buildings

MDPI

Article

Preserving Tradition through Evolution: Critical Review of 3D Printing for Saudi Arabia's Cultural Identity

Monica Moscatelli

Architecture Department, College of Architecture and Design, Prince Sultan University, Riyadh 11586, Saudi Arabia; mmoscatelli@psu.edu.sa

Abstract: In a dynamic era of architectural innovation, Saudi Arabia is pioneering a unique approach to preserving its rich heritage. By integrating traditional Saudi architecture into 3D-printed structures, the nation is forging a path that harmoniously blends the past and the future. This paper aims to show the potential of 3D printing in incorporating aspects of the local culture into construction. Through an analysis of the literature review, this research selected three international case studies to analyze how cultural identity has been integrated and how it evolved into buildings through 3D printing technology. The results demonstrate that aligning 3D printing with authentic local cultural identity can significantly improve the built environment. This direction favors a synthesis between sustainability and cultural heritage, giving rise to the creation of innovative architectural structures that are rooted in the territory at the same time. This cultural reflection in innovative architecture aims to lead Saudi Arabia to reflect on the importance of its heritage while also ushering in a new era of sustainable construction, ensuring that the cultural fabric of the Kingdom remains vibrant for generations to come.

Keywords: cultural identity; evolution; heritage preservation; innovative architecture; sustainable construction; texture; three-dimensional printing technology

check for updates

Citation: Moscatelli, M. Preserving Tradition through Evolution: Critical Review of 3D Printing for Saudi Arabia's Cultural Identity. *Buildings* **2024**, *14*, 697. https://doi.org/10.3390/buildings14030697

Academic Editors: Yi-Kai Juan and Tsung-Hsien Wang

Received: 18 January 2024
Revised: 27 February 2024
Accepted: 29 February 2024
Published: 5 March 2024

Copyright: © 2024 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Three-dimensional (3D) printing technology, an automated process called rapid prototyping, is an up-and-coming alternative to traditional construction methods [1]. Among digital fabrication technologies, 3D printing stands out for its operational advantages in architecture, engineering, and construction. It offers numerous benefits and can reduce the carbon footprint, improve job safety, significantly shorten construction times and costs, reduce material waste, and lead to greater design flexibility [2–4]. Furthermore, 3D printing offers versatility, as it can be employed throughout the entire design process, from developing prototypes to fabricating full-scale structures [5].

In an era marked by globalization and rapid technological advances, architectural practice has significantly expanded, driven by technological advancements and cultural resilience [6]. These technologies are reshaping our understanding of the physical environment [7]. Consequently, the goal of preserving cultural identity has become paramount for many countries. Saudi Arabia is at the forefront of adopting methods oriented toward sustainability while maintaining local identity, aligning with the objectives of Saudi Vision 2030. Furthermore, UNESCO affirms that no development can be considered sustainable without including the "culture" and the "full integration of culture into sustainable development policies" [8]. The aim is to preserve tradition through evolution, which means learning from the past and shaping the future, not by copying it but by evolving it using avant-garde sustainable techniques within the nation's borders, positioning Saudi Arabia as an international leader in integrating technology and culture [9].

Three-dimensional printing in construction offers a unique opportunity to achieve harmony between innovation and tradition, possibly integrating architectural elements

that reflect the local cultural identity into the architecture. It allows the creation of buildings and structures that are not only cutting-edge from a design and construction point of view but also deeply rooted in the cultural fabric of a place. This fusion between technology and cultural identity goes beyond mere aesthetics; it reflects a community's commitment to maintaining its roots by embarking on a sustainable and innovative architectural journey [10]. Integrating cultural identity into architecture through 3D printing involves adapting the design, selecting local materials, and promoting social participation to create structures that reflect the local culture [11]. Each 3D-printed building becomes a canvas for storytelling, a testament to the enduring relevance of tradition in a rapidly changing world.

Modern buildings introduced by globalization have caused identity conflicts in Saudi Arabia, as evident in Riyadh's capital [12]. Saudi Arabia is undergoing a significant expansion, with numerous megaprojects across the Kingdom. These constructions will change the built environment, and it is essential to give an identity to the country by preserving the cultural heritage so that people's identity and collective memory do not dematerialize, creating a connection between the past and present. It is, therefore, necessary to identify guidelines that apply new 3D printing technologies that consider the local architectural identity and reinterpret it in a contemporary key in all phases of the design process, from the shape and typology of the artifact to the scale of manufacturing. Incorporating local architecture within the walls and structures of 3D-printed buildings can amplify the culture of Saudi Arabia for citizens and tourists and help preserve local heritage for future generations [13]. But, if this cultural integration fails, it will lead to the loss of heritage, language, and cultural integrity [14]. Today, it is necessary to materialize its traditions and beliefs in the built environment, leading Saudi Arabia to preserve its heritage and pave the way for a more sustainable future through culturally lively and farsighted architectural innovation [15].

Therefore, this critical review of 3D printing and its possible role in Saudi Arabia's cultural identity is essential to address now, as it wants to be part of the theoretical framework of Vision 2030, which includes building a society based on Saudi heritage and culture and promoting a rich national identity. Sustainability is a crucial part of Vision 2030 as the Kingdom commits to a Net-Zero future by 2060 to address energy and climate challenges with innovative solutions, where 50% of energy will come from renewable sources [16]. For this reason, this research recommends that Saudi Arabia use its local resources and, therefore, the earth, thanks to the rich availability of desert soil. Traditional buildings were built with mud and straw, so using natural soil in 3D printing construction is a suitable and essential technology to be applied in Saudi Arabia. Performing 3D printing with earth can significantly reduce the carbon footprint of buildings since earth is a material with lower embodied energy than other construction materials. At the same time, it offers flexibility in shape and design, with the possibility of creating intricate shapes that innovatively evolve the elements of traditional architecture [17]. This paper, therefore, wishes to contribute to Saudi Arabia's sustainable and culturally vibrant future by redefining its architectural artifacts and preserving its cultural identity.

This article is structured as follows. The following section describes the historical timeline of 3D printing, focusing on Saudi Arabia. Then, the paper presents its methodology, focusing on three significant international case studies that integrate 3D printing technology with the local cultural identity using different materials. The selected case studies are critically analyzed through four 3D printing cultural identity criteria: design elements, material selection, construction method, and community engagement. The Results Section highlights the case studies' comparison matrix to summarize the main characteristics of traditional architecture that has evolved in a contemporary mode through the four criteria related to 3D printing for cultural identity. The Discussion Section defines some strategic guidelines for evolving cultural identity through 3D printing with earth in Saudi Arabia, showing a possible transfer of knowledge and an evolution of vernacular architecture with innovative technology, transmitting cultural identity through innovation. Finally, the paper concludes by highlighting the scientific value of the research, adding limitations and future considerations on this topic.

2. The Historical Timeline of 3D Printing

The origins of 3D printing can be traced back to 1970, but it was introduced in 1984 when Charles "Chuck" Hull unveiled the method for transforming designs into tangible 3D models. This ground-breaking technique, known as Stereolithography or "SLA", involves building up layers of photopolymer material and solidifying it using a UV laser. Recognizing its potential, Hull founded 3D Systems to advance this technology further [18,19]. In 1992, Hull's 3D Systems company produced the SLA-1, the world's first commercial Stereolithography Apparatus (SLA). The same year, Carl Deckard patented the Selective Laser Sintering (SLS) machine. This similar technology utilizes a powder photopolymer reaction rather than a liquid. Additionally, in 1992, Scott Crump patented fused deposition modeling (FDM), which entails extruding a thermoplastic filament through a heated nozzle to incrementally build layers. Throughout the 1990s and into the early 2000s, SLA and SLS were used primarily in the industrial manufacturing setting for casting small parts and components for various plastic products. The 2000s saw the significant advancement and commercialization of 3D printing technologies. Companies like 3D Systems emerged as pioneers in the industry, introducing new materials and applications for 3D printing. Then, the American Society for Testing and Materials (ASTM) 2005 officially acknowledged additive manufacturing (AM) as the standard terminology for these processes. According to ASTM, additive manufacturing combines materials to fabricate objects from 3D model data, typically layer by layer. Three-dimensional printing is rooted in additive manufacturing methodologies [20]. In 2006, Dr. Behrokh Khoshnevis developed the contour crafting system, a large-scale 3D printing system designed for on-site construction. This innovative approach utilizes a step-by-step layering process to construct buildings from materials [21–23].

Since these humble beginnings, 3D printing technology has garnered growing attention within the construction industry. Three-dimensional printing technology holds significant promise as an alternative to traditional construction methods [24,25]. It offers numerous advantages, including expedited construction timelines, reduced material wastage, and enhanced design flexibility [26,27]. Nowadays, 3D printing continues to evolve rapidly, with ongoing research and development focused more on the technical aspects of improving speed, precision, and material properties than on the architectural aspects and the integration of elements belonging to the local culture. The attention of academics, building materials manufacturers, architects, and contractors has been attracted by large-scale additive manufacturing technology that has facilitated several cement-based projects [28]. For example, Khan et al. presented a systematic review of the sustainability potential, assessments, and challenges of 3DP concrete for built environment applications in their study [29]. Prasittisopin et al. [30] experimented with the architectural design of a single textured wall layer with an additive manufacturing structure to improve thermal properties and energy savings compared to the conventional design. Hamard et al. [31] and Agustí-Juan et al. [32] emphasized that combining digital fabrication methods with traditional architectural approaches can uncover sustainability advantages for construction purposes over conventional cement-based 3D printing techniques.

