

# METAMORPHOSIS: A DIGITAL APPROACH TO TRANSFORMING COMMUNITIES THROUGH PHOTOGRAMMETRY AND METAVERSE

N. Abramov<sup>1</sup>, H. Lankegowda<sup>1</sup>, S. Liu<sup>1</sup>, L. Barazzetti<sup>2</sup>, C. Beltracchi<sup>3</sup>, P. Ruttico<sup>3</sup>

<sup>1</sup> M.Sc. Student in Building and Architectural Engineering Politecnico di Milano, Piazza Leonardo da Vinci 32, Milan, Italy  
(nikolai.abramov, havana.lankegowda, shunwei.liu)@mail.polimi.it

<sup>2</sup> Dept. of Architecture, Built environment and Construction engineering (ABC)  
Politecnico di Milano, Piazza Leonardo da Vinci 32, Milan, Italy  
luigi.barazzetti@polimi.it

<sup>3</sup> Politecnico di Milano, Polo di Lecco, Indexlab, Via Gaetano Previati 1c, 23900, Lecco, Italy  
(carlo.beltracchi, pierpaolo.ruttico)@polimi.it

## Commission II

**KEY WORDS:** Blockchain Technology, Metaverse, Participatory Design, Photogrammetry, Rural Regeneration, Voxels

### ABSTRACT:

This research employs a digital strategy to counter rural population decline and urban migration by integrating drone photogrammetry, metaverse, and blockchain technology. The focus is creating detailed 3D models of the settlements, which are subsequently optimized for metaverse platforms such as Voxels and Mona. Voxels facilitates participatory design, utilizing voxel parcels and Rhino-Grasshopper to involve all the stakeholders for renovation design work. Mona transforms parameterized projects into an immersive virtual experience, fuelled by blockchain technology, providing non-fungible token (NFT) marketplaces and economic transitions. These virtual and real realms serve purposes such as decision-making, cultural preservation, economy generation, and virtual tourism, fostering rural revival, virtual economy, and digital representation of real-world environments.

## 1. INTRODUCTION

There has been significant recent development in the field of artificial intelligence (AI), web 3, and the metaverse (Chamola et al., 2023). This fusion is finding its applications in architectural visualisation, real-time design feedback, and collaborative virtual design environments, inspiring architects to explore innovative solutions within their discipline. Furthermore, the concept of crafting a photorealistic world in the metaverse has diverse use cases, including enabling users to virtually visit physically inaccessible locations, aiding in the preservation and spread of cultural heritage (Sharma, 2023) and enhancing territorial resilience through the integration of blockchain, robotics and decentralized artificial intelligence (Beltracchi, 2023). The idea of seamless online exploration and local experience accessible worldwide at one's fingertips, ignited a curiosity in investigating the integration of architecture with photogrammetry and the metaverse, a key aspect studied within this paper.

Rural villages across Europe suffer from depopulation, transforming into ghost towns as residents migrate to cities (Conticelli et al., 2019). Italy, for instance, is on the verge of losing over 179 villages (Di Figlia, 2016). Simultaneously, Europe faces the challenge of assimilating immigrants, who often struggle with language barriers and lack the essential skills to interact with the local communities (Davidov, 2019). In this context, a comprehensive case study of Ostana, an Occitan village near Monviso in Piedmont, is being conducted. Data from local interviews and online databases were collected on cultural and historical significance, which further helped in the process of decision-making and designing a solution-aided module. One of the initiatives involves strategically placing refugees in declining towns and providing language training, and skill development (Razavivand Fard and Mehan, 2018). The study, which is part of the ongoing thesis project (Abramov et al., 2024) at Politecnico di Milano, aims to create a module for revitalising declining villages using architectural solutions with the help of photogrammetry and metaverse (Figure 1).



**Figure 1.** a) Real life drone image; b) Cleaned photogrammetric model; c) Voxelized model of Villa settlement in Ostana.

On-site recording of two settlements of the village were performed using drones and mobile phones. The images were then further processed to create a 3D model of the village, optimized for web 3 platforms such as Voxels and Mona. Voxels facilitates user-friendly design participation, later parametrized into real architectural projects. Mona is used to create an interactive multiplayer virtual environment to establish a space for local residents, refugees, and tourists to interact, bridging the virtual and real realms. Digital goods are commodified in NFT marketplaces, valuing the labour involved in digitization fostering a blockchain-enabled virtual economy. This immersive virtual space within the metaverse serves multiple purposes:

1. Decision Making: Developers and stakeholders can interact and virtually visit proposed design projects before their actual construction;
2. Education: Preserve Occitanian culture and attract new inhabitants;
3. Economy Generation: Mirror real-world economic principles by enabling the trade of digital goods, such as NFTs, within a marketplace;
4. Virtual Tourism: Provide a virtual experience before physical visits and facilitating travel planning in a single virtual web 3 space.

