were calculated.

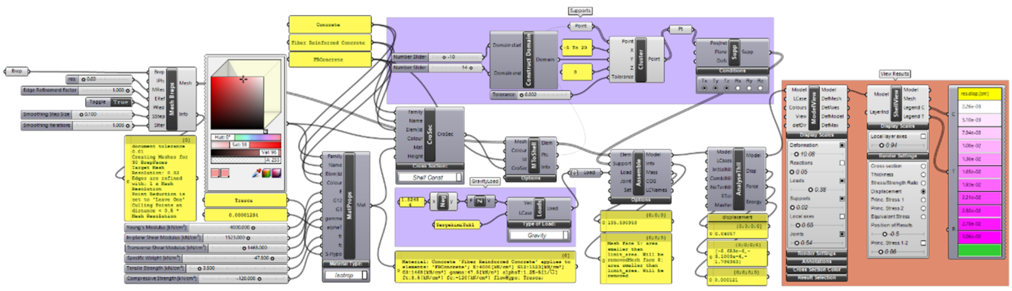

Figure 7. The model was tested digitally after adding all the parameters of the digital simulation.

The analysis results shown in Figure 7 above have been visualised using the "ModelView" and "ShellView" components. In this way, the most critical regions of the structure were identified, and the safety and durability of the design were evaluated. The numerical results obtained were validated by comparing them with data obtained from experimental studies, and the reliability of the model was determined.

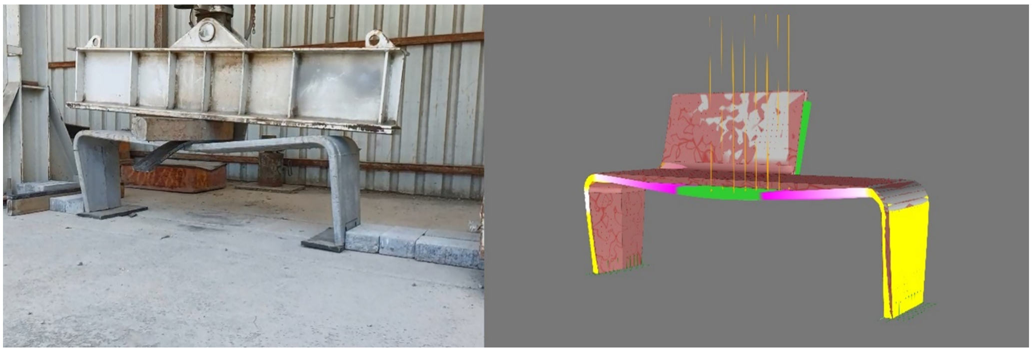

Figure 8. Shows three different designs designed for thin-section urban furniture.

In Figure 8, the maximum load-carrying capacity of the prototype product was experimentally determined by applying a linear load to a point near the predetermined weak region in the numerical model of the prototype product. The experimental data were also simulated in the numerical model, and the physical and numerical results were compared. The results confirmed that the numerical model realistically simulated the mechanical behaviour of the product by showing a similar failure or deformation behaviour in both the physical prototype and the numerical model. Consequently, more definitive results were obtained regarding the reliability and durability of the product design.

4. Discussion

In this study, the potential of using steel fibre reinforced concrete in urban furniture was investigated using experimental and numerical methods. The results of this study show that SFRC offers higher strength, ductility, and crack-delaying properties than traditional concrete. The findings provide strong support for the use of SFRC in urban furniture. In particular, the behaviour of SFRCs for structural elements with different geometries has been successfully modelled using digital simulations, and the experimental results have been verified. This situation indicates that the SFRC will make significant contributions to modern design principles such as aesthetics and durability. In this study, we observed that the steel fibre ratio had an unexpected effect on the mechanical properties of concrete. This indicates that the complex interactions of steel fibres within the concrete matrix require further investigation. While studies on SFRC in the existing literature have mostly focused on structural elements, this study has filled the gap in the field by conducting a more in-depth examination of the specific application of SFRC to urban furniture. Another unique aspect of the study is the use of digital design tools and their verification using experimental results. In this way, the behaviour of SFRCs in structural elements with different geometries was better understood, and a new perspective was offered for design processes. Although this study on steel fibre reinforced concrete sheds light on an important issue, it has some limitations. Experiments conducted on a limited number of mixtures and geometric shapes restrict the generalizability of the results. In addition, critical issues such as the long-term behaviour of the SFRC and its performance under different environmental conditions have not been investigated in detail. One of the most significant limitations of this study is the use of a limited number of samples. This situation does not provide sufficient data to obtain statistically significant results, making it difficult for us to conclude that the results are valid for all SFRC mixtures. In addition, the used material models do not fully reflect the complex interactions of steel fibres within the concrete matrix. In particular, at high stress levels and under complex loading conditions, the model results may differ significantly from the behaviour of the real material. This can create uncertainty in the design process and pose risks to the safety of the structure. Another limitation is that the study was conducted under laboratory conditions. The loading conditions applied in the laboratory environment differ from real-life conditions. Therefore, it may not be appropriate to directly apply the obtained results to the structure. The long-term behaviour of steel fibre reinforced concrete and the effects of different environmental conditions were not investigated. Factors such as corrosion, abrasion, and temperature changes are important parameters that can affect the strength and lifespan of a material. In particular, this is a significant deficiency in outdoor applications. Although the results of the research are promising, further studies need to be conducted to better understand the potential of steel fibre reinforced concrete and to enable its wider use in the construction sector. First, a systematic investigation of different types and ratios of steel fibres and experiments on a larger sample pool will increase the general validity of the obtained results. In this way, the most suitable steel fibre combinations for different applications can be determined. In addition, more accurate results can be obtained in load distribution analyses by using advanced material models that better reflect the real material behaviour, and design processes can be optimised. Another important limitation of the study is the lack of experiments conducted under conditions close to real-use conditions. Experiments conducted under different load combinations and environmental effects can better reveal the real performance of the materials. In particular, it is of great importance to conduct long-term experiments to investigate the long-term behaviour of steel fibre concrete and to examine the effects of different environmental conditions on the properties of concrete. Finally, a cost–benefit analysis should be conducted by comparing the initial cost of steel fibre reinforced concrete with the economic advantages it offers in the long term. In this way, a clearer idea about the economic feasibility of the material can be obtained, and more reliable data can be presented to investors. Studies conducted in line with these recommendations will expand the use of reinforced steel concrete in the construction sector and contribute to the construction of more sustainable structures. In conclusion, this study provides a strong foundation for the use of SFRC in urban furniture. The results of this study show that the SFRC has significant potential for the design of aesthetic and durable urban furniture. However, more comprehensive studies are needed, and further research is needed to apply the findings to different projects. By fully realising the potential of the SFRC, more sustainable and economical solutions can be offered.

5. Conclusions

In this study, the use of steel fibre reinforced concrete in urban furniture was investigated through experimental and numerical analyses. The results show that SFRC exhibits superior performance to traditional concrete. In particular, properties such as high strength, ductility, and crack resistance support the conclusion that the use of SFRC in urban furniture can extend the life of these structures and reduce maintenance costs. Numerical simulations have successfully modelled the behaviour of SFRCs for structural elements with different geometries, making the design process more efficient and cost-effective. One of the significant findings of the study is the determination that the SFRC can contribute to modern urban design principles such as aesthetics and durability. The lightness and aesthetic features of SFRC make it attractive for use in furniture designs with thin sections and complex geometries. In addition, the high energy absorption capacity of SFRCs enables the design of structures that are resistant to natural disasters such as earthquakes. This research has filled a gap in the literature by highlighting the potential use of SFRC in urban furniture. The findings provide new material alternatives for engineers and designers. However, the use of a limited number of samples and simplified material models limits the generalizability of the results. Issues such as long-term durability and environmental effects were not investigated in depth in this study. In future studies, the effects of different types, sizes, and ratios of steel fibres to SFRC. At the same time, it is important to conduct studies that examine the behaviour of SFRCs under various climatic conditions and long-term use. The development of models capable of predicting the properties of SFRC more accurately using technologies such as artificial intelligence and machine learning offers potential for future research. In conclusion, this study presents significant findings on the usability of SFRC in urban furniture and provides a new perspective on design processes. However, there is a clear need for more experimental and numerical research in this area.

Peer Review: Externally peer-reviewed.
Acknowledgments: This study was conducted within the Istanbul Design Center with the support of the Ministry of Industry and Technology. I would like to thank Dr. Adil Orçun KAYA, Quality and R&D Manager, and Serhat Zeytun for their support throughout the study.
Conflict of Interest: The author have no conflict of interest to declare.
Grant Support: The author declared that this study have received no financial support.

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How cite this article

İbiş, A. (2024). Urban Furniture Design Using Steel Fibre Reinforced Concrete with Digital Design. *Journal of Technology in Architecture Design and Planning, 2*(2), 85–93. https://doi.org/10.26650/JTADP.24.009

Journal of Technology in Architecture, Design, and Planning
JTADP 2024, 2 (2), 94–108
DOI: 10.26650/JTADP.24.011

RESEARCH ARTICLE

An Analysis of Rural Housing Architecture in Anatolia: Traditional Arapgir Village Houses*

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ABSTRACT
This study examines the rural housing architecture of Anatolia through the example of Arapgir village houses, highlighting the spatial formations of the structures as well as the characteristics of their construction systems and materials. Arapgir is located in the Upper Euphrates Basin in the Eastern Anatolia region, and it has hosted many civilisations throughout history. The region's geographical and cultural structure has influenced Arapgir's civil architectural heritage, resulting in numerous examples of traditional Anatolian housing in which local materials such as stone, adobe, and wood are used together.
Within the scope of this study, the architectural features and construction techniques of traditional village houses in the villages of Ormansırtı (Cücügen), Koru (Tebte), Onar, and Selamlı, were analysed. The documented village houses were generally two-story structures, with basements and ground floors built from thick stone walls reinforced with wooden beams. The upper floors, often with bay windows or projections, are constructed using timber framing with adobe infill. These structures were designed with both static requirements and aesthetic considerations in mind. Adapted to sloping terrain, the houses are situated on basement or semi-basement levels and include service spaces like stables, barns, and storage rooms opening into the courtyard. The upper floors feature winter and summer rooms, central halls, and guest rooms designed to suit the climate.
This study examines the plan typologies, construction techniques, and architectural details of Arapgir village houses, documenting the region's unique architectural heritage. This study makes significant contributions to understanding and documenting the traditional village architecture of Anatolia.