In addition to cement-based studies, 3D printing with earth materials offers promising solutions to revolutionize the construction industry, addressing sustainability, energy efficiency, and cost concerns [33,34]. In 2021, Mohamed Gomaa et al. [35] outlined the challenges in 3D printing earth materials like cob despite advancements in digital manufacturing. Their work details the development of a cob 3D printing system tailored to modern construction needs. Beyond cob construction, this study contributed to architectural design and construction fields by bridging traditional building methods with digital practices. In the same year, the Italian architect Mario Cucinella and WASP gave life to Technology and Clay (TECLA), the first 3D printer that uses local raw earth and, therefore, reusable and recyclable materials, collected from the local soil, producing zero emissions and adapting to any climate and context [20,36]. Furthermore, several analyses and studies are under development, such as the recent initial study developed in 2024 by the Faculty of Engineering of the University of Porto (FEUP), which investigated the advantages and potential of

3D printing with earth-based mortar [17]. In the future, other studies can define how the relationship with other construction systems occurs in printed constructions.

Three-Dimensional Printing in Saudi Arabia

In 2018, Saudi Arabia announced the successful construction of the first house in the Middle East using 3D printing technology to benefit from the latest technologies and promote innovative construction techniques in the construction sector. The goal is to quickly develop the construction industry and revolutionize how people think about homes through intelligent, futuristic methods [37]. Through new technologies, 70% of the Saudi population will be able to own their own home by 2030. Saudi Arabia reached one of the latest milestones in March 2023 with the construction of the world's tallest 3D-printed home villa in Riyadh [38].

Furthermore, Saudi Arabia participated in the 18th International Architecture Exhibition, La Biennale di Venezia, which began in May and ended in November 2023, with an exhibition entitled IRTH (in Arabic, it means legacy or prized possession). In response to the theme of the current edition of the exhibition, titled "The Laboratory of the Future", the National Pavilion of Saudi Arabia delves into the tangible and intangible qualities of materials of Saudi architecture in an interactive journey that uses the earth as a starting point for this exploration, combining it with experimentation with organic materials. The pavilion explores the dialogue between vernacular lenses and material topographies and between tradition and innovation, material and immaterial, reflecting on the future through nostalgia. The exhibition aims to pay tribute to Saudi vernacular architecture and the evolution of the country's landscape. Inside, the pavilion is crossed by a series of arched doors accommodating ceramic tiles. These sinuous tiles are reminiscent of desert dunes; they were printed with 3D printing and convey mass and lightness (Figure 1).



Figure 1. Three-dimensionally printed tiles at the National Pavilion of Saudi Arabia, Venice Biennale, Italy (credit: Monica Moscatelli 2023).

The exhibition's objective is to interact with visitors; each of them is asked to take a 3D-printed tile and hang it on the structure of the arches to leave a mark on the pavilion [39]. It is precisely through this unprecedented boom that Saudi Arabia could translate the elements that characterize local architecture into a contemporary mode through the

guidance of digitalization and technology, leading to the construction of not only efficient, eco-sustainable, and low-cost buildings but also architectures integrated with local tradition to transmit cultural identity and collective memories through innovation.

3. Methodology

This paper applies a critical qualitative research method (Figure 2). The research framework is divided into three different phases: (i) from the analysis of the literature review, this study selected three 3D printing best practices in architecture that integrate cultural identity in an innovative and contemporary way; (ii) the selected case studies were analyzed through four criteria: design elements, material selection, construction method, and community engagement; and (iii) a critical comparative analysis of the case studies was performed according to the selected criteria. These three phases led to the definition of future strategic guidelines to preserve and transmit cultural identity through the innovation of 3D printing in architecture to be applied in Saudi Arabia.

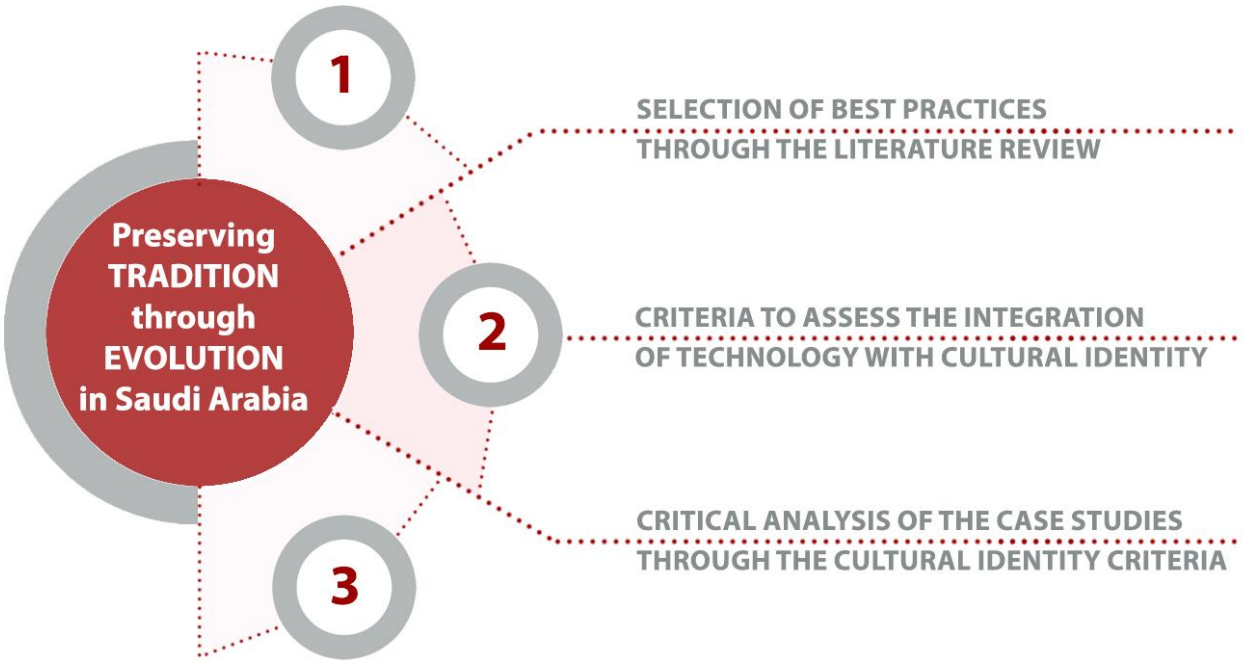


Figure 2. The three phases of the methodological framework (credit: Monica Moscatelli 2023).

3.1. Phase 1: Best Practices of Dialogue between Tradition and Innovation

This research conducted a literature review based on the main databases, like Google Scholar, Scopus, and Web of Science. Through the keywords "3D Printing", "architecture", "additive manufacturing", "heritage", "textures", and "sustainable construction", papers were collected and analyzed to cover all possible application areas of this topic. Most of the articles identified showed a technical approach to the application of 3D printing rather than to the architectural identity of the building. Some articles were not considered because they were focused on the chemical or structural properties of the material used by 3D printing technology. After filtering inadequate papers, the research selected some portals for researching architectural projects, such as ArchDaily, Designboom, and Dezeen, to identify those projects in which the traditional aspects of the architecture of the past have been integrated into a contemporary key with the use of 3D printing. From this research, examples emerged of the application of 3D printing components as a heritage preservation and sustainable application rather than the entire building itself. An example of this is a study conducted in 2016 on the possible use of a parametric Mashrabiya screen as a potential manufacturing method [40]. Other examples, again, include housing or office projects that did not reflect traditional local architecture, such as some offices in the

UAE or houses in Russia [14,20]. For this reason, this research has highlighted only three emblematic case studies that can read the past and shape it innovatively without losing the collective memory of traditional architecture despite different locations and materials. Integrating cultural heritage into architectural buildings requires careful consideration of historical accuracy, cultural significance, and community involvement. Achieving the goal of learning from the past and shaping the future in 3D-printed structures without strategic guidelines can be complex. Although the reflection of cultural identity in buildings created with 3D printing has not been the main objective until now, this research identifies some significant examples (Table 1) that could be considered prototypes to define guiding principles as a roadmap for architects interested in the application of 3D printing.

Table 1. The three selected case studies.

3D Printing Case Studies	Year	Location	Architects	Dialogue between Tradition and Innovation
3D Print Canal House	2014	Amsterdam, The Netherlands	Dus Architects	Interpretation of the past in a contemporary key
Traditional House of the Future	2023	Nanlong Village, Guizhou, China	The University of Hong Kong	Integration between traditional and contemporary methods
New Ghanzi housing	2020–2021	Ghanzi, Botswana, Southern Africa	IACC, Institute for Advanced Architecture of Catalonia	Incorporation of vernacular architecture in contemporary buildings

The three international case studies were selected with the aim of learning about the different experiences with 3D design around the world (Figure 3) by interpreting the dialogue between the past and the future in a different manner.