## 2. RELATED WORKS

The integration of aerial (drone) and terrestrial photogrammetry, metaverse, and blockchain technology in addressing rural population decline and urban migration represents a novel approach that draws on a range of interdisciplinary concepts.

The research on digital photogrammetry's role in creating virtual environments highlights the use and reliability of structure from motion photogrammetry to generate realistic 3D representations, demonstrating its potential to bridge the real and virtual worlds for various purposes, particularly as an educational tool to enhance the learning experience (Fink et al., 2023).

The concept of participatory design in virtual environments has gained prominence in urban planning and architecture, emphasising collaboration between communities, stakeholders, and designers in decision-making processes. In particular, the UN-Habitat program 'Block by Block' involves engaging young people in designing urban public spaces using Minecraft, a voxel-based video game, and then presenting these designs to local authorities and implementing them in real life. ICT can be a catalyst to improve governance in towns and cities and help increase levels of participation, efficiency and accountability in public urban policies (Westerberg and Heland, 2015). The role of digital gamification in co-design processes is a focal point within the "Frontiers in Virtual Reality" research topic (Chowdhury et al., 2023). Exploring its significance, this aspect shows how incorporating of play and interactivity elements along with Virtual Reality (VR) and Augmented Reality (AR) technologies fosters collaborative design, public participation, artistic expression, and visualisation within the metaverse. The use of co-design to tackle rural decline and preserve cultural heritage, engaging inhabitants to share their knowledge and experiences through the metaverse, was examined in a case study involving a small village in Portugal. With the assistance of participants, a digital replica of the village was created (Martins et al., 2022). These examples illustrate the potential of these technologies to revolutionise design processes and enhance public engagement.

The utilization of blockchain technology in Architecture, Engineering and Construction (AEC) industry is grounded in the

growing body of literature on decentralised systems and digital twins (Dounas et al., 2022; Hunhevicz et al., 2022). The application of blockchain to the built environments offers unique opportunities for digital identity, data integrity, self-ownership and the creation of consensus platforms, contributing to the emergence of virtual economies that mirror real-world principles (Hunhevicz et al., 2021).

## 3. CASE STUDY

Ostana (Figure 2) emerged as the ideal choice for further study in the framework of this research, surpassing other Italian villages in key aspects such as vacant buildings, spacious streets conducive to acquiring images, and its dedicated commitment to welcoming refugees. Ostana actively collaborates with institutions such as the Monviso Institute, Politecnico di Torino, University of Lugano and Ambornetti Retreat Project (Ashley et al., 2018; De Rossi, 2019). Its Smart Village Strategy focuses on addressing challenges, such as environmental risks and the perception of mountain territories, through stakeholder engagement and smart solutions. Initiatives like the Monviso Transboundary Biosphere Reserve and collaborations with research centres and private companies are integral to this strategy (Smart Rural 21, 2020).



Figure 2. Ostana image (Sant'Antonio settlement) from the drone.

Ostana, nestled in the Alpine Occitan village in Piedmont, which used to have 1200 dwellers, faces a stark population decline, with a mere six year-round residents, marking a 99.5% depopulation rate (Di Figlia, 2016; ISTAT, 2023). Despite its enchanting status as one of Italy's most beautiful villages (Piemonte Borghi Più Belli D'Italia, 2023), its birth rate saw a notable resurgence. The birth of Pablo in 2016 marked the first time the village had seen a newborn in 28 years (Lombardi, 2016). Besides, cultural initiatives, like the Ostana Prize for Scriptures, underscore the village's commitment to emerging languages and endangered cultures (Premio Ostana, 2023).

Former Mayor Lombardo outlined a multifaceted strategy for revitalization during the visit. The collaboration with Alpine architecture experts aimed to preserve the unique existing alpine architectural characteristics, investing in abandoned houses, fostering technological innovations was highlighted (Fioretti, 2021). Emphasis was paid on quality tourism and language preservation initiatives. Hosting a literary prize dedicated to minority languages and a project integrating Pakistani immigrants, were emphasised as pivotal components of Ostana's revitalization efforts.