Keywords: Arapgir, Anatolian architecture, rural architecture, traditional village houses, traditional construction techniques

Introduction

Arapgir is a settlement located in the Eastern Anatolia Region of Turkey, within the Upper Euphrates Basin, and administratively connected to the Malatya province. Geographically, it is situated between the provinces of Erzincan, Elazığ, and Malatya, bordered by Hekimhan to the west, Arguvan and Keban to the south, Ağın to the east, and Divriği and Kemaliye to the north. The district sits at an elevation ranging from 1,000 to 1,150 metres and covers a total area of 956 square kilometres (Karakaş, 1996).

Arapgir has developed along the old city valley divided by the Kozluk River, which flows into Keban Dam Lake, as well as on the plateau where the new settlement is currently located. This geographic location has been a significant factor shaping the district's historical, geographical, and socioeconomic structure.

In this study, the traditional village houses of Arapgir are examined in detail, focusing on their floor plans, construction techniques, and materials used to reveal their architectural characteristics. This analysis aims to shed light on how Arapgir village houses, as an important example of Anatolia's rural housing architecture, have evolved as part of the local architectural tradition.

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Submitted: 25.10.2024 • **Accepted:** 04.11.2024 • **Published Online:** 15.11.2024

Historical Development of Arapgir

The exact founding date of Arapgir and the origin of its name are unknown. Although Evliya Çelebi claims that the name "Arapgir" is related to a story involving Arab Hatemi Tai settling in the area (Çelebi, 1314), there are differing opinions on this matter. Another theory suggests that the region's ancient name was "Dascusa," but this claim has been rejected by some researchers (Aksın, 2003; Jorke, 1896).

It is plausible to assume that Arapgir was initially founded in a fertile valley between the Göz Stream and the Kozluk River (Karakaş, 1996). Archaeological findings indicate that Early Bronze Age, Roman, and Mediaeval settlements, dating back approximately 4,500 years existed in the region (Erman, 2019; French, 1970). The first established civilisation is thought to have been the Hittites, and after them, the region was ruled by the Assyrians, Medes, Persians, Romans, and Byzantines (Kınal, 1962; Yücel, 1967).

Although the first traces of Turkish settlement in the region can be traced back to the Abbasid period, it is known that the area was fully conquered by Çubuk Bey, a commander of the Seljuks, after the Battle of Malazgirt (Alptekin, 1992). Before the Ottoman rule, Arapgir was governed by the Artuqids, Danishmends, and Ilkhanids. Arapgir joined the Ottoman Empire in 1516 and was administered by various sanjaks (Akçadağ, 2016).

In the 19th century, Harput was elevated to the status of a provincial capital because of the strategic importance of its mineral deposits, and the Imperial Mining Authority (Maden-i Hümayun Emaneti) was established there. According to the 1837 Harput Sharia Court records, Arapgir was also one of the districts under this authority, and during this period, its administrative status was changed from a sanjak to a district. In 1846, Arapgir was listed as a district of the Harput province, and in 1878, it was attached to the central sanjak of the Ma'muratü'l-Aziz province (Aksın, 2005).

In the 19th century, two separate settlements, approximately 5 kilometers apart, were developed in Arapgir. The first settlement, established in the valley, was called "Eskişehir" (Old City), while the newer settlement, which today serves as the district centre, became known as "Yenişehir" (New City) (Figure 1). The 1892 provincial yearbook (salname) notes that the population had shifted towards Yenişehir, and the castle and surrounding areas in Eskişehir had fallen into ruin. As the population declined, the mosque and bathhouse in Eskişehir lost their importance. The same source records neighbourhoods such as Serge, Osmanpaşa, Sekisu, and Göz in Eskişehir, as well as Çarşı and Çobanlı neighbourhoods in Yenişehir (Karakaş, 1996).

Arapgir in the Present Day

The region, which has been influenced by various sociological, political, and cultural factors throughout history and has hosted many civilisations, has developed a rich architectural heritage. Research indicates that Arapgir Castle, believed to date back to the Roman period, along with the Stone Bridge (Taş Köprü) (Figure 2) and rock tombs dating to similar periods, and the Grand Mosque and Hankah structure thought to have been built during the Ilkhanate period (Figure 3), are significant monumental cultural heritage sites in Arapgir. Additionally, Arapgir is a distinguished representative of traditional Anatolian architecture.

The mansions and orchard houses in the town centre of Arapgir and the Eskişehir valley, constructed using a combination of masonry, adobe, and wooden structural elements with the "hımış" building technique, are important examples of traditional Anatolian and Turkish civil architectural heritage. These structures, set within large gardens surrounded by dry stone walls, typically consist of basement and ground floors made of cut stone masonry and appear as large, imposing mansions with three or four stories (Figure 4). In addition to these buildings located in the old and new urban areas of Arapgir, there is also significant architectural heritage in some rural settlements in the region that serve as examples of traditional Anatolian village houses.

Traditional Arapgir Village Houses

Within the scope of this study, traditional village houses located in the villages of Ormansırtı (Cücügen), Koru (Tebte), Onar, and Selamlı, which are part of Arapgir, were examined. The architectural features, plan layouts, construction systems, and current conditions of these structures were documented (Figure 5).

When examining the settlement patterns in the rural areas of Arapgir, it is observed that rural settlements are formed by the aggregation of low-rise buildings situated around flat roads that intersect the slopes of the region's steep terrains. These structures, which define the overall settlement character of the area, are generally constructed on slopes and include semibasements or ground floors used for livestock.

Unlike Koru village, which was also studied, the villages of Selamlı and Ormansırtı are on highly sloped terrains. These villages have been shaped by clustering houses positioned perpendicular to the slope, along narrow roads that intersect the steep

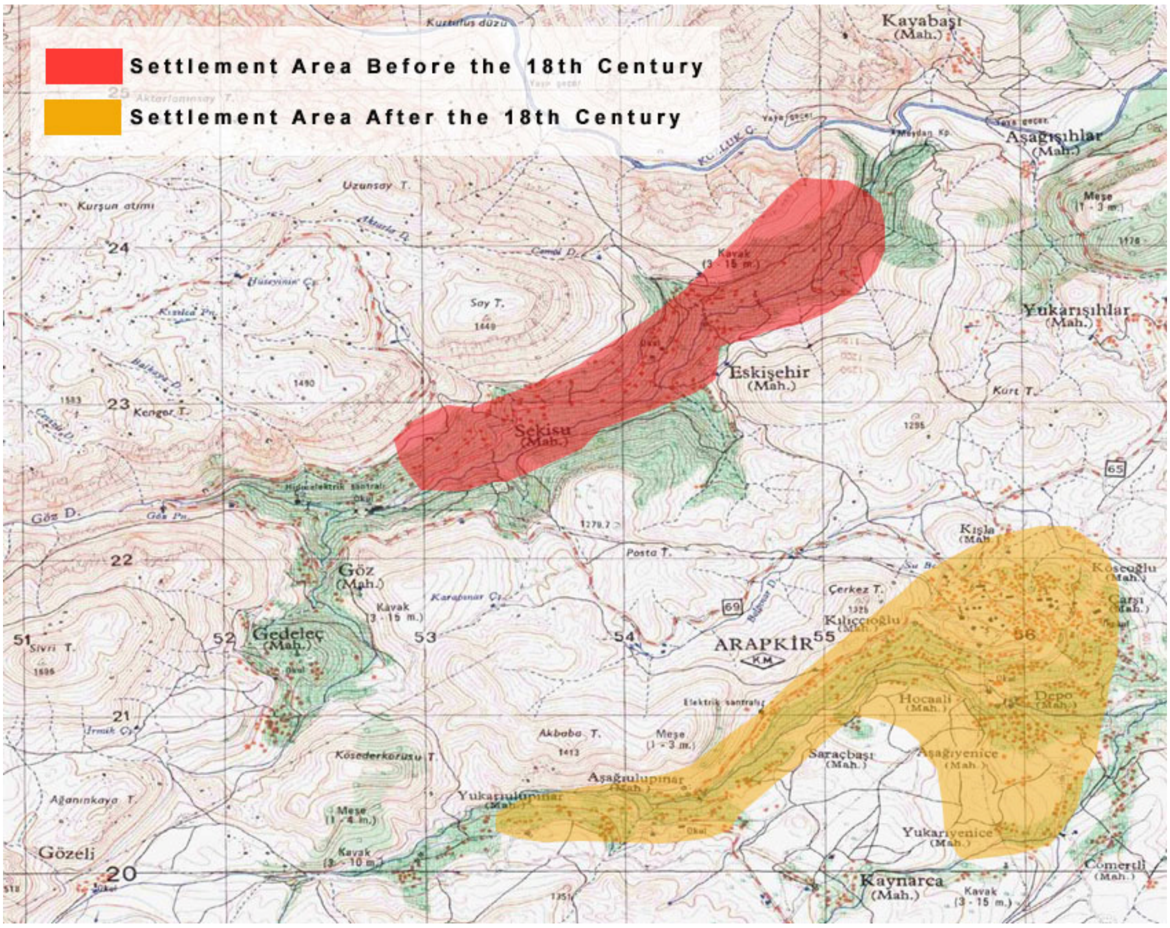

Figure 1. Historical development of Arapgir settlement areas (Archive of General Directorate of Mapping).