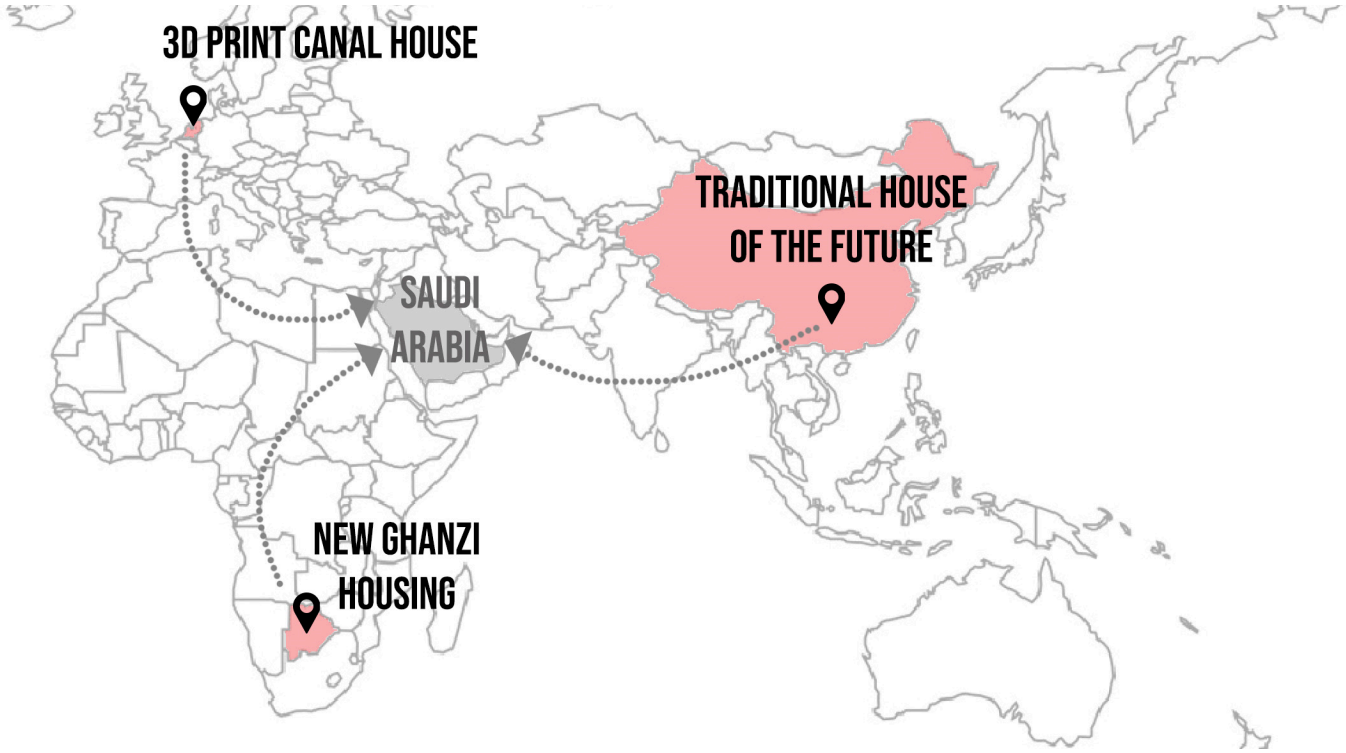


Figure 3. Case studies' locations: the evolution of the cultural identity of the three case studies as a cultural reflection in Saudi Arabia (credit: Monica Moscatelli 2024).

(1) The "3D Print Canal House" in Amsterdam by Dus Architects is a contemporary building that recalls the elements of the local cultural tradition. (2) The "Traditional House of the Future", created by a team of students and researchers from the University of Hong Kong and located in Nanlong Village, Guizhou Province, China, is a notable example that integrates traditional local techniques with 3D printing technology. The innovative prototype aims to revitalize and recycle vernacular houses in response to the urbanization of rural areas. (3) The "New Ghanzi: a hybrid of San heritage with 3D printed clay architecture" by students of IAAC, Institute for Advanced Architecture of Catalonia, is an interesting example that incorporates vernacular architecture into contemporary cluster housing. Raising awareness about the potential of 3D printing in integrating cultural heritage through innovation is the next step to achieve.

3.2. Phase 2: Criteria to Integrate Technology with Cultural Identity

The second phase highlighted the main criteria for constructing buildings that reflect the cultural identity of the place. This phase recognizes the transformative potential of 3D printing technology when seamlessly integrated with various facets of architectural development, such as design elements, material selection, construction methods, and community engagement. Table 2 provides a comprehensive overview of the four key criteria identified for effectively incorporating 3D printing technology into the preservation and promotion of cultural identity [41].

Table 2. The identification of the four criteria to integrate 3DP technology with cultural identity.

3D Printing Cultural Identity Criteria	Criteria Definition
Design elements	The integration of historical elements without imitation into 3D-printed buildings. The past is adopted in the present without being identical to the traditional architectural model. These elements can be incorporated into the space's composition or into the façade.
Material selection	The incorporation of locally sourced or traditional building materials to maintain a connection to the local culture.
Construction method	The combination of construction methods, in conjunction with local collaborators, creating an architectural synthesis that respects the local cultural identity while embracing contemporary technology.
Community engagement	The involvement of the local community in the design and construction process to ensure the building complements the cultural identity. Local input can provide valuable preferences that should be taken into account in the design.

3.3. Phase 3: Critical Analysis through Cultural Identity Criteria

The last step is a critical analysis of the three selected case studies, giving the essential support to define strategic guidelines for obtaining an innovative 3D printing architecture without forgetting the characteristics and elements of the local tradition.

Architecture is studied through other previous architectures. Therefore, the analysis of case studies leads to an understanding of the relationship between traditional and innovative architecture. The acquisition of elements from the past leads to their mastery and the ability to translate them with the 3D printed design.

(1) The 3D Print Canal House was completed in 2014 by Dus Architects; it is firmly contemporary yet influenced by the local architecture (Figure 4). The style of the houses of the 17th century inspires the design of the complex.

- Design elements. The picturesque landscape of Amsterdam is made up of a network of canals overlooked by buildings dating back to the Golden Age, i.e., the period that coincides with the political triumph of the state. The urban design of Amsterdam has an exceptional feature, with houses placed on narrow lots due to the high taxes payable in the 17th century related to the size of

the land. Therefore, the architecture was characterized by narrow houses with several floors. The 3D Print Canal House recalls Dutch colonial architecture by occupying a narrow lot overlooking one of Amsterdam's canals. The 700 sqm house is 6 m high, narrow, and deep and has a sloping roof: a perfect union of coexistence between the past and an innovative future constantly developing.

- Materials selection. It uses a bioplastic recycled material, which reduces the transport cost and works better with FDM printing techniques. However, architects and researchers are developing another biobased material that should be sustainable, strong, and aesthetically pleasing. It is research and design by doing; it is a process to continue to be developed. This material made it possible to obtain a three-dimensional façade that recalls the decorations of the houses of merchants and wealthy bourgeoisie of the 17th century.
- Construction method. The house was divided into components (Figure 5) created with the KamerMaker 3D printer, the world's first portable 3D printing machine. The design process occurs through software, where architects develop models of the various components at the desired scale. The material, heated by the printer, reaches the liquid state to be spread by the printer nozzle, creating a stratification of levels. The house was built in three years, as the speed of construction was different from the objective. Still, instead, the aim was to study the various technologies, creating elements that combine ornaments, structures, inner façades, and outer facades in one. The innovation is not only in the technique but also in the design, translating the characteristic elements of the Dutch colonial house through the design process by innovatively reinterpreting the colonial style.
- The research team wishes to move production out of the factory into the city to show the people they can be part of the fabrication. It is an actual exhibition open to everyone. Therefore, the 3D Print Canal House is not only an exhibition but also a research and building site for 3D printing architecture. It is a unique project where a research team collaborates in "research by doing", linking science, design, construction, and community by 3D printing a house along a canal in the heart of Amsterdam [42].

(2) The Traditional House of the Future was recently completed in January 2023 by a design team from the University of Hong Kong, with on-site 3D printing by Tsinghua University of Beijing, China. Situated within the rural landscape of Guizhou Province, this house seeks to breathe new life into and repurpose local vernacular dwellings as a response to the ongoing process of rural urbanization (Figure 6).

- Design elements. The house is located in Nanlong Village, a rural area surrounded by wooded areas; the very green area is, therefore, rich in wood that is available as local construction material. Thus, the new house incorporates traditional local woodworking techniques with on-site robotic printing. Through this fusion between tradition and innovation, those typical elements of the local tradition are maintained: not only wood as a building material but also the courtyard plan, located in the center of the building; the sloping roof, typical of the local culture; and the layout of spaces around the central space, including an entrance courtyard, a skylight, a balcony, a kitchen and bathrooms (Figure 7).
- Material selection. The perfect harmonization of innovative 3D-printed construction and traditional timber-framing techniques characterizes the house. This mix of contemporary and traditional techniques serves to rethink the concept of the traditional wooden house, embracing contemporaneity while respecting cultural identity. Three-dimensional printing simplifies construction processes by reducing waste [43,44].
- Construction method. Using on-site robotic printing allows for a precise and efficient construction method. Technological sustainability is achieved by combining 3D printing with the expertise of local wood artisans. This synergy creates a sensational architectural expression, encouraging a dialogue between the past

and the future (Figure 8). Furthermore, the ability to dismantle and reconfigure the original structure in one day exemplifies the flexibility and adaptability of traditional Chinese houses. A characteristic that emerges from this project is the cultural sustainability that is preserved by integrating traditional construction methods and celebrating the cultural identity given by the use of space by the community residents.