However, challenges persist managing tourist influx. The Reading Festival brought economic benefits but also underscored the need to regulate tourism to maintain Ostana's tranquility.

Striking a balance between economic growth and sustainability remains a priority. Continued collaboration with experts and the community will be crucial in navigating these challenges, ensuring Ostana's allure endures for both residents and visitors.

#### 4. METHODOLOGY FOR DATA ACQUISITION AND PROCESSING

##### 4.1 Photogrammetric data collection

The focus was on Villa and Sant'Antonio, the two primary settlements in Ostana. A thorough examination of the environment was conducted, DroneDeploy was used to plan the flight path and the images were recorded using DJI Air 2s and DJI Mini drones. The process, conducted over a span of two days under favorable weather conditions, followed a predetermined route along the predetermined route. Key areas were identified based on photo content and the drone was manually piloted to capture additional detailed images.

Challenges during the drone mapping process included coincidental scheduling of the local reading festival which led to the presence and movement of vehicles and dynamic crowds. These elements in the captured photos further impacted the subsequent model reconstruction, compromising the quality of the acquired data.

##### 4.2 3D modelling

During the mapping of the village Ostana, a total of 2632 photos were captured with DJI Air 2s, and 2570 with DJI Mini. Two recording campaigns over the course of 2 days were conducted, and low-quality images were eliminated. Ultimately, 1774 and 591 images were used for Villa and Sant'Antonio, respectively. These images were processed with RealityCapture, DroneDeploy, and Agisoft Metashape, separately. The model produced with Agisoft Metashape was selected to continue data processing. Processing at high resolution was then repeated for two clusters following the typical photogrammetric workflow: image orientation, mesh generation and texture mapping (Figure 3).

##### 4.3 Optimization of the model

The proposed solution does not require an accurate as-built model revealing actual conditions, therefore manual editing is carried out to enhance visual quality and remove artifacts. Although most results reflect the actual conditions of Ostana, the aim is the creation of a model suitable for metaverse, therefore manual editing is carried. During the modelling phase, numerous residual images of vehicles and individuals emerged, leading to significant imperfections in the model's details. Moreover, trees are difficult to reconstruct accurately through mapping.

To address these issues, the high-resolution model obtained from Agisoft Metashape was then imported into ZBrush (Maxon, 2023), which offers a multitude of tools for smoothing or shaping specific parts of the model. These tools, for instance, Adobe Photoshop add-ons (Adobe, Maxon, 2023), were employed to eliminate the vehicles, restoring the flat ground by copying the materials from unaffected regions and repainting them wherever necessary (Figure 3).

After editing the model with ZBrush, the model was further moved to Blender for some additional editing, in particular for minimizing the number of faces of the large photogrammetric model (The Blender Foundation, 2023). Considering the terrain of Ostana, the complexity of the model could only be reduced by decreasing the number of existing faces in the high-resolution model mesh, which further contributed to the simplification of the project file size.

For this purpose, the high-resolution model consisting of 1,809,080 faces in Villa and 11,988,496 in Sant' Antonio was first converted from triangular meshes into quad meshes using the software Instant Meshes (Jakob and Davor, 2015), reducing the number of faces drastically to 939,163 and 446,235, respectively, resulting in a retopologized model (Figure 3). It was then imported into Blender 4.0 for further processing. The editing process on Blender 4.0 involves deleting all the tree meshes and correcting artifacts existing in the model, recovering them back to create a smooth terrain for the texture baking process.