Figure 2. Roman Stone Bridge (Taş Köprü - Suceyin District).

Figure 3. The Grand Mosque and Hankah (“Ulu Cami ve Hankah”).

Figure 4. A Historical Mansion in Arapgir “Yenişehir”.

topography at different levels. As a result, the village houses in Selamlı and Ormansırtı typically have one or two upper floors built atop semi-basement levels. In contrast, Koru village is on flatter, more expansive terrain. The gentler slope in Koru allows for some buildings to be constructed with one or two floors directly on the ground without a basement, while in most other structures, the basement level occupies the entire building footprint, adapting to the terrain.

The architectural style of the village houses, which are often seen in traditional Anatolian villages, is characterised by their proximity to one another, with the houses arranged around a small central square. This square is the focal point of the settlement, and it is surrounded by narrow streets that run from it. As one moves away from the centre, the buildings become less dense, and it is observed that the houses are located independently in the gardens.

The traditional houses in the rural settlements examined in this study are often low-rise structures. It has been observed that residences located on sloped plots, known locally as kom or kozik, consist of one or two upper floors built on semi-basement levels that house small livestock (Figure 6, Figure 7).

Arapgir village houses are typically open to the street through double-winged doors located under a bay window. The area at the entrances of these residences, referred to by the local community as "havlu / avlu” or “taşlık" serves as a transitional space that provides access to service areas fulfilling the daily needs of traditional Arapgir village life. This space connects to units such as stables and kozik, and “merek” where winter firewood is stored. These structures generally align with the inward-facing courtyard plan type. On the upper floors, which can be accessed via wooden stairs from the courtyard, there are summer and winter rooms opening to the central hall, along with areas such as kitchens and pantries (Figure 8, Figure 9).

When examining the spatial arrangements of traditional Arapgir village houses, it is observed that in the majority of these structures, service areas are positioned around a central courtyard, forming ground floor entrances. In fewer examples, the courtyard extends along one side of the building, with rooms opening onto the courtyard in a single direction (Figure 10). In some examples from Selamlı village, the courtyard was constricted to the corner of the structure, transforming it into a small reception area.

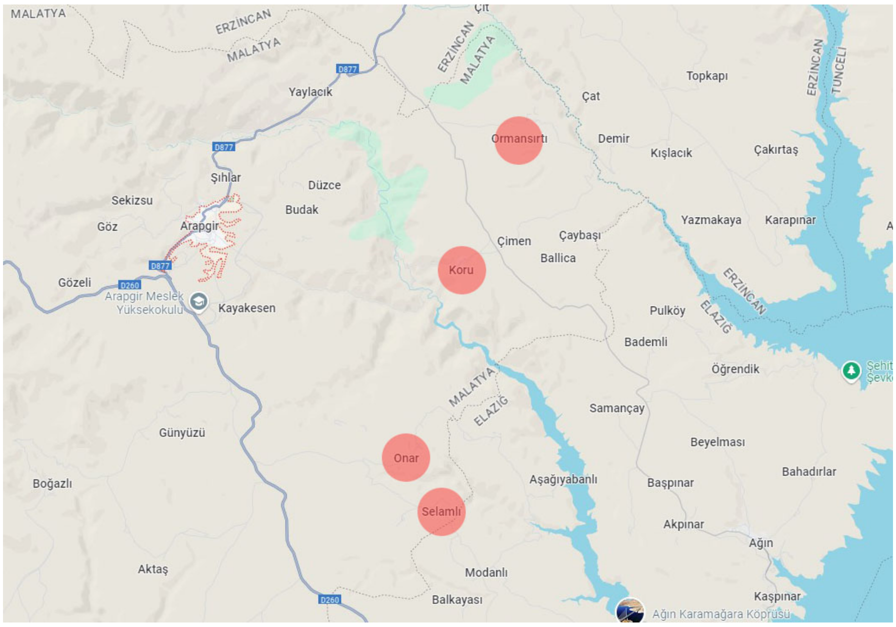

Figure 5. Villages analysed within the scope of the study (Google Maps https://maps.google.com/).

Figure 6. General View of Koru Village.

In the examined buildings, access to the courtyard from the outside is generally provided through a low threshold with a slight slope; however, in some cases, the entrance is elevated with the aid of several steps. In addition to these structures, which are typically organised on a single level, it is also possible to find courtyard houses that are arranged on two different levels in a staggered format.

In the Kayalısu neighbourhood on the outskirts of Onar Village, it has been observed that some structures consist of two separate levels positioned on the slope, with no internal connection between the two floors. Each level has an independent external entrance. These buildings serve as examples of plan layouts that do not include a courtyard or transitional space functioning as a "havlu" or "taşlık."

The courtyard of a traditional village house in Arapgir serves as a functional space that brings together various service areas essential for village life. It provides access to functional spaces within the structure, such as stables for livestock, kom (or kozik), storage areas for firewood and straw, granaries for grain storage, and pantries, as well as facilities like the tandır evi (tandoor

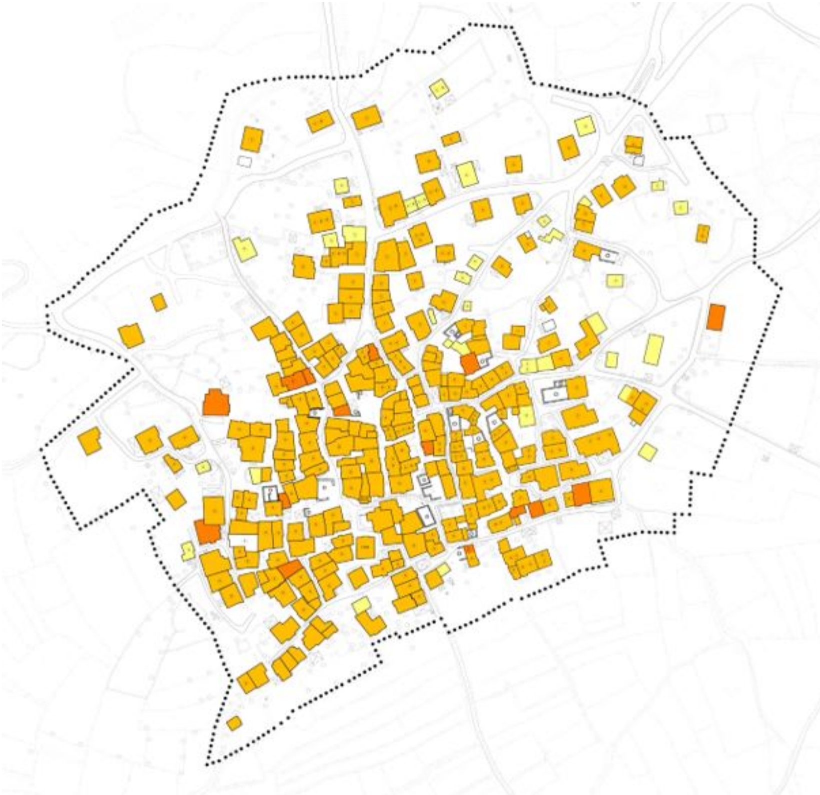

Figure 7. Number of Floors Analysis for Koru Village Settlement.

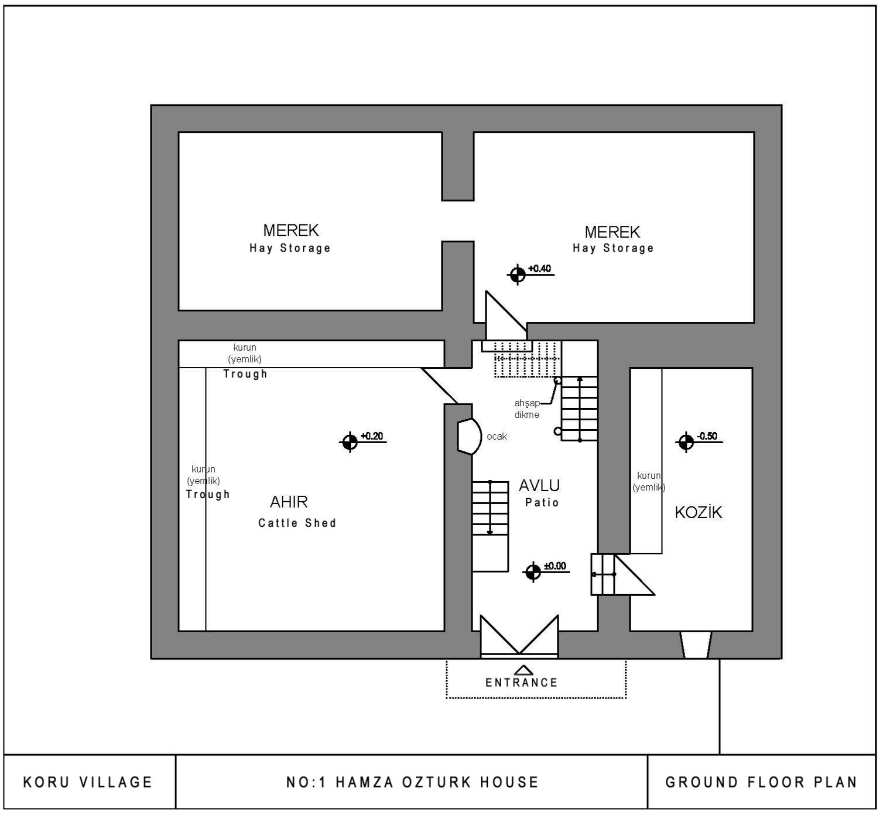

Figure 8. Ground Floor Plan of Hamza Öztürk House.

house) and üzüm evi (grape drying house) where grapes are processed. Notably, in more recently constructed village houses, the courtyard typically includes a small toilet located at a corner of the entrance area.