- Community engagement. Social engagement is achieved by actively involving the community and promoting self-sufficiency. The Traditional House of the Future catalyzes social change and emancipation within the village in the rural area. By involving the rural residents in both the deconstruction and restoration of the existing building, the project adopts a collaborative approach to design and construction. This framework of inclusiveness allows the community to contribute to the design and construction through their knowledge of local construction techniques and their way of inhabiting spaces to preserve their cultural heritage. Therefore, technology through 3D printing strengthens local building practices by promoting a sense of belonging [45].

(3) New Ghanzi housing is an experimental prototype designed by a team of students from IAAC, the Institute for Advanced Architecture of Catalonia, Spain, and developed through the Open Thesis Fabrication in 2020/2021. The project, located not far from Ghanzi, Botswana, leads to the integration of vernacular typology and construction technology in contemporary buildings (Figure 9).

- Design elements. The site is located among the accommodations provided by the Botswana Housing Cooperate, which are individual houses with small patios that do not reflect the traditional typology of the local inhabitants. For this reason, the experimental project takes up the vernacular housing typology, consisting of circular-shaped huts grouped around a courtyard, with the set of these housing groups reaching the cluster typology with courtyards of different sizes and functions (Figure 10). The project, therefore, considers local uses and living styles, giving importance to the open spaces enclosed between the built volumes, where the population spends most of their time. Furthermore, the circular volume of each living space respects the local tradition through the integration of 3D-printed openings in the walls and roof.
- Material selection. The project integrates local resources, such as molded clay, with innovative 3D printing technology to provide sustainable housing. This material uniquely blends traditional construction methods with contemporary technology, allowing for efficient and environmentally friendly structures. The material choices in this project show a clever blend of tradition and innovation, emphasizing sustainability, cultural integration, and climate suitability in housing for the local population in a hot and dry climate.
- Construction method. The construction approach for this project is a carefully planned process that aligns with the project's sustainability goals, cultural considerations, and climate factors. The community is developed in three well-defined phases, each contributing to the housing's overall functionality and environmental consciousness. In the initial phase, there is the excavation, movement, and mixing of earth, utilizing the local terrain as a foundational element. The second phase employs the Wasp crane, a large-scale 3D printer, to simultaneously create clusters of geometry, showcasing technological innovation and encouraging collaboration between skilled labor and technical expertise. In the final phase, strategically placed, regionally sourced gum pole columns and locally sourced timber beams support the flat clay printed roof structure, emphasizing the use of locally available materials. The construction process also incorporates the courtyards in various roles, functioning as spaces for material storage, mixing, and redistribution.

- Community engagement. The construction method involves collaboration with the local community. The project places a high priority on working together with both skilled labor and technical experts, as demonstrated by the use of the Wasp crane. This tool is lightweight and user-friendly and requires minimal training, ensuring that local workers can acquire new skills in 3D printing construction. This collaborative approach encourages community participation and knowledge sharing throughout the project's realization. The courtyards play a crucial role in the construction process, serving as communal spaces during building phases and later contributing to the overall communal lifestyle of the San community. This strong emphasis on community engagement signifies that construction is more than just a physical task; it is a joint effort that honors the traditions and heritage of the local people [46].



Figure 4. On the **left**, a view of the traditional houses of Amsterdam; on the **right**, the 3D Print Canal House as a contemporary interpretation of the past (credit: Monica Moscatelli 2024).

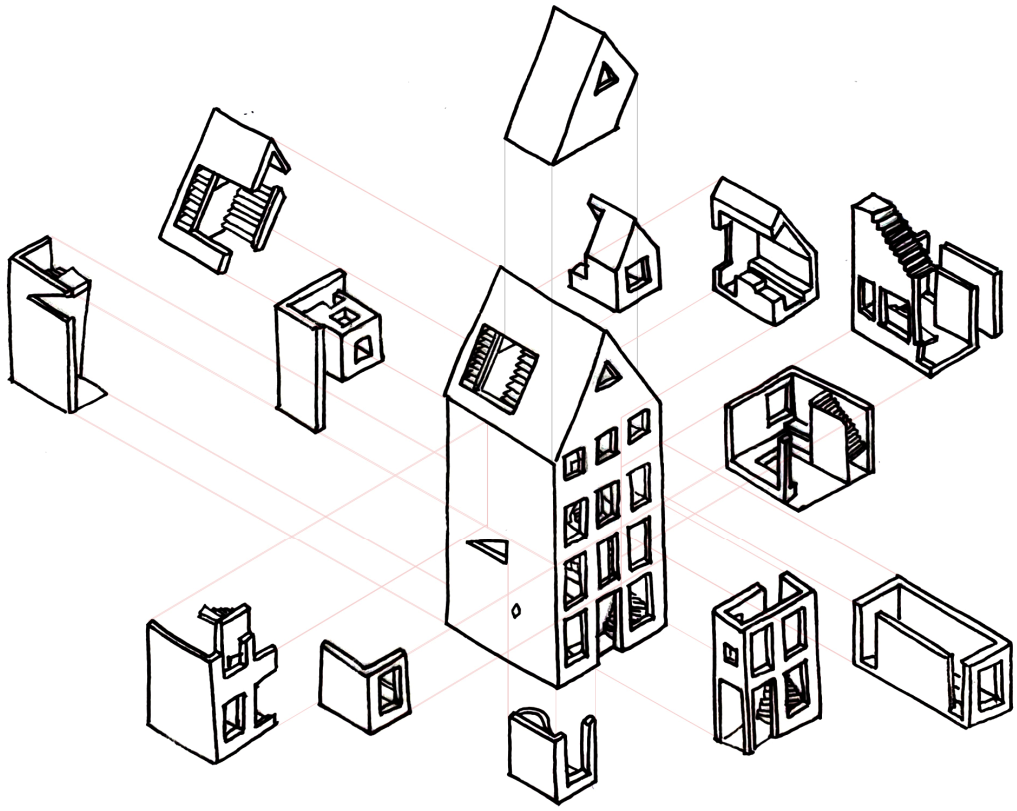


Figure 5. The 3D Print Canal House: 3D printing components (credit: Monica Moscatelli 2024).



Figure 6. Traditional House of the Future: on the **left**, 3D-printed walls were integrated with the original structure of the wooden house; on the **right**, the 3D-printed exterior walls expand the space of the original house with a terrace (credit: Monica Moscatelli 2024).

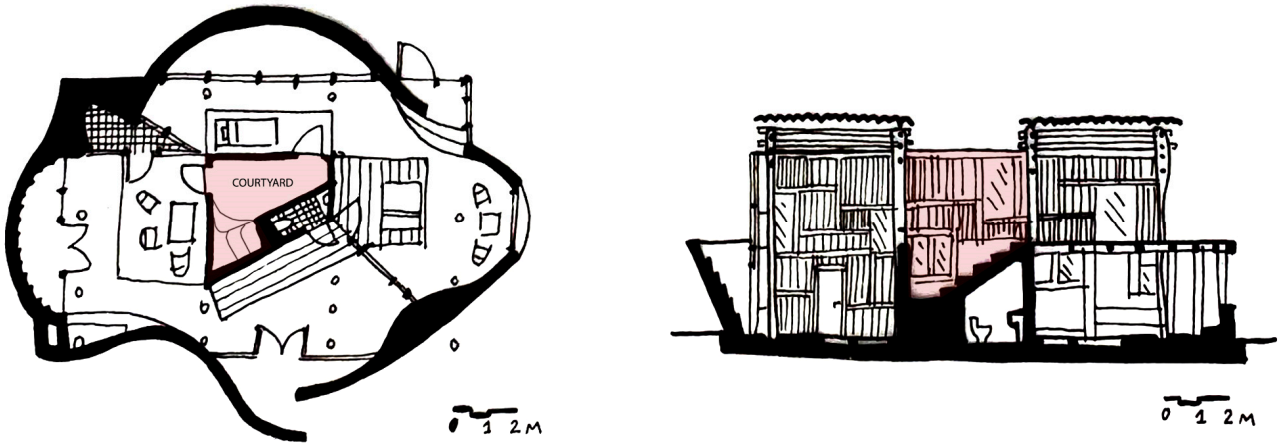


Figure 7. Traditional House of the Future: on the **left**, the spatial organization around a central courtyard; on the **right**, the house's section with the central space (credit: Monica Moscatelli 2024).