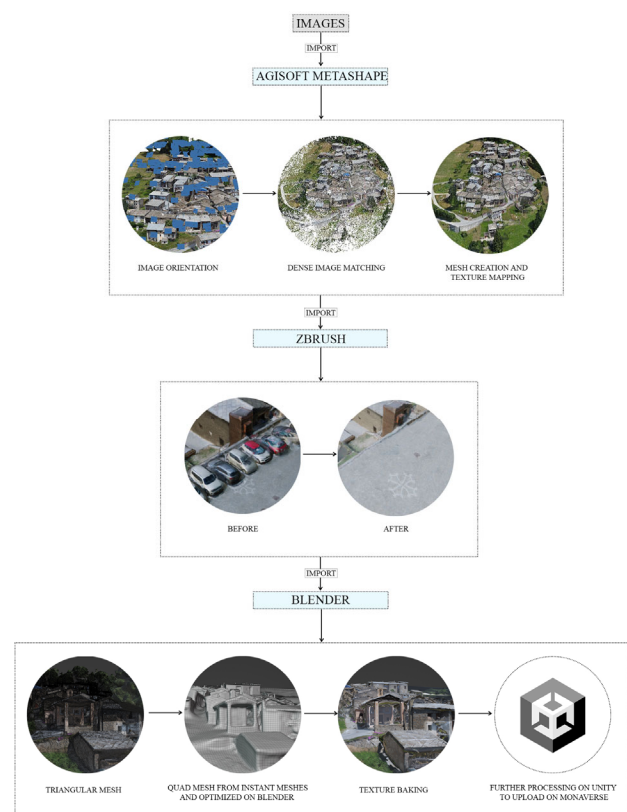


Figure 3. Data processing workflow

The texture baking is a process of extracting the existing high-resolution textures from the Zbrush imported model to baking or imprinting the same onto the low-resolution mesh model, resulting in an optimized model suitable to be uploaded on metaverse platforms. The whole workflow diagram is shown in Figure 4.

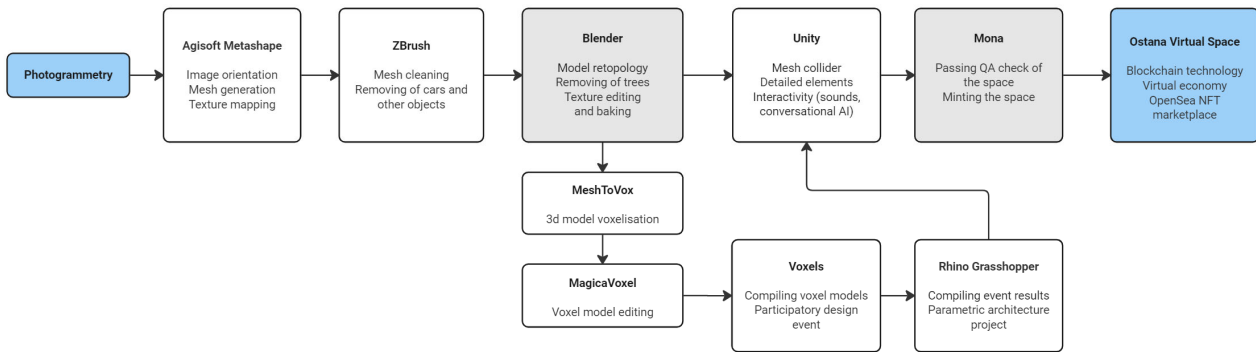


Figure 4. General workflow diagram: from images to the metaverse.

## 5. DESIGN THROUGH METAVERSE

### 5.1 Blockchain technologies

Transforming a decaying rural area requires incentives from various professionals particularly architects and urban designers. As the AEC industry moves to web 3, it is important to adopt new ways of client-contractor relations utilizing performance-based smart contracts (Hunhevicz et al., 2022). The process illustrated in Figure 5 could be implemented through metaverse and blockchain technologies following these steps:

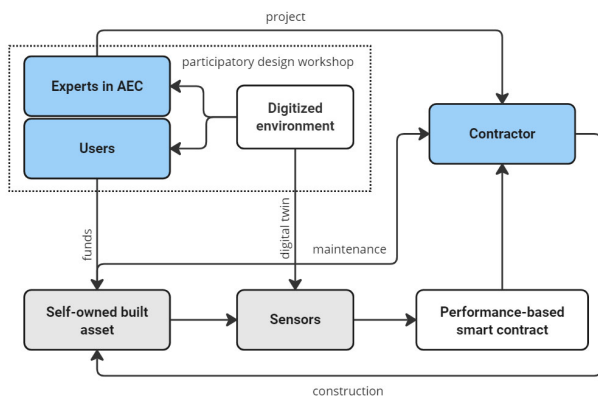


Figure 5. Design process through blockchain and metaverse.