Figure 9. Front Facade of Hamza Öztürk House.

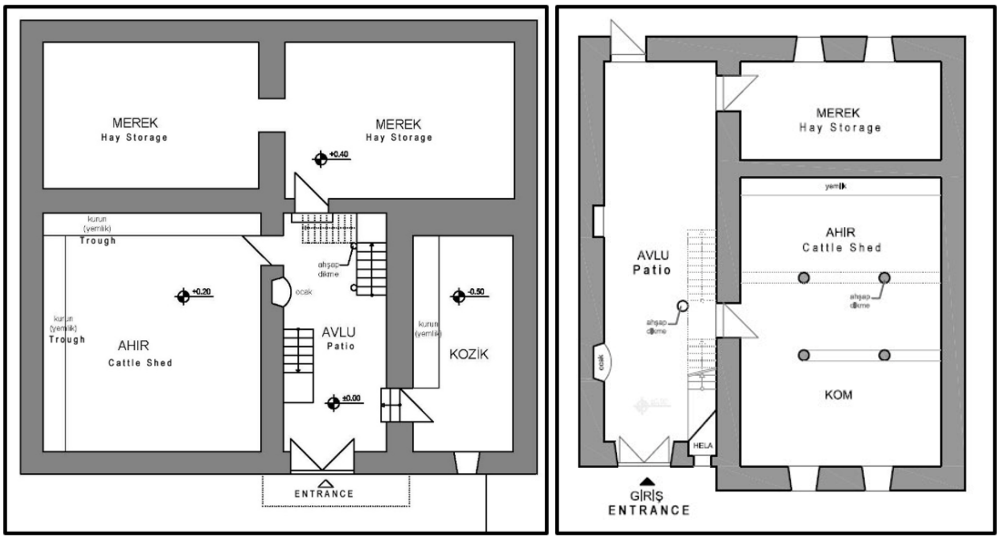

Figure 10. Varied Plan Types According to the Location of the Courtyard in Arapgir Village Houses.

In a significant proportion of the structures examined in this study, the ground floor was constructed at a higher level than the first floor. The elevated ground floor contains intermediate levels, often referred to as stable mezzanines, which are generally used during the winter months due to their easier heating. These intermediate levels, characteristic of traditional Arapgir village houses, are classified as "winter room" or "stable mezzanine" depending on their configuration, location within the building, and differences in usage (Figure 11).

Access to the winter rooms is typically provided by a separate wooden staircase from the courtyard, although there are also examples in which the main staircase of the building connects to this space at the mid-landing. The winter rooms feature smaller windows than the other living areas in the house, with window openings angled inward to reduce the impact of cold air from outside while maximising the intake of sunlight. On the wall corresponding to the blind façade of the building or the short side of the room, there is a wooden-framed stove in the centre, flanked by wall niches with wooden shelves on either side. It has also been observed that some winter rooms have a corner for a water cabinet if needed (Figure 12).

In the examined village houses, it was observed that the semi-basement levels beneath raised winter rooms are used as kom/kozik for housing small livestock. These spaces, typically lacking windows and characterised by low ceilings, are often

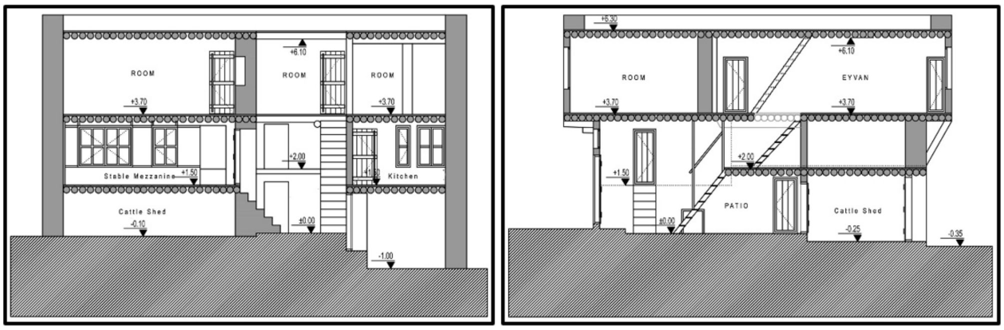

Figure 11. Section Drawings of a Village House with “Stable Mezzanine”.

considered adequately ventilated. Access to these areas can be achieved either by entering directly from within the structure or by descending a few steps from the courtyard.

Due to the region’s climatic conditions, spaces such as stables and kom for housing large and small livestock have been integrated into traditional Arapgir village houses. In examples where there is generally no winter room or where a large, high-ceilinged stable exists within the structure, living areas known as stable mezzanines are present, which are used in winter. This space is accessed via four or five wooden steps from within the stable and is raised on wooden posts to provide a platform for the animals to rest. In some examples, access to the stable mezzanine can also be made via a separate wooden staircase from the courtyard (Figure 13). Similar to the winter rooms, this area features small windows that taper outward, a stove with wall niches on either side, and a corner designated for a wheel.

Additionally, in many examples, there are open consoles referred to by the local community as "tahtalık," located at one corner of the mezzanine and extending towards the stable, and used for storing items such as bedding, quilts, and mattresses (Figure 14).

Figure 12. An Example of a winter room that preserves its function today.

In the village houses of Arapgir, it is common to find either a winter room or a stable mezzanine; however, there are also examples in which both spaces coexist within the same house. Additionally, in some larger family homes, two separate stable mezzanines were observed to accommodate specific needs. The stables located on the ground floor of the examined village houses typically feature small windows and are surrounded by thick stone walls, creating high-ceilinged spaces supported by wooden posts. In houses situated on sloping terrain, large niches, wooden feeding troughs referred to as "kürün," and salt stones known as "sal," where animals lick salt, can be found in blind walls buried underground.

To meet rural living needs, areas designated for storing firewood, straw, and animal feed during winter months are called "merek." Arapgir village houses generally have one or two mereks, which may either be single-story structures or extend over two stories with high ceilings. These spaces, which are important for enhancing the functionality of a village house, can be accessed from the courtyard in some examples, while in others, access is provided from the stable (Figure 15).

The vertical circulation between floors in Arapgir houses is typically facilitated by wooden staircases. These staircases are usually arranged as single flights; however, in instances where the space they lead into is not sufficiently wide, they may take an "L" shape. The steps, supported by wooden posts with a diameter of 8-10 cm, have widths ranging from approximately 80 cm to

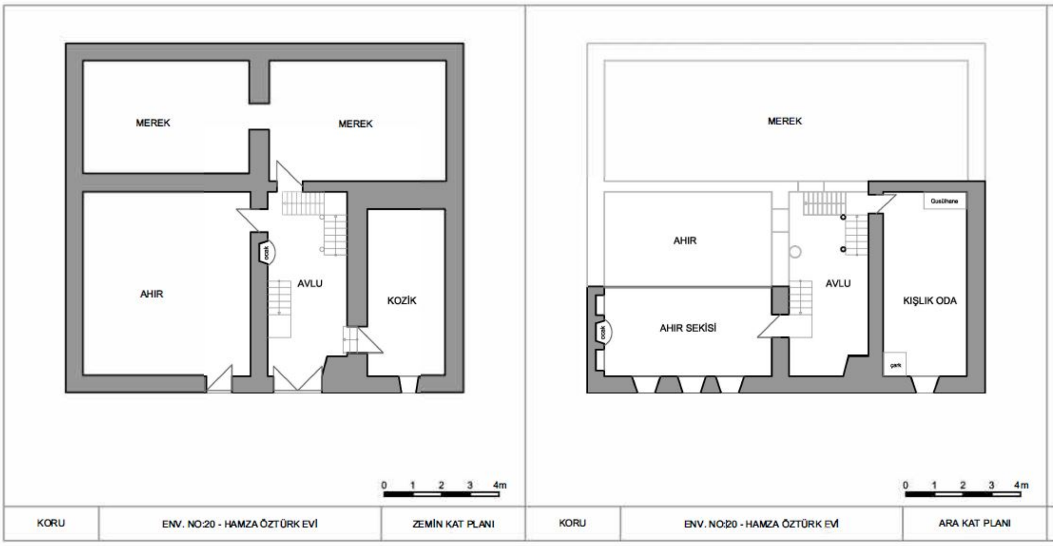

Figure 13. An Example of a Village House Plan Scheme with Stable Mezzanine and Winter Room.

Figure 14. Example of a Stable Mezzanine that Preserves its Function Today.