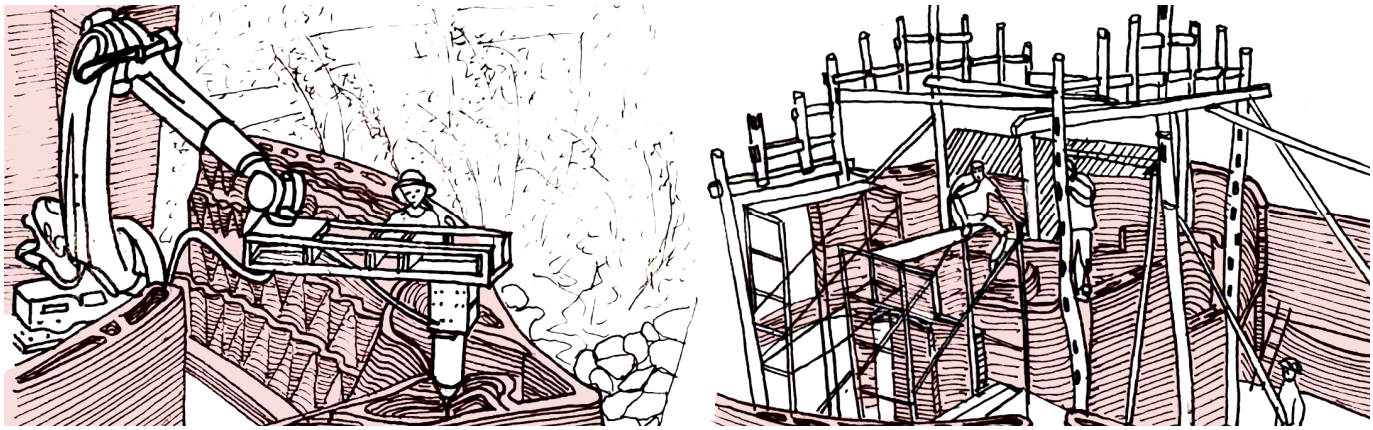


Figure 8. Traditional House of the Future: on the **left**, the integration of on-site robotic printing; on the **right** traditional wood craftsmanship (source: Monica Moscatelli 2024).

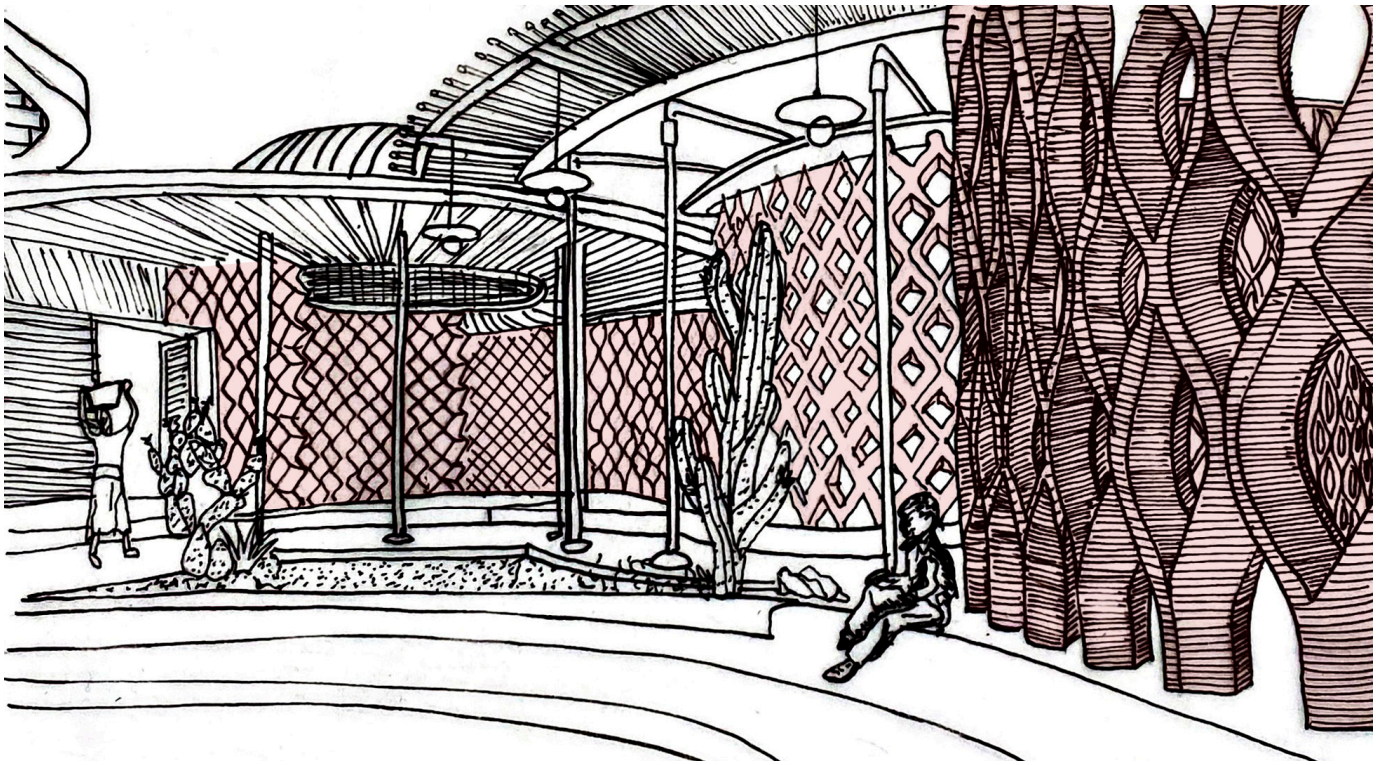


Figure 9. New Ghanzi housing: the interpretation of vernacular architecture in contemporary buildings (credit: Monica Moscatelli 2024).

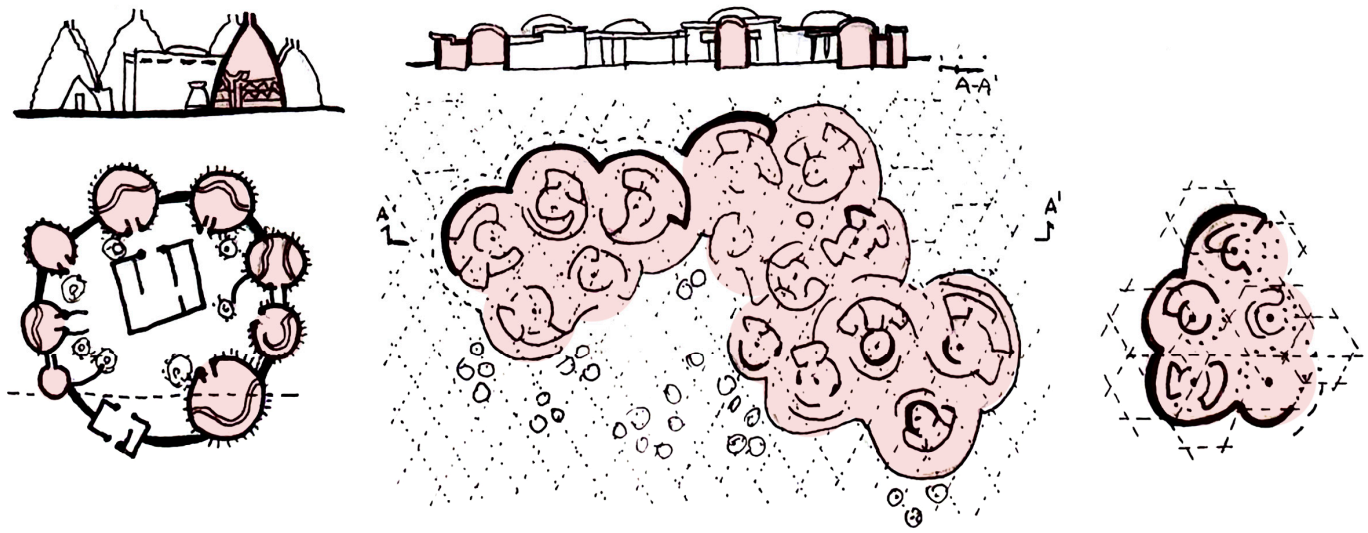


Figure 10. New Ghanzi housing: on the **left**, the traditional cluster typology around a courtyard and circular formed huts; on the **center** the plan and section of the evolution of the vernacular housing typology; on the **right** a zoom on the radial distribution of a group of houses based on the grid (credit: Monica Moscatelli 2024).

4. Results

The comprehensive analysis of the case studies is highlighted through a comparative matrix (Table 3), which summarizes the main characteristics of the traditional architecture that has evolved in a contemporary mode through the four criteria related to 3D printing for cultural identity. To achieve an optimal result, the cultural identity criteria for building with 3D printing technology must go hand in hand with aspects related to sustainability

and technology, such as material waste, passive design strategy, modular components, and construction time. The four criteria were analyzed through a transversal analysis of sustainable aspects, which made it possible to have a complete picture of the 3D-printed building and the link between architectural design and sustainable construction. In any case, the construction and sustainable aspects must not prevail over the architectural typology, space hierarchy, or texture and geometry of the façade. Still, they should be complementary elements to achieve the success of an architecture that integrates with the place.

Table 3. A comparison matrix of the case studies through the four criteria and integration with sustainable construction aspects.

