Water Plays: The Architectural and Acoustic Reconstruction of Sabīl wa Kuttāb of Ismāʿīl al-Maghlawī

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This paper proposes a serious game that explores and digitally reconstructs the soundscape of the relocated Ottoman Sabīl (water dispensary) wa-Kuttāb (Quran elementary school) of Ismāʿīl al-Maghlawī, in historic Cairo, dated to 1657 CE. The sabīl was relocated in 1939 from its original location in Khān al-Khalīlī Street. It used to have an underground cistern, filled yearly with pure water from the Nile River, and provided water to passersby from its water dispensary room's window. Based on primary and secondary sources, the authors digitally reconstruct the building's context, architecture, and spatial practices, integrating the sabīl's hidden sounds, crucial location, water, and people. The authors employed acoustic surveys to collect the impulse responses (IRs) in this sabīl toward developing an auralization using Odeon software. The auralized files were then deployed as a game using the Unity game engine, where players can identify the sabīl's architecture, sounds, and its spatial practices. Additionally, they experience the sabīl's soundscape: the sounds of prayer calls and vibrant markets. The game is available to the public, allowing their engagement with a forgotten sabīl and bringing it back to life.

Keywords:
Islamic monuments, Digital heritage, Serious games, Acoustic reconstruction, Architectural reconstruction.

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1. INTRODUCTION

Water is significant for its physical, social, economic, and religious effects [Oestigaard 2019]. In Islamic architectural heritage, water is functionally and aesthetically crucial [El Shakhs and Ezzat 2018]. On account of the scarcity and high cost of pure water, people were eager to provide charitable water, leading to the flourishing of the sabīl as a building type [Ali 2006]. The sabīl started in the Mamluk period and thrived during the Ottoman period [Raymond 1979] as either a standalone building or attached to other functions, such as a mausoleum, a Quran school, or a mosque. The significance of the sabīl lies in its hidden stories: the relationship to water and the Nile River, the Cairene society, and guilds and craftspeople like water carriers and waterskin makers guilds [Soliman 2017]. It played a crucial role in shaping Cariene's urban fabric since the sabīls' network required a walkability distance not exceeding 150 m [Ismaeel et al. 2022]. Later, due to changes in endowment and water supply systems, sabīls became obsolete, and their numbers decreased from two hundred in the early 17th century to only sixty in the 18th century [Mubārak 1886].

Today, the sabīl is forgotten, and passersby no longer recognize its history and function. Thus, this paper aims to integrate the architectural and acoustic reconstruction of a unique Islamic water structure typology and disseminate it to the public in an interactive and immersive way as a serious game. The paper virtually reconstructs the acoustics of the Ottoman Sabīl wa Kuttāb of Ismāʿīl al-Maghlawī, constructed in 1657 between al-Mashhad al-Ḥussaynī and al-Azhar Mosque at Khān al-Khalīlī Street, Historic Cairo. It proposes a video game that simulates water carriers' voices as they filled the underground cistern of the sabīl yearly with water from the Nile River. Passersby could drink water from the window of the water dispensary room at the ground level and hear the children reciting the Quran in the kuttāb at the upper level. In doing so, the paper aims to reveal new aspects of the building's intangible heritage that escape common ocular-centric reconstructions.

The paper starts with a section that examines previous work on architectural and acoustic virtual reconstructions. Afterward, it provides background for Sabīl wa Kuttāb of Ismāʿīl al-Maghlawī. The Methods section follows and comprises three sub-sections: They address first the architectural reconstruction, then the acoustic auralization, and finally the game design. The paper ends with discussions and conclusions which reflect on these results and make recommendations for future work.

2. LITERATURE REVIEW

Broadly, world heritage is rich with historical water architectural building types, from dams to aqueducts. Unfortunately, some of these types are faced with deterioration, relocation, loss of functionality, or extinction. Thus, digital heritage becomes essential in preserving existing water heritage, reconstructing those which are lost, and communicating their presence and function with the public [Wang et al. 2020]. For example, using photogrammetry, researchers documented and represented the Niolometer which was used to measure the water level of the Nile River [Ministry of Tourism and Antiquities 2019] and the relocated sabīl (water dispensary) of Faraj ibn Barquq (1408-1409 CE) [ARCE 2023]. Using 3D modeling software, researchers digitally reconstructed the existing ruins of both the 16th-century Ottoman Bath in Apollonia, Greece [Sylaiou et al. 2021] and an 18th-century Italian hydroelectric plant [Morandi et al. 2017]. Researchers could even simulate and understand the water level and flow when reconstructing a 3D model of the “incile” of the extinct ancient Fucino Lake, rather than depending only on 2D representation [Di Angelo et al. 2019].