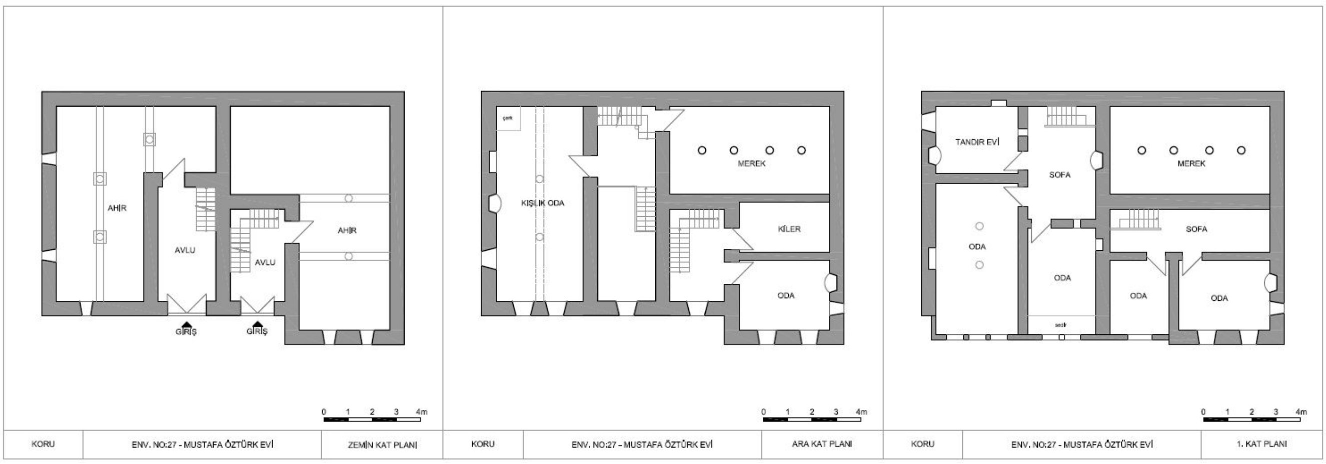

Figure 15. Mustafa Öztürk House Plan Scheme (Example of a two-story "merek").

1 metre. In examples where there are intermediate spaces, such as winter rooms, it has been observed that the wooden staircase is divided by a landing at the level of these rooms, connecting them effectively (Figure 16).

In the structures examined in this study, the staircases leading from the courtyard to the upper floors generally reach the sofa. The opening created by the staircase in the sofa is covered with wooden lids known locally as "kepenk," which prevents air circulation and interfloor transition. This arrangement facilitates easier heating of the building during winter (Figure 17).

Figure 16. Wooden Stairs in a Traditional Arapgir House.

Figure 17. Traditional Wooden Staircase Cover "Kepenk".

The upper floors of the examined traditional village houses typically exhibit a plan typology that can be described as featuring a central sofa. In houses built in a contiguous arrangement, blind façades between the structures have been used through side sofas, allowing for the design of rooms opening onto the sofa with open façades. These sofas, which connect the living areas on the upper floor, usually culminate in an evan projection or a bay-window room, thereby enhancing the functionality of the space and the architectural aesthetics of the structure.

The small windows located above the doorways of rooms that open onto the sofa provide natural light to the adjacent interior spaces. The wooden shelves known as "çıralık" or "kandillik" positioned in front of these windows serve as areas for placing lamps that illuminate both the rooms and the sofas, particularly at night. Additionally, small coffee stoves, found approximately one metre above the ground in the sofas of local houses, are used for brewing coffee to be served to guests.

In traditional Arapgir village houses, there are evans extending from the narrow end of the sofa entrance façade, protruding approximately 80 cm to 1 metre from the building's façade, with a seating area furnished with benches in front. This space is generally elevated by a step and left open to be seen from the sofa (Figure 18). In some examined structures, it has been observed that these evans are divided by a windowed wooden door, transforming the space into a bay-window room that projects from the entrance façade. Typically located above the main entrance door of the building, these bay windows may feature a single row of windows along the long side of the space or a triplet window arrangement on all three façades of the bay (Figure 19).

Figure 18. Examples of “Eyvans” opening to the central and side sofas.

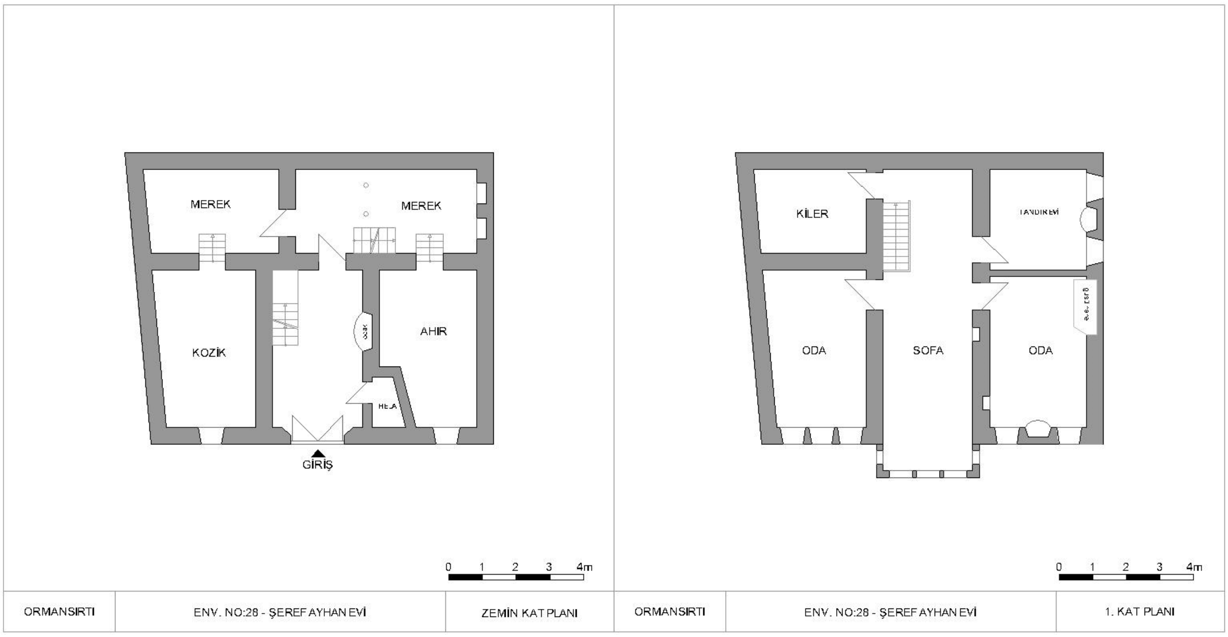

Figure 19. Plan Scheme of Şeref Ayhan House (Ormansırtı Village).

In addition to the commonly seen intermediate-story structures in the region, houses with two upper floors feature winter rooms that open onto a sofa. Surrounded by thick stone walls, these rooms are typically oriented towards the south or west. Small windows, which taper inward from the outside, along with hearths flanked by wooden shelf niches and wooden benches placed in front of the windows, are among the distinctive architectural elements of these winter rooms.

A significant portion of life in Arapgir houses takes place in the summer rooms ("yazlık oda" or "baş oda"), which are larger, brighter spaces that stand out from the other parts of the building due to their façade characteristics. Family members gather in these rooms to share meals or host guests. The summer rooms often protrude by 40-50 cm along one or two façades, separating them from the lower floor. The projecting façades are characterised by a series of three or five windows arranged in rows, opening up to views of the surroundings or the street where the building is located (Figure 20).

In the “baş oda” of wealthy families or local dignitaries’ homes in the villages, there are elevated naves known as "nim sofa" These naves are separated from the rest of the room by wooden posts and railings along one side, creating a distinct area within the space (Figure 21). Architectural elements such as large windows, wooden benches extending along the walls, shelf niches, and wooden-railed hearths are also present in these rooms. In addition, in some examples, wall niches shaped like mihrabs can be found (Figure 22).

Figure 20. Summer Room in a Traditional Arapgir House (Baş Oda).

Figure 21. “Nim Sofa” Example in a Traditional Arapgir House.

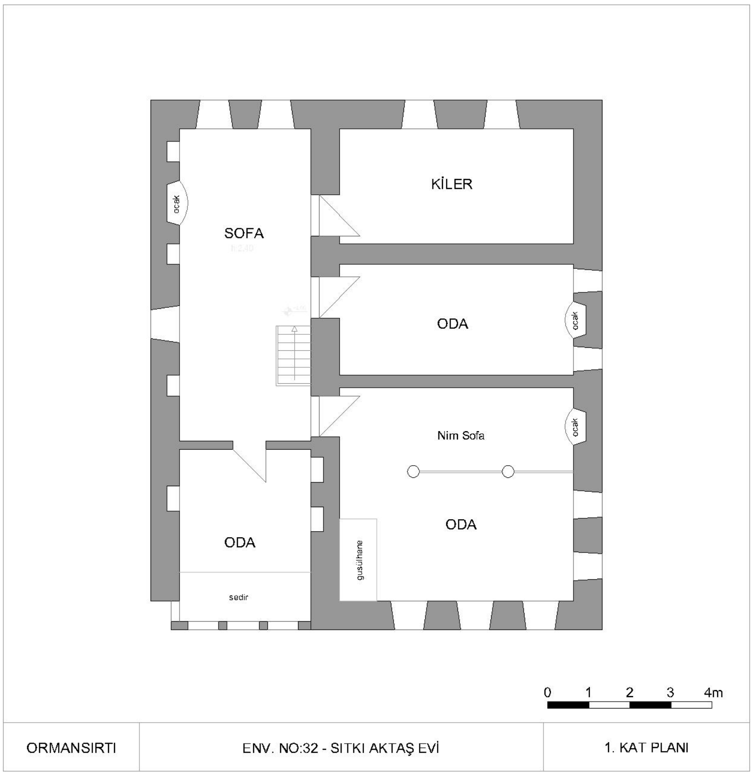

Figure 22. Plan Scheme of Sıtkı Aktaş House (Ormansırtı Village).