3D Printing Case Studies	3D Printing Cultural Identity Criteria					Common Sustainable and Construction Aspects
	Design Elements	Material Selection	Construction Method	Community Engagement		
3D Print Canal House	A narrow, deep, sloping-roof house recalling the 17th-century Dutch colonial architecture.	Bioplastic recycled material with on-site 3D printing to reduce the transport cost and works.	The subdivision of the house into different components, developed through software.	Three-dimensional printing production is on-site to show people the manufacturing process of the components.	SUSTAINABILITY AND TECHNOLOGY	• Material waste: The use of 3D printing minimizes waste and material consumption, using only what is necessary for the construction of the building. • Passive design strategy: The application of traditional architectural typologies to implement passive design strategies to maximize solar gain and shading and facilitate natural ventilation (e.g., courtyard typology, orientation of the building). • Modular components: The creation of modular components facilitates both the construction phase and the disassembly phase and its reuse. • Construction time: Three-dimensional printing technology can be implemented directly on construction sites continuously, day and night, eliminating the need for the transportation of materials while reducing construction times compared to traditional methods.
Traditional House of the Future	The typology of traditional Chinese houses: the courtyard and the distribution of spaces around it and the sloping roof.	The incorporation of traditional local wood with the 3D printing of sustainable material to reduce construction costs and reduce material waste.	The combination of traditional local wooden construction techniques with on-site robotic printing techniques.	A collaborative approach with the community to deconstruct and restore the existing buildings.		
New Ghanzi housing	Vernacular cluster dwellings' circular typology around a courtyard, perforated walls, and gabled roofs typical of the local tradition.	The integration of molded clay with 3D printing technology to provide sustainable housing for the local population in a hot and dry climate.	The use of 3D-printed clay merges traditional building techniques with contemporary methods, blending cultural identity and climate considerations.	Local labor receives new skills in 3D printing construction, allowing for community participation and skills transfer in the project.		

The analysis of the three projects shows a design and construction approach attentive to the surrounding context, both relating to the landscape and the physical environment, such as the dense juxtaposition of the houses along the canal in the case of Amsterdam, the scattered houses in the wooded landscape in a rural area of China, and the clustered dwellings in the hot arid climate of Botswana.

As can be seen from the comparative table, the case studies analyzed adopt design elements of the past, employing the historical typology, distribution, and hierarchy of spaces of traditional architecture: the historical narrow-lot typology of Amsterdam, the courtyard typology of traditional Chinese houses, and vernacular cluster dwellings' circular typology around a courtyard. These projects capture the architectural typology of the local tradition through an evolution of the architectural elements rather than their translation or transfer approach. There is, therefore, a strong focus on the past and the desire to evolve the elements of local tradition in a contemporary way through an on-site robotic printer. Furthermore, the orientation of the buildings, the applied courtyard typology, and the careful study of the openings and windows in the case studies mentioned allow

the implementation of passive design strategies to maximize solar gain and shading and facilitate natural ventilation.

Each of the three case studies adopts materials that are easily workable with 3D printing, which allows them to obtain surfaces with a strong expressive value through the materiality of the rough and tactile surfaces with raised textures. Furthermore, the materials used, such as recycled bioplastic, clay, and wood, are sustainable and renewable, contributing to environmental sustainability and reducing the environmental impact. Reusing materials promotes a circular economy by reducing the materials needed for future construction projects.

The construction method with 3D printing also allows it to be integrated with traditional local methods, keeping in mind the construction techniques known by the community, and combined with the most innovative techniques, such as component construction, which facilitates the assembly and disassembly of the construction elements without the need for extensive transportation of materials and equipment. Furthermore, the construction time is reduced thanks to the continuous 3D printing process, occurring at any time of the day, direct on-site construction, and the speed of component construction.

Finally, the community participatory aspect proved to be fundamental in 3D printing construction. Through workshops and educational events, residents can increase their understanding of the potential benefits of 3D printing applications in construction. Involving residents in the design and construction phases can create projects that meet community needs and generate employment opportunities.

The following strategies work as a guide and inspiration that can be applied to new projects in Saudi Arabia. The comparison matrix is a valuable and practical tool that allows the designer to have a base of design guidelines that can be later applied to the proposal of new buildings.

5. Discussion: Cultural Reflection of Innovative Architecture in Saudi Arabia

The best experience-based design strategies for the development of 3D-printed architecture were identified from the previous comparison matrix and divided into four cultural identity criteria. These criteria could be applied in Saudi Arabia, showing a possible transfer of knowledge and an evolution of vernacular architecture with innovative technology. Saudi Arabia is a vast territory with different architectural styles, depending on the region. We can identify at least six different native architectures: the Najd architecture of Riyadh and the Central Region, the architectural style of the Western Region (Hijaz, Makkah, and Madinah), the native architecture in the mountain site of Asir, Abha and Khamis Mashayt, the architecture of the Southern Region (Jazan, Najran, Farasan Islan, and Thiama), the architectural style of the northern territories (Hail, Qasim, Buraidah, Tayma), and finally, the native architecture of the Eastern Region and the Gulf Coast [47]. This diversity of native architecture, along with its history, form, character, and aesthetic quality, highlights the importance of the vernacular architectural heritage of Saudi Arabia [48]. Due to the adaptation to modern life, rapid changes occurred across Saudi Arabia, leading to a loss of identity for cities by adopting new and contemporary lifestyles and abandoning the traditional way of life [49]. The development of new buildings built with advanced technologies, such as 3D printing, must integrate the elements that characterize each region's different architectural styles, leading to an evolution of cultural identity and avoiding loss. The following four criteria represent generic guidelines for a cultural reflection applied to Saudi Arabia, which led to an evolution of the main elements that characterize the architectural styles of the different regions (Figure 11):

(1) Design elements. The aim is to create continuity between the past and the present through the search for identity without "falsifying" history or being "identical" to tradition. Once knowledge of the past is acquired, it will be possible to define an evolution of these elements of tradition through 3D printing by defining contemporary solutions. This knowledge will provide an essential basis for integrating vernacular

architecture principles into contemporary 3D-printed building designs, leading to more resilient buildings adapted to the needs of inhabitants and local conditions [50–52].

(2) Material selection. The materials selected for construction in Saudi Arabian architecture often reflect the region's climate and cultural heritage. Local materials such as limestone, mud bricks, and palm wood are commonly used, providing a sustainable and contextually relevant approach to construction [53]. These materials connect to Saudi Arabia's historical building practices and serve functional purposes, such as providing natural insulation in desert climates.

(3) Construction method. Vernacular building construction methods in Saudi Arabia are deeply rooted in tradition and respond to the region's unique climate challenges. Traditional techniques, such as mudbrick construction using sundried mud bricks, demonstrate a sustainable and locally adapted approach. These materials provide adequate insulation against the intense desert heat, reflecting the practical wisdom of generations. For this reason, the 3D-printed clay applied, for example, in the experimental project in Botswana, is a technological evolution that can very well be applied in Saudi Arabia and provide sustainable buildings in a hot and dry climate [54]. Construction through 3D printing not only ensures the durability of the structures but also maintains a strong connection with the region's cultural heritage, creating buildings that harmonize with the environment and bear witness to Saudi Arabia's rich architectural history [55].

(4) Community engagement. Incorporating 3D printing technology in Saudi Arabia presents a transformative opportunity to blend new construction methods with traditional communities. A collaborative approach is crucial to involving communities in this technological transition. Initiatives can be launched to educate and train the local workforce in operating and maintaining 3D printing equipment, ensuring community members acquire new skills. Local artisans can be enlisted to contribute their traditional design expertise to digital models used in 3D printing, preserving cultural aesthetics in the contemporary context. Community workshops and training programs can be orchestrated to facilitate knowledge transfer and foster a sense of belonging. Moreover, using locally sourced materials for 3D printing, such as sand and other sustainable resources, aligns with Saudi Arabia's commitment to environmental responsibility. This collaborative integration of 3D printing technology modernizes construction practices and empowers and enriches local communities, ensuring their active participation in the technological advancement shaping the built environment.

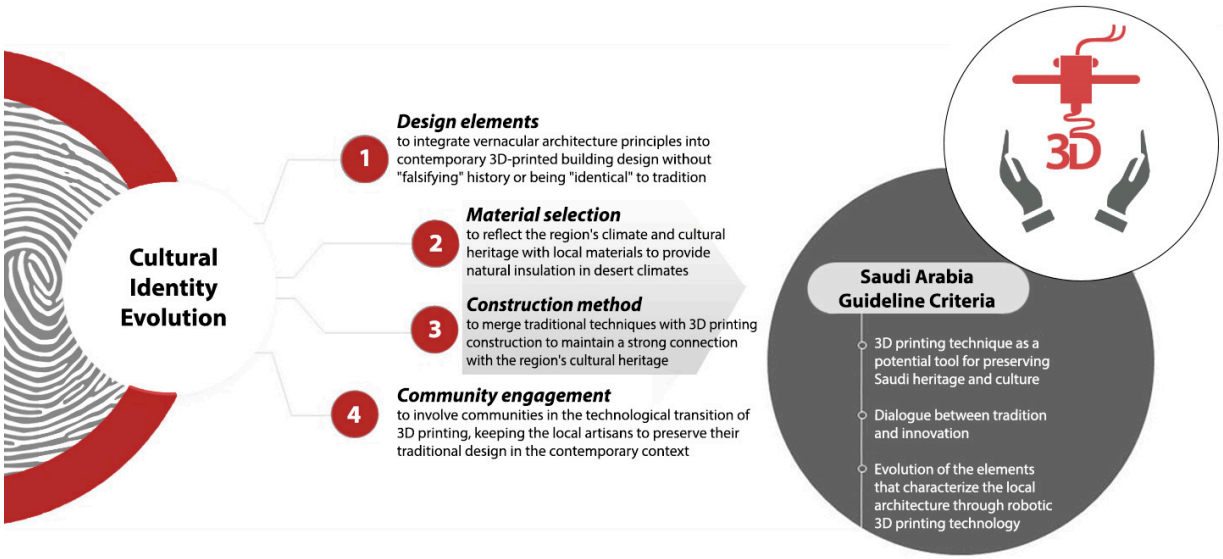


Figure 11. Strategic guidelines for evolving cultural identity through 3D printing in Saudi Arabia (credit: M. Moscatelli 2023).