Researchers tend to move beyond ocular-centrism and include other senses in their reconstruction both to avoid the abstraction of heritage from its holistic sensory experience [Tilley 2019] and to enrich users’ engagement and interpretation of tangible [Chalmers 2017] and intangible heritage [Rueff et al. 2023].

Focusing on the study of acoustics helps document the sounds of existing heritage sites and reconstruct the sounds of extinct ones. It offers subjective perception corresponding to the location of the sound source using auralization [Suárez et al. 2016]. Experiencing the acoustic environment (the soundscape) enhances the perception of the past. Soundscape includes both natural and human events [Orio et al. 2021]. Sikora et al. reconstruct the soundscape of a medieval archaeological site in Croatia [Sikora et al. 2018]. Otondo and Rabello-Mestre discuss the soundscape of several wetlands [Otondo and Rabello-Mestre 2022]. Godwin integrates Geographic Information Systems (GIS) and Virtual Reality (VR) to explore the acoustics of ancient Maya cities [Goodwin 2018]. Orio et al. employ GIS to explore the soundscape of the city of Padua [Orio et al. 2021]. Based on historical archives, Sullivan used 3D GIS to virtually represent the multisensory experience of the Necropolis of Saqqara [Sullivan 2023].

Focusing on the building scale critical to this study, researchers collected the impulse response, the acoustic fingerprint, of existing Turkish baths [Bora Özyurt and Sü Gül 2023] and Mamluk mosques [Elkhateeb and Eldakdoky 2021] through site visits and acoustic surveys. Researchers can also reconstruct the impulse response into an auralization (simulation). For example, visitors could hear the reconstructed choir voices of the Spanish Saint Jerome Monastery [Sender et al. 2018] and the prayer call in Cordoba’s Aljama Mosque [Suárez et al. 2018]. Moreover, researchers can integrate 3D models and auralization for reconstruction if the heritage building is extinct or partially damaged. For example, researchers reconstructed the sensory experience of the historical Jesuit chapel [Boren 2023] and the voices of the choirboys in Notre Dame de Paris [Canfield-Dafilou et al. 2024].

Meanwhile, serious games can facilitate the public's awareness of digital heritage and the dissemination of digital reconstructions. Serious games offer the integration of education with fun and the development of users’ cognitive behaviors through interactivity [Rickards et al. 2020]. Additionally, they afford the integration of acoustic reconstruction, enhancing players’ immersivity and understanding of the architecture-sound nexus [Bellia 2023]. Researchers integrate narratives with serious games to enrich meaning-making [Malegiannaki et al. 2020]. Bourke and Green integrate soundscape in serious games, allowing users to experience the significance of historical locations in Western Australia [Bourke and Green 2016]. “Defend the Walls” is a serious game allowing players to learn about the city walls of Paestum, Italy, and experience its soundscape [Pietroni 2021]. "A Night in the Forum" enables players to experience the reconstruction of the Forum of Augustus, ancient Rome, and its soundscape [Ferdani et al. 2020]. The reconstruction of Sambor Prei Kuk temple allows players to participate in its rituals [Gill 2009]. Players experience the spatial transformation of the Castle of Corsano while listening to stories and oral history about the castle and its transformation into a tobacco warehouse [De Paolis et al. 2022]. Players learn to become tile makers in Dar al-Said Palace, Andalusia [Torres et al. 2022].

Unfortunately, multisensory reconstructions of water architectural heritage that use acoustic auralization and interactive simulations are scarce. Therefore, this paper seeks to contribute to the literature by reconstructing the relocated Sabīl wa Kuttāb of Ismāʿīl al-Maghlawī, available to the public as a serious game.

3. HISTORICAL REVIEW

This section builds on site visits, historical archives, endowment documents, publications of the Comité bulletins, and contemporary literature on water systems and the historic architecture of Cairo.

There are mainly two design prototypes for the sabīl: (1) the traditional Mamluk and early Ottoman, and (2) the late Ottoman inspired by Istanbul's Turkish architecture [El-Hosseiny 1988]. The difference between the two prototypes is in the superstructure. The traditional design is rectangular, with no more than three windows, like Sabīl Khusrū Pasha (1535). The Turkish prototype has arches in its façade with more than three windows and no shādharwān in its water dispensary room, like Sabīl wa Kuttāb Ruqayya Dūdū (1761).