1. Digitization process: Real-world environments digital representation is vital for the proposed process;
2. Decision making: To consider the needs of the community (users) participatory design workshop is conducted in metaverse;
3. Open call for professionals: Experts in AEC are invited to process the workshop results and present a final community-led architectural project;
4. Presentation: The project is put for public discussion in an interactive web 3 digitized environment;
5. Construction: Smart contract is set up defining performance logic, users and contractor. When the structure is completed, it is registered in the performance contract along with its digital twin and corresponding sensors. This approach replaces the traditional method of paying for construction with a performance-based model, where the user pays for the provided services, aligning the interest in designing and building for the best possible performance with the interest in minimising operational, maintenance, and disposal costs. The integration of digital twin of a built asset with blockchain-based smart contracts enables

real-time performance evaluation and automatic payments based on predefined performance conditions. Digital twin is a virtual representation of a built asset created during the digitization process. It requires the connection between the physical product and replica through Internet of Things (IoT) devices that gather and exchange various performance data in real time such as energy consumption and the level of comfort of the users (Hunhevicz et al., 2022);

6. Maintenance: Concept of “Decentralised Autonomous Space” (DAS) developed in “no1s1” project is proposed (Hunhevicz et al., 2021). Built asset is self-owned and self-maintained throughout its life cycle. Reducing the need for traditional ownership structures and intermediaries, leads to a more efficient use of resources and lowering the costs. Self-ownership of the space requires financial autonomy, which involves establishing blockchain funds storage, where revenue comes from the users and the community. It enables DAS to cover essential expenses and investments such as paying for operation and maintenance. Technical systems should be controlled by the DAS using inputs from sensors and IoT devices, either reactively responding to human activities or proactively influencing behaviour through incentive mechanisms such as variable pricing or token-based rewards. Furthermore, to ensure the longevity of operations, maintenance autonomy is necessary. The DAS must be capable to detect faults through sensors, human feedback, or usage data, and it should have coordination mechanisms to define and commission the required services for the space. Ethereum blockchain smart contracts are core elements of the autonomy triggered by user actions.

### 5.2 Participatory design platform

Voxels, a user-friendly metaverse platform powered by Ethereum blockchain, has been selected to enable people to be actively involved in decision-making for proposed design projects (Voxels, 2023). Created spaces are playable in-browser which makes it suitable for participatory design events. This approach is similar to the UN-Habitat ‘Block by Block’ program which gives voice to those who are not usually heard, but who are most impacted by the planning decisions (Westerberg and Heland, 2015). In order to facilitate community-driven design processes, individuals without architectural or 3D-modelling skills need easy tools to effectively describe their ideas and desires to professionals.

To create the intended space in voxel metaverse 3D model needs to be converted into vox format. Considering the size limitation of Voxels megavox feature (126x126x126 voxels) the small central area of Villa was cut out from the model in Blender and then low-resolution texture was baked for FileToVox tool (Perrier, 2022). The voxelized model then was processed in

MagicaVoxel software (Ephracy, 2020) eliminating texture and excessive volumes mistakes.

Voxels workshop was organised following the main principles of 'Block by Block' playbook on the use of voxel-based platform as a participatory design tool (Imam and Lahoud, 2021). 20 participants were selected among the focus-group of people meeting the criteria of basic computer skills. They work in separate spaces to create their own project proposals using workshop guidelines. Guidelines contain basic information about Ostana, urban context, possible functions and instructions on Voxels interface and created voxel space. According to the conducted field research and Ostana Mobility Experiment survey (Affolter et al., 2018) design of a sustainable modular structure adjustable to different functions such as a language centre is proposed. To promote use of local materials and green energy small voxel models were created representing timber panels and frames with photovoltaic elements. Participants can use any of the given solutions to represent their own idea in a voxel format (Figure 6).



**Figure 6.** a) Voxels space basic configuration; b) One of the proposed results in Voxels space.

Event results are processed and showcased at Archiversus Educational Playground, parcel within the same Voxels platform (Archiversus, 2022). Further, they are intended to be parameterized into architectural projects using Rhino-Grasshopper in the development steps of the project.

### 5.3 Interactive web 3 environment

Mona, a metaverse platform designed for interactive multiplayer environments, is utilized to create a virtual Ostana experience. This procedure involves adding artifacts and interactive elements like characters, artworks, and sounds using Unity (Mona, 2023); (Unity Technologies, 2022). The goal is to establish a space for local residents, refugees, and tourists to interact, promoting a resilient local economy and bridging the gap between virtual and real worlds (Figure 7). This immersive virtual space within the metaverse serves multiple purposes:



**Figure 7.** a) Real life photograph; b) Avatar walkthrough in Mona space.

1. Decision making: Developers and stakeholders can interact and virtually visit proposed design projects before their actual construction. It involves not only community-driven proposals but also any other urban transformation, new construction, or renovation projects.