6. Conclusions

This research achieved positive results by providing an overview of cultural relevance and highlighting a starting point for integrating cultural identity using a new and promising application of 3D printing technology to construct contemporary buildings accurately and sustainably and then disseminating it, especially for the application of new projects in which the aim is to maintain the identity of the place.

This paper explores the transformative potential of three-dimensional (3D) printing technology in preserving and evolving Saudi Arabia's cultural identity in architecture. Over the last decade, the use and experimentation of the technology underlying 3D printing have spread widely, with applications in various sectors showing exciting potential in the architectural field and becoming an object of study in research. The 3D printing technique could represent a new frontier for construction as a potential tool for preserving Saudi heritage and culture. The juxtaposition of cutting-edge design and construction techniques with deeply rooted cultural elements offers a compelling narrative for safeguarding Saudi Arabia's architectural heritage. Incorporating local architecture in the architectural spaces, in the walls, and on the façades of 3D-printed buildings can effectively reflect the culture of Saudi Arabia for citizens and tourists and help to evolve the local heritage for younger and future generations.

This article contributes to reflecting on the dialogue between tradition and innovation from the design process to the construction phase. The aim is to define a strategy to integrate the elements that characterize the local architecture through robotic 3D printing technology, demonstrating that even contemporary technologies, if guided appropriately, can achieve an architecture that respects the past and evolves it. Design elements, material selection, construction methods, and community engagement are Saudi Arabia's main criteria for a dialogue between tradition and innovation. Innovation is not only in the technique but also in the design. This article's scientific value is in showing how to learn from the past and shape the future by evolving the characteristic elements of traditional architecture through the design process, not by copying but by reinterpreting them in a contemporary key. If something is imitated or copied, there is no making of architecture. Choosing sustainable materials and construction methods deeply rooted in the local climate and heritage becomes crucial in creating structures that resonate with Saudi Arabia's architectural history. Furthermore, community involvement is highlighted as an essential component, ensuring that integrating 3D printing technology is a technological advancement and a collaborative effort that empowers and enriches local communities.

This study was limited to the critical analysis of some relevant projects through the main databases, but it can be expanded in future studies by searching for other scientific articles and using keywords similar to the topic to search for other significant architectures in which this cultural continuity between the past and present emerges to obtain broader comparative results.

Additionally, this research focused more on aspects of cultural identity and less on technical aspects, as the paper's main objective was to highlight the importance of integrating cultural identity into contemporary buildings. But in the future, greater attention to technical aspects, such as structural aspects, thermal efficiency, construction costs, and their comparison based on the materials used, can undoubtedly give a more detailed and precise vision of the results.

As Saudi Arabia continues to make strides in adopting 3D printing technology, the proposed guidelines serve as a future roadmap for architects, policymakers, and communities. The successful implementation of these guidelines can redefine Saudi Arabia's architectural landscape, allowing it to evolve while preserving the cultural richness inherent in its built environment. Ultimately, this harmonious fusion of tradition and innovation through 3D printing can contribute to the nation's sustainable and culturally vibrant future.

Funding: This research received no external funding.

Data Availability Statement: Data are contained within the article.

Acknowledgments: This contribution is part of the Sustainable Architecture Lab (SA Lab). The author would like to acknowledge the support of Prince Sultan University for paying the Article Processing Charge (APC) for this publication.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Yan, X.; Gu, P. A review of rapid prototyping technologies and systems. *Comput. Aided Des.* **1996**, *28*, 307–318. [CrossRef]
2. Guamán-Rivera, R.; Martínez-Rocamora, A.; García-Alvarado, R.; Muñoz Sanguinetti, C.; González-Böhme, L.F.; Auat-Cheein, F. Recent Developments and Challenges of 3D-Printed Construction: A Review of Research Fronts. *Buildings* **2022**, *12*, 229. [CrossRef]
3. Howeidy, D.R.; Arafat, Z. The Impact of Using 3D Printing on Model Making Quality and Cost in the Architectural Design Projects. *Int. J. Appl. Eng. Res.* **2017**, *12*, 987–994. Available online: https://www.ripublication.com/ijaer17/ijaerv12n6_30.pdf (accessed on 18 January 2024).
4. Mathur, R. 3D Printing in Architecture. *IJISET—Int. J. Innov. Sci. Eng. Technol.* **2016**, *3*, 583–591. Available online: https://ijiset.com/vol3/v3s7/IJISET_V3_I7_70.pdf (accessed on 18 January 2024).
5. Žujović, M.; Obradović, R.; Rakonjac, I.; Milošević, J. 3D Printing Technologies in Architectural Design and Construction: A Systematic Literature Review. *Buildings* **2022**, *12*, 1319. [CrossRef]
6. Bay, M.A.; Alnaim, M.M.; Albaqawy, G.A.; Noaime, E. The Heritage Jewel of Saudi Arabia: A Descriptive Analysis of the Heritage Management and Development Activities in the At-Turaif District in Ad-Dir'iyah, a World Heritage Site (WHS). *Sustainability* **2022**, *14*, 10718. [CrossRef]
7. Younus, I.; Al-Hinkawi, W.; Lafta, S. The role of historic building information modeling in the cultural resistance of liberated city. *Ain Shams Eng. J.* **2023**, *14*, 102191. [CrossRef]
8. UNESCO—United Nations Educational, Scientific and Cultural Organization. Florence Declaration: Culture, Creativity and Sustainable Development. Research, Innovation, Opportunities. In *UNESCO World Forum on Culture and Cultural Industries*, 3rd ed.; UNESCO: Florence, Italy, 2014; Available online: https://unesdoc.unesco.org/ark:/48223/pf0000230394 (accessed on 18 January 2024).
9. Al Arabiya News. Saudi Arabia Builds First House Using 3D Printing Technology in the Middle East. Available online: https://english.alarabiya.net/business/technology/2018/11/05/Saudi-Arabia-builds-first-house-using-3D-printing-technology-in-the-Middle-East (accessed on 18 January 2024).
10. Yang, H.; Qiu, L.; Fu, X. Toward Cultural Heritage Sustainability through Participatory Planning Based on Investigation of the Value Perceptions and Preservation Attitudes: Qing Mu Chuan, China. *Sustainability* **2021**, *13*, 1171. [CrossRef]
11. Ibach, M.K. Printing Utopia: The Domain of the 3D Printer in the Making of Commons-Based Futures. *Des. Cult.* **2023**, *15*, 323–344. [CrossRef]
12. Al Naim, M.A. Urban Transformation in the City of Riyadh: A Study of Plural Urban Identity. *Open House Int.* **2013**, *38*, 70–79. [CrossRef]
13. Mazzetto, S. Heritage conservation and reuses to promote sustainable growth. *Mater. Today Proc.* **2023**, *85*, 100–103. [CrossRef]
14. Ibrahim, I.; Eltarabishi, F.; Abdalla, H.; Abdallah, M. 3D Printing in Sustainable Buildings: Systematic Review and Applications in the United Arab Emirates. *Buildings* **2022**, *12*, 1703. [CrossRef]
15. Moscatelli, M. Rethinking the Heritage through a Modern and Contemporary Reinterpretation of Traditional Najd Architecture, Cultural Continuity in Riyadh. *Buildings* **2023**, *13*, 1471. [CrossRef]
16. Vision 2030. Available online: https://www.vision2030.gov.sa/en/ (accessed on 15 February 2024).
17. Buson, M.; Varum, H.; Rezende, M.A. First Impressions on Three-Dimensional Printing with Earth-Based Mortar at the Faculty of Engineering of the University of Porto. *Buildings* **2024**, *14*, 312. [CrossRef]
18. Iftekar, S.F.; Aabid, A.; Amir, A.; Baig, M. Advancements and Limitations in 3D Printing Materials and Technologies: A Critical Review. *Polymers* **2023**, *15*, 2519. [CrossRef] [PubMed]
19. Simedru, A.F.; Becze, A.; Cadar, O.; Scurtu, D.A.; Simedru, D.; Ardelean, I. Structural Characterization of Several Cement-Based Materials Containing Chemical Additives with Potential Application in Additive Manufacturing. *Int. J. Mol. Sci.* **2023**, *24*, 7688. [CrossRef] [PubMed]
20. Kidwell, J. *Best Practices and Applications of 3D Printing in the Construction Industry*; California Polytechnic State University: San Luis Obispo, CA, USA, 2017; Available online: https://api.semanticscholar.org/CorpusID:115193412 (accessed on 15 February 2024).
21. Ali, M.d.H.; Issayev, G.; Shehab, E.; Sarfraz, S. A critical review of 3D printing and digital manufacturing in construction engineering. *Rapid Prototyp. J.* **2022**, *28*, 1312–1324. [CrossRef]
22. Jesus, M.; Guimarães, A.S.; Rangel, B.; Alves, J.L. The potential of 3D printing in building pathology: Rehabilitation of cultural heritage. *Int. J. Build. Pathol. Adapt.* **2023**, *41*, 647–674. [CrossRef]