In both types, the water dispensary room links passersby to the sabīl through its windows, basins, marble floor, decorated wooden ceiling, and shādharwān. The function of the room may extend as a prayer and study hall like in Sabīl wa Kuttāb Riḍwān Agha al-Razzāz (1754). Otherwise, cisterns vary in their shape, material, and dimensions. Generally, they could be rectangular, covered with shallow domes, or circular, like in Sabīl wa Kuttāb ʻAlī Zayn al-ʻAbidīn (17th century) [Supreme Council of Antiquities 2002]. They are built with stone or brick and plastered with lime and ash-dust mortar for water resistance. Sometimes, they are even carved in bedrock, like Sabīl al-Amīr Shaykhū (1354). Their dimensions are defined by the footprint of the water dispensary room in the superstructure, but they can sometimes exceed it, like the cistern of Sabīl wa Kuttāb Qāytbāy (1479) [Abushadi 2022]. In large sabīls, the cistern supplies the water dispensary room with water through a well in the annex room. In smaller ones, the well is in the water dispensary room, like Sabīl Sulaymān Aghā al-Ḥanafī (1792) [El-Hosseiny 1988].

Ismāʿīl al-Maghlawī constructed his Sabīl wa Kuttāb between al-Mashhad al-Ḥussaynī and al-Azhar Mosque at Khān al-Khalīlī Street, Historic Cairo, c. 1657. Water carriers filled its underground cistern yearly with pure water from the Nile River. Passersby could drink water from the window of the water dispensary room at the ground level and hear the children reciting the Quran in the kuttāb at the upper level. Due to changes in endowment and water provision systems [Ismail 2017], the sabīl has gradually lost its function. Accordingly, during site visits by members of the Comité de Conservation des Monuments de l'Art Arabe, "Committee for the Conservation of the Monuments of Arab Art" (Comité) in 1905-1906, they noted the conversion of the sabīl to a coffee shop and the reuse of its kuttāb as an inn [Herz et al. 1906]. The sabīl's demise was in its relocation in 1939 to its current location in Ḥārit al-Badrī. This relocation by the Comité resulted from the widening of al-Azhar Square by the Ministry of Public Works in 1930 to provide a tramway terminal. The relocation process was complicated, leaving the sabīl's water cistern abandoned, losing some important elements, and damaging other parts [Warner 2005]. Mona Elghezawi photo-documented the reuse of the relocated sabīl as a primary school in 1996 [Elghezawi 1996]. It was conserved and closed in 2000.

4. METHODS

This section illustrates the digital architectural and acoustic reconstruction of the sabīl towards the game's design (Figure 1).