The primary building materials used in Arapgir houses are stone, adobe, and wood. The structural system of the buildings is supported by wooden beams and consists of walls approximately 80 cm thick made of stone. Basalt and limestone sourced from local quarries are used in the load-bearing walls of these structures. The interior walls, which have relatively low load-bearing capacity, as well as the protruding walls of the bay windows and summer rooms, consist of thin walls with wooden framing and adobe infill. The thickness of these walls varies between 15 and 20 cm.

Typically, rough-faced stone walls are concealed with earthen plaster to hide random masonry. In other examples where the masonry is more uniform, the walls are left unplastered. Due to the elevation differences, high walls are often found in the facades, and fine cut stones are used at the corners of the building for structural strength and aesthetic considerations (Figure 23). However, all wooden-framed walls within the structure are covered with earthen plaster. From the outside, the thick stone walls with few windows can be easily distinguished from the thin, lightweight framed sections with numerous windows.

Figure 23. Earth Plastered Rough Masonry Facade and and Smooth Cut Corner Stones.

The placement of wooden beams at intervals of 50 to 70 cm in the stone walls is an effective technique for enhancing the resistance of mud-mortar walls against compression and lateral forces. Considering the walls that rise vertically across the structure, it is evident that such structural precautions were taken due to Arapgir's location in an earthquake-prone area (Eyüpgiller, 2012).

Due to the maintenance challenges posed by contemporary climatic conditions, gabled roofs constructed from wood and metal have become the dominant architectural features in the region. However, traditional rural houses in Arapgir were originally designed with earthen flat roofs. (Figure 24) The earthen flat roofs, which constitute a significant characteristic of the houses in the region, are formed by a layer of clay approximately 30-40 cm thick, projecting out from all sides of the structure to create eaves. When viewed from the interior, the earthen layer structure consists of closely arranged wooden beams and thinner wooden rods known as "aruda." This layer is made from a locally sourced clay that is blue and yellow in colour, characterised by its plasticity and oiliness. To ensure a waterproof surface and protect the structure from rainwater, this layer is compacted biannually during the spring months using cylindrical stones referred to as "loğ taşı".

Figure 24. A Traditional Village House with Earthen Flat Roof.

The flooring, walls, and ceiling coverings in the spaces of Arapgir rural houses vary depending on the intended use of the area, the economic status of the homeowner, and the construction period. In structures designated for specific functions, such as animal shelters, storage rooms, and haylofts, flooring is frequently made of stone, with basalt commonly used as the primary material. In service areas located on the ground floor, such as courtyards, storerooms, and traditional bread ovens, brick coverings are typically preferred; however, in some instances, stone flooring has also been observed in these spaces. In the upper floors, particularly in the living rooms and the central hall (sofa), flooring is predominantly wood. Nevertheless, certain homes feature stone or brick flooring in their sofas.

n the examined rural houses, the walls of the stables and stores were typically left unplastered, while the remaining interior walls were generally covered with mud plaster mixed with straw. A decorative finishing technique known locally as "çarpım sıva" is applied over the mud plaster. This technique, frequently employed by villagers, involves mixing regionally sourced, lime-rich soil with water and then hand-applying it to the walls in a circular pattern. The appearance of the walls treated with çarpım plaster is one of the most significant and unique features of traditional Arapgir houses (Figure 25).

Figure 25. Interior Walls with Traditional “Çarpım” Plaster Technique.

Conclusion

This study elaborates on the rural housing architecture of Anatolia through an examination of Arapgir village houses, highlighting the unique structural characteristics and functionality of the region. As a settlement that has been influenced by numerous civilisations throughout history, Arapgir reflects this cultural richness in its architecture. Traditional Arapgir houses skilfully utilise local materials such as stone, adobe, and wood, emphasising the harmony and durability of these structures with their natural environment.

In the examined houses, it was observed that the settlement plans are organised to suit the sloping terrain, with courtyards serving as the centre of village life, where much of the social activities take place. Architectural details such as the internal courtyard plan typology and the protruding bay windows on the facade enhance both the aesthetic and functional aspects of the buildings. The combined use of wooden beams and stone walls increased the structural resistance to lateral forces while ensuring adaptability to climatic conditions.

Arapgir village houses not only meet the need for shelter but also represent an important architectural heritage that reflects social and cultural life. The compatibility of traditional building materials and architectural techniques with the region’s natural and climatic conditions has allowed these structures to endure for centuries. This study provides significant data on rural architecture in Anatolia and underscores the necessity of preserving and ensuring the sustainability of such structures.

Note: The editor in chief was not involved in the evaluation, peer-review and decision processes of the article, and these processes were carried out by the associate editors.
Peer Review: Externally peer-reviewed.
Author Contributions: Conception / Design of Study – M.O.K., K.K.E.; Data Acquisition – M.O.K.; Data Analysis / Interpretation – M.O.K.; Drafting Manuscript – M.O.K.; Critical Revision of Manuscript – K.K.E.; Final Approval and Accountability - M.O.K., K.K.E.; Technical or Material Support – M.O.K.; Supervision – K.K.E.
Conflict of Interest: The authors have no conflict of interest to declare.
Grant Support: The authors declared that this study have received no financial support.

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How cite this article

Kasapgil, M. O., & Eyüpgiller, K. K. (2024). An Analysis of Rural Housing Architecture in Anatolia: Traditional Arapgir Village Houses. *Journal of Technology in Architecture Design and Planning, 2*(2), 94–108. https://doi.org/10.26650/JTADP.24.011

Journal of Technology in Architecture, Design, and Planning
JTADP 2024, 2 (2), 109–120
DOI: 10.26650/JTADP.24.012

RESEARCH ARTICLE

The Role of Earthquake-Resistant Building Elements in Parametric Architecture Design; Balancing Aesthetics and Performance

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ABSTRACT
While traditional methods prioritise structural strength but limit design flexibility, parametric design provides a data-driven method that can maximise seismic performance and aesthetics. This article analyzes the core principles of earthquake-resistant buildings and discusses how seismic braces and critical structural components can be integrated aesthetically into parametric designs. Furthermore, this paper explores various parametric design parameters that contribute to aesthetics, including form, texture, light, repetition, and variation. In addition to analysing the parameters of architecture and parametric design and taking a general look at the structure of the theoretical foundations of this contemporary artistic realm, this classification emphasises the importance of prioritising structural integrity while strategically using these parameters for visual appeal.
Finally, by highlighting the transformative potential of parametric design in earthquake-prone areas, this paper tries to show that parametric design can pave the way for creating visually captivating architectural wonders and flexible seismic architecture. This represents a significant advancement in the design process, offering a path towards safer, stronger, and more aesthetically pleasing structures in earthquake-prone regions.

Keywords: Earthquake-resistant design, Parametric architecture, Parametric aesthetics, Seismic bracing

1. Introduction

In the dynamic world of architecture, the advent of parametric design has marked a revolutionary shift, redefining the boundaries of what is possible in architectural design and construction. At its core, parametric design is a process that utilises algorithms and computational thinking to generate complex forms and structures that are both aesthetically groundbreaking and functionally innovative.

This approach, steeped in the fusion of art and technology, is not only reshaping our skylines but also the very way architects approach the creative process (Schumacher, 2009).

Earthquakes pose a constant threat to communities globally, causing devastating loss of life and infrastructure damage. Building design plays a crucial role in mitigating these consequences by prioritising structural integrity and occupant safety (Schumacher, 2009). However, traditional methods often struggle to balance these needs with design flexibility and adaptation to specific site conditions. This article explores a holistic and adaptable approach to the potential of parametric architecture to revolutionise the use of earthquake-resistant building elements to obtain aesthetic and safety parameters, based on the parametric architecture approach.

Parametric architecture offers exciting possibilities for creating earthquake-resistant structures that are not only safe but also visually compelling. This paper delves into the architectural aspects of parametric design, specifically focusing on its potential to enhance building aesthetics and safety in seismically active areas by integrating performance-based design with unique form generation and optimisation capabilities. The focus of this paper is to investigate how parametric architecture can improve building aesthetics and safety from an architectural perspective.

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Submitted: 14.08.2024 • **Revision Requested:** 23.10.2024 • **Last Revision Received:** 26.10.2024 • **Accepted:** 09.11.2024 • **Published Online:** 15.11.2024

2. Background

The term "parametric architecture" itself emerged in the late 20th century, signalling a new era in which design complexity could be managed and fine-tuned through algorithms. Traditional earthquake-resistant building design relies on established engineering principles, prioritising structural strength through robust materials and systems such as shear walls and braced frames. However, this approach often limits design flexibility and the ability to optimise for specific site conditions or architectural aspirations.

Parametric architecture offers a compelling alternative and can trace its lineage to the pioneering works of Antonio Gaudi (Figure 1) and Frei Otto (Figure 2), as it embraces natural forms and intricate structures. Gaudi's use of geometric rules and Otto's lightweight, tensile structures exemplify early examples of parametric thinking. The advent of powerful computing has since propelled parametricism into a more widely applicable design approach.

Figure 1. Sagrada Familia (started 1882) by Antoni Gaudi, Available at: https://www.archdaily.com.br/br/787647/classicos-da-arquitetura-la-sagrada-familia-antoni-gaudi

Figure 2. International and Universal Expo, 1967 (Montreal, Canada), by Frei Otto https://hyperallergic.com/189699/frei-otto-master-of-tensile-structures-dies-day-before-winning-pritzker-prize/

In recent years, there has been an increasing focus on innovative design approaches to address these limitations. As a background review, two notable case studies—the Nanjing International Youth Olympic Sports Centre (Figure 3) and The Bosco Verticale (Figure 4) exemplify this trend.