2. Education: Preserving Occitanian culture and attracting new inhabitants. Interactive space can be used as an educational ground for learning Occitanian language and culture as well as for other languages of the growing community. Access to education is a vital amenity to attract people to rural areas and metaverse can be an effective tool for teaching. The platform also gives wider opportunities for refugees and immigrants providing language and skill training for integration into the local community.

3. Economy generation: Mirroring real-world economic principles by enabling the trade of digital goods, such as NFTs, within a marketplace generates a proper virtual economy with the use of Blockchain technology enabling the metaverse to function as a virtual space where individuals are distinctly identified by a blockchain address. In this digital sphere, virtual goods, much like the space they occupy, can be commodified within the NFT-marketplace such as OpenSea (Finzer and Atallah, 2017) where users buy, sell and trade them. Interacting with the metaverse, users can showcase and engage with their NFTs in virtual spaces, and ownership is recorded on the blockchain, tied to the user's wallet, providing a transparent and decentralized record of ownership. The valuation of these artefacts reflects the labour invested by the people involved in the digitization process, suggesting the possibility of a marketplace for digital representations of real-world environments.

4. Experiential space: Providing a virtual experience before physical visits and facilitating travel planning in a single virtual web 3 space to encourage sustainable tourism. This experience includes a virtual tour of the place explaining the rich Occitanian cultural heritage of Ostana as well as first-hand perspective on local life. Visitors will be able to book their accommodation and activities through NFT which serves as a 'digital ticket'. These tokens represent customised travel experiences, exclusive content, virtual tours and facilitate seamless transactions within the travel industry. Another use of technology is to employ NFT-powered rewards program to store customer records securely.

Each customer is assigned a unique NFT that contains their pertinent information, enabling streamlined processes for making reservations at hotels or restaurants (Team CoinSwitch, 2023). This blockchain based sustainable tourism approach not only enables new forms of interaction, ownership and monetization but also helps to address issues of overtourism which according to Tobias Luthé, director of Monviso institute, is becoming apparent even in remote areas such as Ostana. In peak season the number of tourists could be 6 times more than the population. Despite the fact that tourism is playing a major role in its economy the municipality opts for low-impact sustainable tourists (Ostana Smart village strategy). In future some settlements may decide to impose restriction strategies and utilizing blockchain based platforms could be one of the ways to tackle the issue efficiently. To become publicly accessible the space should go through the minting process which requires passing Q&A from Mona.

## 5. CONCLUSION

This research explored a novel method for future exploration in building resilient and thriving communities, with a focus on economic growth and sustainable tourism with immersive metaverse experiences. The combined use of digital recording, metaverse, and blockchain provides a holistic framework for rural regeneration. It addresses economic, cultural, and community aspects, fostering a comprehensive revitalization process.

The achieved photogrammetric models requires further editing to become effectively useful in metaverse platforms like Mona. For instance, some AI techniques could be useful to automated and support some tasks of the modelling phase. An example could be the automatic classification of elements (buildings, cars, vegetation, etc.) from point clouds. However, the complexity of the considered scenes still required significant manual work performed by a human operator. The outlined methodology requires a substantial amount of manual effort in different software. The exploration of alternative approaches with the comparable outcomes while minimizing manual intervention, warrants further study. This investigation would contribute to the advancement of cost-effective and efficient methodologies for digitization and metaverse integration.

The participatory design elements, especially in the metaverse, enable active community engagement. Stakeholders, including local residents and refugees, can actively contribute to decision-making processes, enhancing a sense of ownership and inclusivity. Using voxel-based platform in participatory design proved to be an effective tool for engaging participants. However, the selection of alternative platforms, such as Sandbox (TSB Gaming, 2021), warrants further scholarly investigation to comprehensively enhance the co-design process, ease of use and engagement through the integration of gamification elements. The upcoming phases of the research should also involve parametrizing the resulting design data and exploring Generative Design obtained from participatory workshops and realizing architectural projects with local involvement, targeting economic enhancement, tourist attraction whilst rejuvenating decaying villages one community at a time.

Incorporating blockchain ensures transparency and trust in financial transactions, particularly in the utilization of NFT marketplaces. This decentralized ledger technology provides an immutable record of ownership and value, instilling confidence in the digital economy. While in its proposal stage and untested, the facilitated transformative workflow for the AEC industry

anchored with blockchain technology mandates continued research and development of the working prototype. Full integration of described proposals such as performance-based smart contracts, DAS, potential shift in ownership concept and client-contractor relationships in the AEC sector, is necessary for practical application and validation of the research.