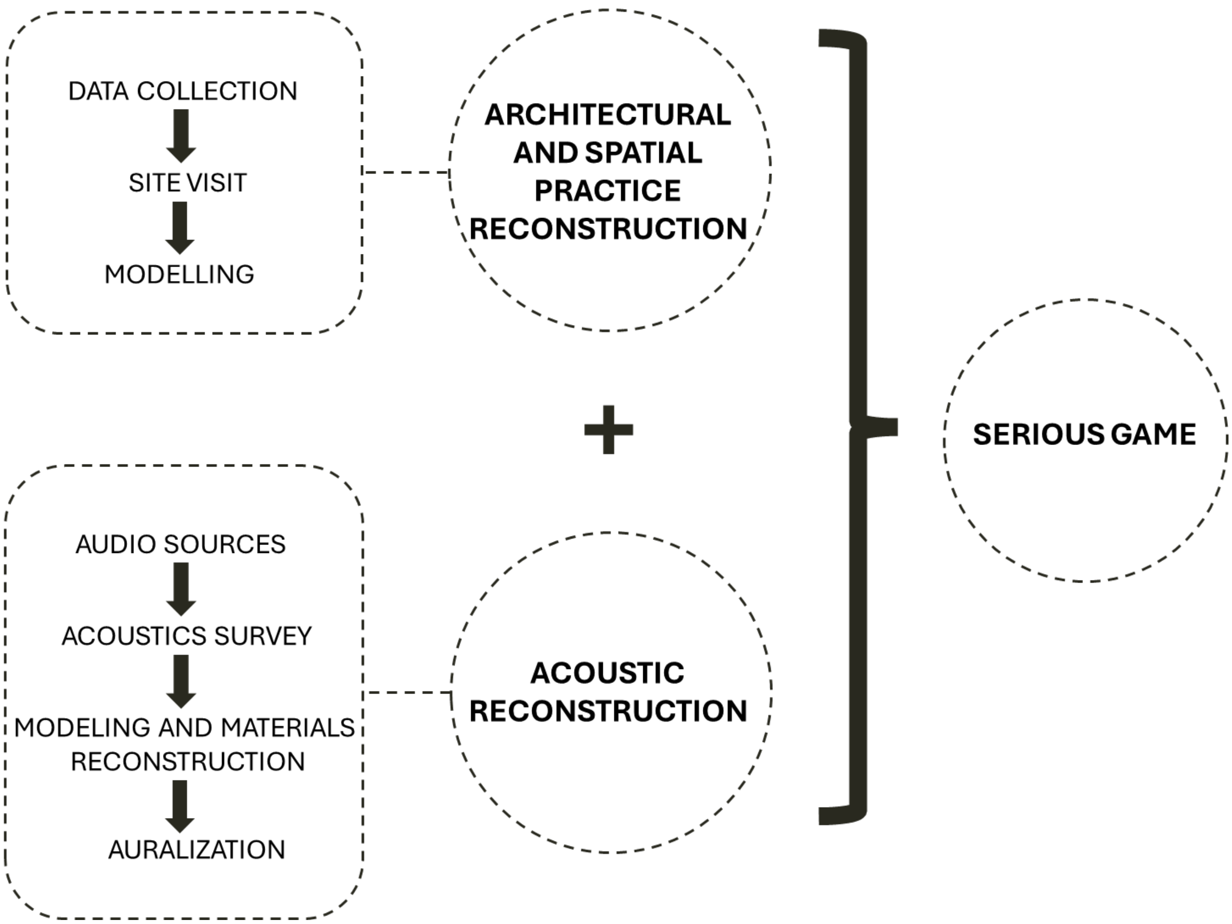


Figure 1. A diagram summarizing the methods used in the architectural and acoustic reconstructions

4.1 Architectural reconstruction

We reconstructed the architectural features of the sabīl and its context using 3D modeling software (Rhino 7). The context is based on the 1809 "Description de l' Egypte" map. The original location of the sabīl was in Khān al-Khalīlī Street, at the intersection of al-Mashhad al-Ḥussaynī Street and al-Bab al-Akhdar Street, near a vibrant khān (caravansary) and several markets [Elghezawi 1996]. In front of the sabīl was another sabīl and the small mosque of al-Bāzdār. The two notable mosques in the sabīl's vicinity were al-Ḥussaynī and al-Azhar.

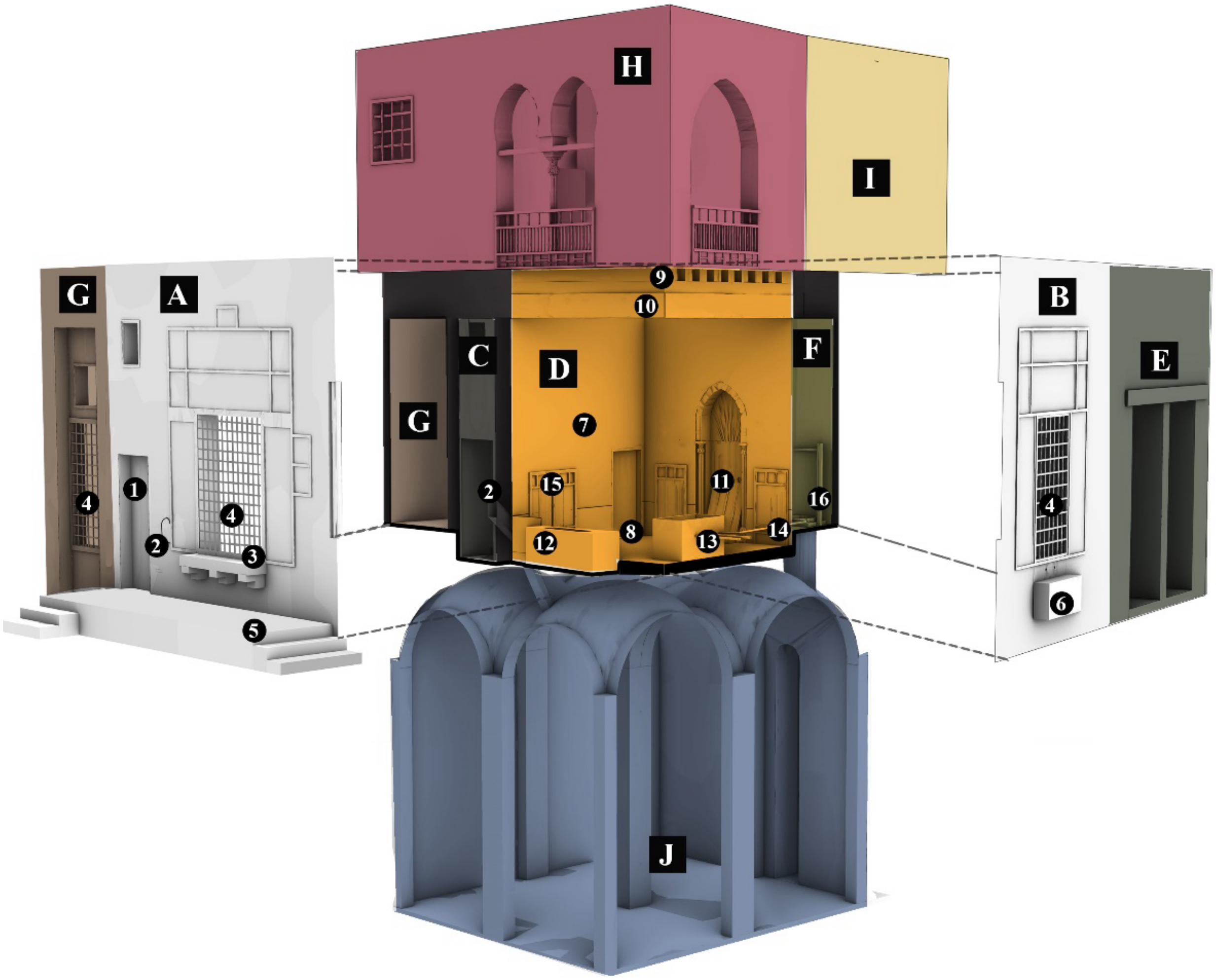
The reconstruction of the architecture of the sabīl and its spatial presence depends on: (a) the endowment document reproduced in ElGhezawi's thesis [Elghezawi 1996], (b) the archives of the