Figure 3. The Nanjing International Youth Olympic Sports Centre, 2002 (Nanjing, China) by Arup Architects https://sportsmatik.com/sports-corner/sports-venue/nanjing-olympic-sports-center

The Nanjing International Youth Olympic Sports Centre utilizes parametric design tools to optimise a complex, curvilinear roof structure. The roof spans a large open area without columns, creating a visually striking architectural form (Figure 3). The parametric design process considered seismic loads during optimisation. The resulting structure is lightweight yet robust and can withstand the significant horizontal forces exerted by earthquakes. The integration of performance-based design with a unique architectural form exemplifies the potential of parametric architecture in earthquake engineering.

The Bosco Verticale incorporates natural elements like vegetation into the building's facade. A parametric design was used to optimise the structural support for the additional weight of the trees and planters while maintaining the building's aesthetics (Figure 4). In this project, the analysis considered the extra weight and wind resistance due to the vegetation. The resulting structure is strong and flexible and can withstand the lateral forces of earthquakes. Bosco Verticale demonstrates how parametric design can be used to create earthquake-resistant buildings that integrate with the natural environment.

These projects showcase the potential for innovative design strategies that balance structural performance with architectural expression. However, a critical gap exists in the research dedicated to exploring the intersection of aesthetic parameters in parametric architecture and earthquake-resistant building design. We try to fill a part of this gap in the literature by presenting a few examples of this interdisciplinary field.

Figure 4. The Bosco Verticale, 2014 (Milan, Italy) by Stefano Boeri Architects. https://milano.repubblica.it/cronaca/2019/10/09/news/bosco_verticale_milano_tra_50_grattacieli_piu_iconici_al_mondo-238111573/ www.Google.com

3. Principles and Definitions of Parametricism

Schumacher initially introduced the idea of Parametricism in his work Parametricism Manifesto (Schumacher, 2008), and (Schumacher, 2009), as well as in another book (Schumacher, 2011), he presented two approaches to this idea called Dogmas to follow this concept and Things to avoid known as Taboos (Al-Azzawi & Al-Majidi, 2020).

The use of scripts instead of models, Inter-articulating, Hyperdizing, and Utilising Splines and Nurbs were among the Taboos in his paper (Schumacher, 2008), whereas the use of Platonic objects, Straight lines, Right angles, and other well-known topologies was among the Dogmas. The Dogmas were further defined in Schumacher's work Parametricism; a New Global Style for Architecture & Urban Design (Schumacher, 2009), in which all forms must be parametrically malleable, inflected, or connected systematically and distinctive gradually. Meanwhile, Schumacher introduced new principles for the Taboos, including Simple Repetition and the Juxtaposition of Unrelated systems and elements, and incorporated hermetic forms within the platonic forms mentioned in his previous paper (Schumacher, 2008).

Finally, Schumacher repeated the same Dogmas and Taboos in his book Autopoiesis of Architecture (Schumacher, 2011), highlighting the process of producing forms and integrated systems inside it. He also used the phrase Rigid Geometric Primitives for Taboos instead of "Platonic" or "hermetic" forms (Al-Azzawi & Al-Majidi, 2020).

In an overview, parametricism is a defining approach in architecture, where design incorporates dynamic characteristics and overcomes rigid restrictions (Figure 5). This signifies the beginning of a paradigm shift in which responsiveness and adaptability drive the evolution of architectural expression. Parametricism, in contrast to traditional methods, promotes a fluid design process in which variables determine form, thus bringing about a new era of inventive and flexible architecture.

Complexity and flexibility are fundamental concepts in parametricity. Avoiding minimalism in favour of complex and dynamic designs, it moves through a space where each architectural component is interrelated and ready to adjust to contextual or environmental changes. The theory emphasises the dynamic interaction between volume, function, and the surrounding context, generating a developed environment that promotes harmony with the surrounding environment (Isabella, 2024).

Figure 5. Ray and Maria Stata Centre (Massachusetts, USA) (2004) by Frank Gehry https://farm4.staticflickr.com/3624/3351701515_baabf8128e_o.jpg

3.1. Parametric Architecture

Luigi Moretti used the term parametric architecture in the early 1940s to describe the study of architectural systems based on the identification of connections between various parameters and their dimensions. This is where the term parametric in architecture first appeared. However, a study published by Maurice Ruiter in 1988 with the title "Parametric design" may be the first usage of this phrase in the discipline (Al-Azzawi & Al-Majidi, 2020).

Parametric design is a concept supported by the increasing availability of computer-aided techniques and the development of manufacturing processes that facilitate the achievement of complex forms. As an approach, parametric design relies on defining variables; whenever a parameter changes, the results also change. Thus, it has been used in recent decades as part of computational design to support the design process and achieve unique design products. Architectural practise has experienced significant changes because of working parametrically, which converts all programming decisions into design decisions and raises the need for architects to acquire new skills to become proficient in new techniques (Isabella, 2024) (Figure 6).

Figure 6. Hyder Aliyev Centre (Baku, Azerbaijan) by Zaha Hadid Architects, (www.parametric-architecture.com)

At the edge of the frontiers of architectural innovation is parametric architecture, defined by its computational flexibility, fluidity of forms, and variety. The primary use of computational tools in the architectural design process has been parametric design in architecture. However, this approach was not popular until the late 20th and early 21st centuries. The proliferation of advanced computer technology and software has been a key driver, enabling architects to explore new forms and structures that were previously unimaginable or more complex. The elements and concepts of parametric architecture inspiration often originate from natural and organic forms. A unique aspect of this method is the conversion of natural structures and patterns into design elements for architecture. The complex geometry of patterns and fluid curves evokes images of chaos and order in natural settings.

Using algorithms as guidelines, designers create structures that dynamically balance form and function in response to shifting conditions. Parametric design includes complexity and drives beyond conventional limits to create complex forms that arouse curiosity. Within this field, structures appear as manifestations of mathematical elegance and technical mastery, altering the landscape of the constructed surroundings of the future (Isabella, 2024).

Parametric architecture offers a new threshold to the world of unique design characterised by adaptability and the ability to create curved and flowing shapes that are reminiscent of nature. This fluidity in form and content allows architects to integrate aesthetics with functional needs. However, this would not be possible without the deep integration of digital tools and software.

Parametric design software utilizes parameters, as well as variables, to describe and connect multiple elements in a design. This allows substantial flexibility and consistency throughout the design process. Modifying a single parameter may cause automated alterations across the model to ensure consistency and coherence in the outcome.

3.2. Aesthetically Effective Parameters in Parametric Architecture

The parametric architecture, with its data-driven design and algorithmic control, offers a unique approach to aesthetics. Here are the key parameters, Form-Geometry, Materiality-Texture, Light-Shadow Play, and Repetition-Variation in Design, that contribute to the aesthetic impact of parametric buildings to explore further:

- **Form and Geometry**
- Organic Shapes and Complexity: Parametric design allows for creating intricate, nonlinear forms that deviate from traditional geometric shapes. These forms can be visually striking and create a sense of dynamism and movement (Kolarevic, 2009).
- Curvature and Variation: The ability to define and manipulate curves within design software allows architects to explore flowing lines, tapered elements, and varying thicknesses. This approach creates visual interest and helps to break away from the monotony of straight lines and sharp corners (Oxman, 2010).
- Optimisation and Efficiency: The underlying concepts of parametric design often result in visually beautiful shapes. By optimising structures for performance and material utilisation, the resulting shapes can seem attractive and efficient, demonstrating a harmonic balance between functionality and aesthetics.

- **Materiality and Texture**
- Differentiation and Customisation: Parametric design allows for precise control of material properties and textures across different parts of a building. This allows architects to create buildings with unique material expressions, using variations in colour, texture, and even translucency (Kolarevic, 2009).
- Integration with Structure: The integration of structural elements into the overall design scheme can represent a purposeful aesthetic approach. Architects may achieve a coherent and visually cohesive design by modifying the form and texture of the columns, beams, and support systems.
- Sustainability and Innovation: Parametric design can facilitate the incorporation of sustainable and innovative materials. This can include the use of recycled materials with unique textures or the exploration of new materials with specific visual properties.
- **Light and Shadow Play**
- Dynamic Effects: The complex geometries and varied material properties created through parametric design can interact with light in unique ways. This can lead to dynamic effects like shifting shadows or the creation of moiré patterns on the building's façade (Eltaweel & SU, 2017).
- Environmental Control and Daylight Optimisation: Parametric design tools can be used to optimise the building's form and façade elements to control the amount of natural light entering the building. This can create a more comfortable and visually interesting interior environment (Baker & Steemers, 2013).
- **Repetition and Variation in Design**
- Rhythm and Pattern: Parametric design allows for creating intricate patterns and rhythmic elements across a building's facade or other components. This can create a sense of order and visual interest, even in complex geometries (Burry, 2013; Schumacher, 2009).
- Fractals and Natural Patterns: Parametric tools can generate natural patterns, such as fractals and branching structures. These patterns can create a sense of harmony and organic beauty in a building (Schumacher, 2009).
- Uniqueness within Repetition: The ability to define variations within a repeating pattern allows architects to create a sense of visual complexity while maintaining a cohesive overall design.

4. Earthquake-Resistant building design with braces for aesthetic purposes

During a ground shake, an earthquake-resistant structure should be able to provide all of its seismic resistance concurrently. If not, the stepping happens, putting the building at risk of collapse (Giuliani, 2000).

Therefore, the goals of earthquake-resistant architecture are to prevent buildings from stepping during earthquakes and to ensure that all elements interact positively during an earthquake.

Traditional earthquake-resistant building design relies on several core principles:

- Structural Strength: Utilizing robust materials (e.g., steel-reinforced concrete) and structural systems (e.g., shear walls, braced frames) capable of absorbing and distributing earthquake forces.
- Seismic isolation: Employ base isolation systems to decouple buildings from the ground, reducing the transfer of seismic energy and minimising damage.
- Energy Dissipation: Integrating elements such as dampers or fuses that absorb and dissipate earthquake energy and protect the primary structural elements.