Blockchain-based sustainable tourism model intertwined with virtual environments and community-driven design strategies allows for innovative and sustainable tourism models. It addresses issues like overtourism and provides a new paradigm for economic transactions within the virtual environment. Yet, it must be investigated further to ensure the preservation of both cultural heritage and natural resources as well as to assess the scalability and adaptability of the approach to diverse contexts. Created interactive web 3 environment must be tested with real-world users to evaluate its effectiveness in fostering community engagement and promoting sustainable tourism. This involves conducting user experience (UX) studies and gathering feedback from stakeholders, including local residents, refugees, tourists, and professionals in the architectural and tourism sectors.

In summary, this multidimensional proposal offers a promising bridge between virtual and real realms, introducing fresh possibilities for sustainable rural and urban revival, digital economy generation, and digital representation of real-world environments. The research lays the foundation for future exploration and refinement of these novel strategies in the pursuit of resilient and thriving communities worldwide.

## ACKNOWLEDGEMENTS

We would like to sincerely thank the following people for their valuable help and feedback: Giacomo Lombardo, former mayor of Ostana in the period 1985-2014, Dr. Tobias Luthé, director of MonViso Institute, and Dr. Shuwa Chowdhury (North Carolina A & T State University).

## REFERENCES

- Abramov, N., Lankegowda, H., Liu, S., 2024. Metamorphosis: a digital approach to transforming communities through photogrammetry and metaverse. Master thesis in Building and Architectural Engineering, School of Architecture Urban Planning Construction Engineering, Politecnico di Milano.
- Adobe, 2023. Adobe Photoshop, Version 24.5. adobe.com (01.09.23).
- Affolter et al., 2018. Ostana mobility experiment: a survey for implementing sustainability in mountain tourism, Monviso Institute.
- Agisoft, 2023. Agisoft Metashape, Version 2.1.0. agisoft.com (24.07.23).
- Ashley et al., 2018. Ostana mobility experiment: a survey for implementing sustainability in mountain tourism, University of Lugano. Monviso Institute (WWW Document), n.d. URL: <https://monviso-institute.org/> (accessed 10.12.23).
- Archiversus, 2022. Archiversus Educational Playground. voxels.com/parcels/4329 (23.09.23).