23. Khoshnevis, B.; Hwang, D.; Yao, K.; Yeh, Z. Mega-scale fabrication by Contour Crafting. *Int. J. Ind. Syst. Eng.* **2006**, *1*, 301–320. [CrossRef]
24. El-Sayegh, S.; Romdhane, L.; Manjikian, S. A critical review of 3D printing in construction: Benefits, challenges, and risks. *Arch. Civ. Mech. Eng.* **2020**, *20*, 34. [CrossRef]
25. Kyratsis, P. Computational design and digital manufacturing applications. *Int. J. Mod. Manuf. Technol.* **2020**, *12*, 82–91. Available online: https://ijmmt.ro/vol12no12020/11_Panagiotis_Kyratsis.pdf (accessed on 18 January 2024).
26. Hager, I.; Golonka, A.; Putanowicz, R. 3D printing of buildings and building components as the future of sustainable construction? *Procedia Eng.* **2016**, *151*, 292–299. [CrossRef]
27. Hossain, M.A.; Zhumabekova, A.; Paul, S.C.; Kim, J.R. A Review of 3D Printing in Construction and its Impact on the Labor Market. *Sustainability* **2020**, *12*, 8492. [CrossRef]
28. Sadakorn, W.; Prasertsuk, S.; Prasittisopin, L. 3D Cement Printing: DFMA Guideline of Patterned Load-Bearing Walls for Small Residential Units. In Proceedings of the 5th International Conference on Civil Engineering and Architecture, (ICCEA 2022), Hanoi, Vietnam, 16–18 December 2022; Kang, T., Ed.; Lecture Notes in Civil Engineering, 369. Springer: Singapore, 2022. [CrossRef]
29. Khan, S.A.; Koç, M.; Al-Ghamdi, S.G. Sustainability assessment, potentials and challenges of 3D printed concrete structures: A systematic review for built environmental applications. *J. Clean. Prod.* **2021**, *303*, 127027. [CrossRef]
30. Prasittisopin, L.; Jiramarootapong, P.; Pongpaisanseree, K.; Snguanyat, C. Lean manufacturing and thermal enhancement of single-layer wall with an additive manufacturing (AM) structure. *ZKG Intern* **2019**, *4*, 64–74.
31. Hamard, E.; Cazacliu, B.; Razakamanantsoa, A.; Morel, J. Cob, a vernacular earth construction process in the context of modern sustainable building. *Build. Environ.* **2016**, *106*, 103–119. [CrossRef]
32. Agustí-Juan, I.; Müller, F.; Hack, N.; Wangler, T.; Habert, G. Potential benefits of digital fabrication for complex structures: Environmental assessment of a robotically fabricated concrete wall. *J. Clean. Prod.* **2017**, *154*, 330–340. [CrossRef]
33. Thejeel, M.; Balázs, G. 3D printing for earth construction—Review. *Concr. Struct.* **2022**, *23*, 64–67. [CrossRef]
34. Silva, G.; Quispe, L.; Kim, S.; Nakamatsu, J.; Aguilar, R. Development of a stabilized natural fiber-reinforced earth composite for construction applications using 3D printing. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *706*, 012015. [CrossRef]
35. Gomaa, M.; Jabi, W.; Veliz Reyes, A.; Soebarto, V. 3D printing system for earth-based construction: Case study of cob, Automation in Construction. *Autom. Constr.* **2021**, *124*, 103577. [CrossRef]
36. Wasp. Available online: https://www.3dwasp.com/en/3d-printed-house-tecla/ (accessed on 15 February 2024).
37. Stein, J.A. The Political Imaginaries of 3D Printing: Prompting Mainstream Awareness of Design and Making. *Des. Cult.* **2017**, *9*, 3–27. [CrossRef]
38. Molitch-Hou, M. "World's Largest On-site 3D Printed Building" Completed in Saudi Arabia. Available online: https://3dprint.com/298925/worlds-largest-on-site-3d-printed-building-completed-in-saudi-arabia/ (accessed on 18 January 2024).
39. Ministry of Culture. National Pavilion of Saudi Arabia. Available online: https://saudipavilion.org (accessed on 18 January 2024).
40. Almerbati, N.; Headley, D. Heritage conservation in the new digital era: The benefits of 3D printing architecture screens in sustaining architecture and identity. In Proceedings of the Sustainable Heritage: Local Experience Global Vision, the Fourth International Architectural Conservation Conference, Dubai, United Arab Emirates, 14–16 February 2016.
41. Salameh, M.; Touqan, B. From Heritage to Sustainability: The Future of the Past in the Hot Arid Climate of the UAE. *Buildings* **2023**, *13*, 418. [CrossRef]
42. DUS Architects. 3D Print Canal House. Available online: https://houseofdus.com/project/3d-print-canal-house/ (accessed on 18 January 2024).
43. Porretta, P.; Pallottino, E.; Colafranceschi, E. Minnan and Hakka Tulou. Functional, Typological and Construction Features of the Rammed Earth Dwellings of Fujian (China). *Int. J. Archit. Herit.* **2022**, *16*, 899–922. [CrossRef]
44. Teixeira, J.; Schaefer, C.O.; Rangel, B.; Maia, L.; Alves, J.L. A road map to find in 3D printing a new design plasticity for construction—The state of art. *Front. Archit. Res.* **2023**, *12*, 337–360. [CrossRef]
45. Barandy, K. University of Hong Kong's 'Traditional House of the Future' 3D-Printed in China. Designboom. Available online: https://www.designboom.com/architecture/university-hong-kong-3d-printed-traditional-house-future-china-05-17-2023/ (accessed on 18 January 2023).
46. IAAC 2021. New Ghanzi: A Hybrid of San Heritage with 3D Printed Clay Architecture. Available online: https://www.iaacblog.com/programs/san-heritage-x-3d-printed-clay-architecture/ (accessed on 18 January 2023).
47. Ishteeaque, E.M. Native Architecture of Central Region (Najd) and Northern regions. In *The Native Architecture of Saudi Arabia*; Riyadh Municipality: Riyadh, Saudi Arabia, 2008; pp. 24–27.
48. Philokyprou, M.; Aimilios, M. Environmental Sustainability in the Conservation of Vernacular Architecture. The Case of Rural and Urban Traditional Settlements in Cyprus. *Int. J. Archit. Herit.* **2021**, *15*, 1741–1763. [CrossRef]
49. Torabi, Z.; Brahman, S. Effective Factors in Shaping the Identity of Architecture. *Middle-East J. Sci. Res.* **2013**, *15*, 106–113. [CrossRef]
50. Alnaim, M.M. Understanding the Traditional Saudi Built Environment: The Phenomenon of Dynamic Core Concept and Forms. *World J. Eng. Technol.* **2022**, *10*, 292–321. [CrossRef]
51. Hu, M.; Suh, J.; Pedro, C. An Integrated Framework for Preservation of Hawaii Indigenous Culture: Learning from Vernacular Knowledge. *Buildings* **2023**, *13*, 1190. [CrossRef]

52. Ghazala, A.A.S.A. The Concept of Visual Scope for Heritage Values and Vocabulary as an Introduction to Restoring Urban Identity in the Twenty-First Century. A Case Study of the Kingdom of Saudi Arabia. *Archit. Res.* **2021**, *11*, 1–10. [CrossRef]
53. Kamel, M.K.; Mahgoub, Y.M. The Role of Decorative Design in Reviving the Aesthetics of the Gulf Architectural Heritage. *Psychol. Educ.* **2021**, *58*, 1055–1066. Available online: http://psychologyandeducation.net/pae/index.php/pae/article/view/4760/4188 (accessed on 17 January 2024).
54. Kaihoul, A.; Sriti, L. Towards public identity and climate awareness architecture. In *Cities' Identity through Architecture and Arts*, 1st ed.; Catalani, A., Nour, Z., Versaci, A., Hawkes, D., Bougdah, H., Sotoca, A., Ghoneem, M., Trapani, F., Eds.; Taylor & Francis Group: London, UK, 2018; pp. 129–137. [CrossRef]
55. Tawfiq, M.A. Vernacular architecture education in the Islamic society of Saudi Arabia: Towards the development of an authentic contemporary built environment. *Habitat Int.* **1997**, *21*, 229–253. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.