4.1. Integration of Seismic Bracing and Elements

Seismic Bracing is one of the most essential structural components utilized in parametric architecture projects. Structural characteristics based on seismic bracing used in parametric architecturally designed structures play a significant role in earthquake resistance and maintaining optimal structural performance. These elements, in cooperation with other structural members of the building, can create a suitable platform for greater flexibility and fluidity of the volume and overall structure of the building. Also, to give architects and engineers the possibility of more confidently designing higher, more complex, and finally more beautiful buildings in harmony with the aesthetic paradigms of contemporary architecture (Figure 7).

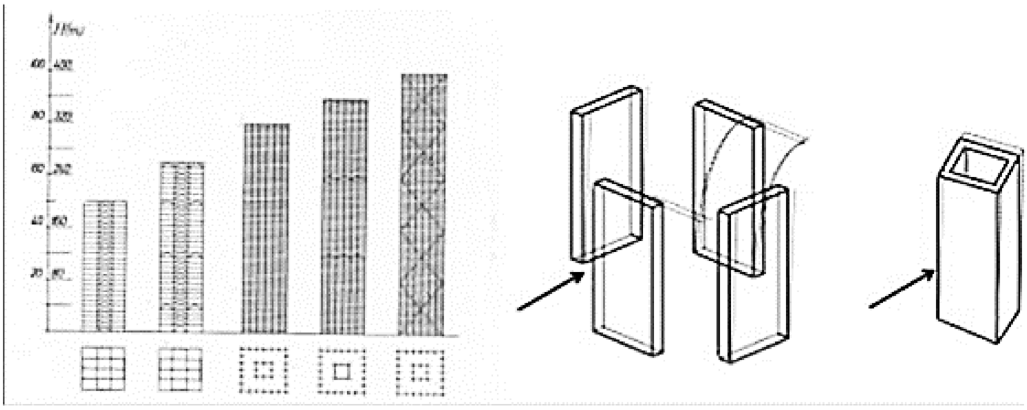

Figure 7. On the left: structural systems for tall buildings. On the right: wall versus tube behaviour (Laghi & Palermo, 2017).

Although seismic bracing is not strictly a parametric element, it can be strategically incorporated to complement its overall form. This creates a unified aesthetic and demonstrates a harmonious relationship between structure and aesthetics (Figure 8).

Figure 8. From the top left, clockwise: John Hancock Building; Sears Tower; Onterie Centre; Agbar Tower, Barcelona; CCTV, Beijing; 30 St. Mary's Axe, London (Laghi & Palermo, 2017).

The installation of seismic bracing can provide several benefits:

1. Enhanced Structural Stability (ASCE standard, ASCE/SEI, 2017, p.41-17).
2. Improved Performance During Seismic Events (NEHRP, FEMA P-1051, 2016).
3. Mitigating Non-Structural Damage (Lorant, 2016).
4. Compatibility with the aesthetics of parametric design (Bento & Simões, 2021).
5. Adaptability to specific building design needs, such as high building height and special design due to general building uses, as well as geographical or climatic constraints.

Seismic bracing should be considered in conjunction with the inherent strengths of parametric design for earthquake resistance. This combined approach can lead to the creation of highly resilient and visually striking buildings in earthquake-prone areas.

4.2. The Role of Parametric Architecture in Earthquake-Resistant Building Design

Architecture is quickly being transformed by parametric design. This design methodology uses computational methods to produce innovative, fluid, and efficient structures. On the other hand, parametric architecture may play a crucial role in reducing the danger of earthquakes, which makes designing structures in seismically active locations a big challenge for architects and engineers (Figure 9).

Figure 9. CCTV Headquarters (Beijing, China) by Rem Koolhaas (www.parametric-architecture.com)

Parametric design can enhance earthquake-resistant building design in several ways such as (Figure 10):

1. Automated Structural Analysis (ETABS-SAP2000-RISA-3D-Grasshopper (with Rhino 3D).
2. Form-Finding for Seismic Performance (Rhino 3D- Revit).
3. Integrated Design for Efficiency (BIM (Building Information Modelling) - Parametric Design Integration).

Figure 10. CCTV Headquarters (Beijing, China) by Rem Koolhaas (www.parametric-architecture.com)

5. Result and Suggestions

While seismic bracing prioritises structural integrity, some parametric design parameters can be strategically chosen to achieve both aesthetic appeal and seismic performance. In the following sections, the main aesthetic parameters mentioned in the previous section, Form-Geometry, Materiality-Texture, Light-Shadow Play and Repetition-Variation in Design, which seismic bracing can affect their production and creation have been analysed in order.

- **Form and Geometry**
- Organic Shapes and Complexity: While these parameters can be aesthetically appealing and fall into the category of parametric architecture, they may not always translate well into optimal seismic performance. Complex geometries can lead to tension concentrations and require detailed structural analysis (Figure 11).

Figure 11. Guangzhou Opera House (Guangzhou, China) by Zaha Hadid Architects, (www.parametric-architecture.com)

- Curvature and Variation: Curved elements, such as arcs, shells, and various surfaces, can provide intrinsic strength and efficient load distribution under seismic loads while meeting aesthetic requirements in design.
- Optimisation and Efficiency: The parametric design allows for the exploration and analysis of various forms to achieve optimal performance under seismic loads. This analysis of various shapes and volumes using parametric architecture software continues to achieve the best performance for the desired form of designers (Figure 12).

Figure 12. Guangzhou Opera House (Guangzhou, China) by Zaha Hadid Architects, (www.parametric-architecture.com)

- **Materiality and Texture**
- Differentiation and customisation: While this can enhance aesthetics, it may not directly contribute to seismic bracing. However, using parametric design standards to optimise material placement based on stress analysis can be beneficial (Figure 13).

Figure 13. Broad Museum (Los Angeles, USA) (Material: GFRC-Glass Fibre Reinforced Concrete) by Diller Scofidio + Renfro (www.whereisthenorth.com)

- Integration with the structure: This is critical for seismic performance. Parametric design can be used based on its theoretical foundations which emphasise the use of curve designs, repetitive surfaces, and shells to combine integrated structural elements in the overall form, creating a unified and efficient system.
- Sustainability and Innovation: Stable materials with good seismic performance, such as high-performance concrete or engineered wood, can be examined using parametric design to achieve a good level of strength and approved structural performance. This can meet the goals of architects and designers in complex designs in the realm of parametric design.
- **Light and Shadow Play**
- Dynamic Effects, Environmental Control, and Daylight Optimisation: While important for occupant comfort and energy efficiency, it does not impact seismic performance.
- **Repetition and Variation in Design**
- Rhythm, Pattern, and Uniqueness within Repetition: Patterns and styles and in general parametric architectural design that can be applied aesthetically are challenging in many aspects for earthquake-resistant design because, for seismic performance, the focus on regularity and symmetry in the structural system is often useful for efficient load distribution. However, with the help of today's computational software, a well-proportioned and well-balanced architectural designer can achieve good results against different loads simultaneously with complex designs (Figure 14).

Figure 14. Galaxy Soho (Beijing, China) by Zaha Hadid Architects, (www.parametric-architecture.com)

- Fractals and natural patterns: Although they can be visually intriguing, they may not always translate to optimal seismic performance due to the presence of potential stress concentrations.

6. Conclusion

By strategically utilising parametric design capabilities, architects and engineers can enhance the collaboration between aesthetics and seismic performance. While prioritising the structural integrity of today's buildings remains a priority, by focusing on parameters such as curvature, optimised geometry, strategic material placement, and integrated structural integration, parametric design empowers the creation of buildings that are both visually captivating and seismically resilient. The interaction between the theoretical and aesthetic foundations of the parametric world paves the way for a future in which seismic safety and visual appeal co-exist in architectural wonders.

Parametric architecture exemplifies the progression of the design process by combining creative vision with computational methodologies, as well as representing a transition away from traditional architectural practice and towards computational design. Due to its high degree of adaptability and customisation, it creates settings that are responsive to its surroundings and the needs of its users. The use of algorithms and computational design allows parametric architecture to achieve unprecedented levels of depth and complexity in design expressions, optimise structural aspects, and increase sustainability.

Parametric architecture represents a possible route to improving earthquake-resistant building design. This technique, by taking advantage of its capacity to improve performance, combine various design requirements, and develop novel forms, can result in safer, stronger, and visually appealing structures. More studies are needed to create established methods and case studies that show the full potential of parametric design in this vital subject.

Peer Review: Externally peer-reviewed.
Author Contributions: Conception / Design of Study – S.M.A.M.M., S.E.; Data Acquisition – S.M.A.M.M., S.E.; Data Analysis / Interpretation – S.M.A.M.M., S.E.; Drafting Manuscript – S.M.A.M.M., S.E.; Critical Revision of Manuscript – S.M.A.M.M., S.E.; Final Approval and Accountability - S.M.A.M.M., S.E.; Technical or Material Support – S.M.A.M.M., S.E.; Supervision – S.M.A.M.M., S.E.
Conflict of Interest: The authors have no conflict of interest to declare.
Grant Support: The authors declared that this study have received no financial support.

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How cite this article

Mousavi, S. M. A. M., & Ersoy, S. (2024). The Role of Earthquake-Resistant Building Elements in Parametric Architecture Design; Balancing Aesthetics and Performance. *Journal of Technology in Architecture Design and Planning, 2*(2), 109–120 https://doi.org/10.26650/JTADP.24.012