- Beltracchi, C., 2023. Resilience and the Metaverse: A Toolkit Approach. In: Ruttico, P. (eds) Coding Architecture. Digital Innovations in Architecture, Engineering and Construction. Springer, Cham. DOI: 10.1007/978-3-031-47913-7\_5
- CapturingReality, 2022. Reality Capture, Version 1.0.3.6310. capturingreality.com (23.07.23).
- Chamola, V. et al., 2023. Beyond reality: the pivotal role of generative AI in the metaverse. DOI: 10.48550/arXiv.2308.06272
- Chowdhury, S., Schnabel, M.A., Lo, T.T.S., 2023. Editorial: Metaverse in co-virtual city design, *Frontiers in Virtual Reality*, volume 4. DOI: 10.3389/frvir.2023.1166107.
- Conticelli, E., De Luca, C., Egusquiza, A., Santangelo, A., Tondelli, S., 2019. Inclusion of migrants for rural regeneration through cultural and natural heritage valorization, Planning, nature and ecosystem services, 323-332. Naples: FedOAPress. ISBN: 978-88-6887-054-6, DOI: 10.6093/978-88-6887-054.6.
- Davidov, E., Semyonov, M., 2019. Attitudes toward immigrants in European societies. *International Journal of Comparative Sociology*, 58(5), 359-366. DOI: 10.1177/0020715217732183.
- De Rossi, A., 2019. Ostana: architettura e rigenerazione. *We Arch* (WWW Document), n.d. ISSN 2611-8777, URL: <https://www.wearch.eu/ostana-architettura-e-rigenerazione/> (accessed 10.12.23).
- Di Figlia, L., 2016. Turnaround: abandoned villages, from discarded elements of modern Italian society to possible resources, *International Planning Studies*, 21:3, 278-297. DOI: 10.1080/13563475.2016.1186530.
- Dounas, T., Lombardi, D., Vele, J., Prokop, S., 2022. A crypto-twin framework for the AEC industry, *ASCAAD: Hybrid Spaces of the metaverse*.
- DroneDeploy, 2023. DroneDeploy. dronedeploy.com (23.09.23).
- Ephtracy, 2020. MagicaVoxel, Version 0.99.6. ephtracy.github.io (12.11.23).
- Fink, M.C., Sosa, D., Eisenlauer, V., Ertl, B., 2023. Authenticity and interest in virtual reality: Findings from an experiment including educational virtual environments created with 3D modeling and photogrammetry, *Frontier in Education*, volume 8. DOI: 10.3389/feduc.2023.969966
- Finzer, D., Atallah, A., 2017. OpenSea. opensea.io (09.01.24).
- Fioretti, M., 2021. Riutilizzo della parte materiale e riattivazione delle comunità: il processo di rigenerazione delle aree interne comincia da qui, *Orticalab* (WWW Document), n.d. URL: <https://www.orticalab.it/Riutilizzo-della-parte-materiale-e/> (accessed 09.01.24).
- Hunhevicz, J., Motie, M., Hall, D., 2022. Digital building twins and blockchain for performance-based (smart) contracts. DOI: 10.1016/j.autcon.2021.103981.
- Hunhevicz, J., Wang, H., Hess, L., Hall, D.M., 2021. NO1S1 - a blockchain-based DAO prototype for autonomous space, 2021 European Conference on Computing in Construction.
- Imam, A., Lahoud, C., 2021. The Block By Block playbook: Using Minecraft as a participatory design tool in urban design and governance, United Nations Human Settlements Programme.
- ISTAT / Official website – 2023. Ostana Census (WWW Document), n.d., URL: <http://dati.istat.it/Index.aspx> (accessed 10.12.23).
- Jakob, W., Davor, B., 2015. Instant Meshes. github.com/wjakob/instant-meshes (01.10.23).
- Lombardi, P., 2016. Italian town welcomes first baby in almost 30 years. *CNN NEWS* (WWW Document), n.d., URL: <https://edition.cnn.com/2016/01/29/europe/italian-town-first-baby-in-28-years/index.html#> (accessed 10.12.23).
- Martins, D., Oliveira, L., Amaro, A.C., 2022. From co-design to the construction of a metaverse for the promotion of cultural heritage and tourism: the case of Amiais, *Procedia Computer Science*, 204, 261–266. DOI: 10.1016/j.procs.2022.08.031.
- Maxon, 2023. ZBrush, Version 2023.2.2. maxon.net/en/zbrush/ (01.09.23).
- Mona, 2023. Mona. monaverse.com (25.09.23).
- Perrier, N., 2022. FileToVox, Version 1.16. github.com/Zarbuz/FileToVox (12.11.23).
- Piemonte Borghi Più Belli D'Italia / Official website – 2023 Ostana: Borgate Occitane Sotto il Monviso (WWW Document), n.d. URL: <https://borghiplusbelliditalia.it/borgo/ostana/> (accessed 10.12.23).
- Premio Ostana / Official website - 2023: Premio Ostana scritte in lingua madre - escrituras en lenga maire (WWW Document), n.d., URL: <https://www.premioostana.it/> (accessed 10.12.23).
- Razavivand Fard, H. and Mehan, A., 2018. Adaptive reuse of abandoned buildings for refugees: lessons from European context, *Suspended Living in Temporary Space: Emergencies in the Mediterranean Region*, 188-197.
- Sharma, P., 2023. How can metaverse help re-imagine the future of heritage preservation, *ParametricArchitecture* (WWW Document) n.d., URL: <https://parametric-architecture.com/> (accessed 15.12.23).
- Smart Rural 21, 2020. Smart Village strategy of Ostana (Italy), Preparatory Action for Smart Rural Areas in the 21st Century (WWW Document) n.d., URL: <https://www.smartrural21.eu/> (accessed 10.12.23).
- Team CoinSwitch, 2023. Understanding the role of NFTs in the travel industry, *Switch* (WWW Document) n.d., URL: <https://coinswitch.co/switch/crypto/understanding-the-role-of-nfts-in-the-travel-industry/> (accessed 09.01.23)
- The Blender Foundation, 2023. Blender, Version 4.0. blender.org (27.09.23).
- TSB Gaming, 2021. The Sandbox. sandbox.game (10.01.24).
- Unity Technologies, 2022. Unity engine, Version 2022.3.9.f1. unity.com (05.10.23).
- Voxels, 2023. Voxels. voxels.com (23.09.23).

Westerberg, P., Heland, F., 2015. Using minecraft for youth participation in urban design and governance, United Nations Human Settlements Programme.