Ministry of Tourism and Antiquities which provides architectural drawings to the sabīl before its relocation, (c) Bulletins of the Comité, (d) historical and contemporary literature, and (e) site visits to the relocated sabīl.

Water carriers using either camels or donkeys would come yearly to the sabīl to fill their raī (ox-hide waterskin) and qirba (goat-leather waterskin), filling them with water from the Nile River [Lane and Thompson 2003]. As they approached the sabīl, the water carriers could see its ground- and first-floor levels, with two red-ashlar stoned elevations [Elghezawi 1996]. The ground floor included a water dispensary room, an annex room, a tomb, and shops (ḥawānīt) [Elghezawi 1996]. The first floor included a Quran school (kuttāb), restrooms, and a portico (riwāq) [Elghezawi 1996]. The sabīl had an underground cistern with four shallow domes [Elghezawi 1996]. This paper focuses on the relationship between the water dispensary room, the annex room on the ground floor, and the underground cistern. Figure 2 shows an exploded 3D model of the sabīl before its relocation, showing the different architectural features of the building.

The water dispensary room had two copper window grills. The first one, facing al-Mashhad al-Ḥussaynī Street at the main elevation, had a marble platform, allowing passersby to drink water by climbing three stone steps [Elghezawi 1996]. Next to this window was an opening with a marble cover through which the water carrier could pour fresh water inside the cistern [Elghezawi 1996]. The other window grill on the secondary elevation facing al-Bab al-Akhdar Street was smaller than the first one. Underneath it was al-muṣaṣa stone, a stone block with two copper faucets that allowed passersby to fill their buckets with water [El-Hosseiny 1988]. The only entrance to the sabīl was from the main elevation, leading to a wooden ceiling passageway. A two-leaf door led to the water dispensary room, a rectangular space with colored marble flooring, decorated wooden beam ceilings, ashlar stone walls, and marble skirting. It contained a shādharwān (inclined marble plane for water purification), wooden cabinetry, a big marble basin connected to al-muṣaṣa stone, and another basin at the window of the main elevation [Elghezawi 1996]. The passageway also led to a tomb, a staircase, and an annex room. The annex room housed the marble well rim above the cistern's opening, a basin providing the big marble basin with water through embedded lead pipes inside the walls, and a small basin behind the shādharwān [El-Hosseiny 1988]. From this opening, al-mizammilātī, the employee responsible for operating the sabīl, lifted water from the cistern. Janitors descended in the cistern through the same opening once a year to clean and sanitize the cistern, which had four shallow domes and humidity-resistant plastered walls [Elghezawi 1996].

The relocation of the sabīl, which did not include the annex room and the cistern, impacted its architecture and function. It now has a different orientation and an orthogonal plan [Warner 2005]. The exterior elements are extinct, including the marble opening, al-muṣaṣa stone, the three stone steps, and the marble platform (Figure). The floor of the water dispensary room now has stone tiles and no marble skirting, shādharwān, nor marble basins (Figure).



A. MAIN EXTERIOR ELEVATION
1. main entrance door
2. filling opening
3. marble block
4. window grill
5. three stoned steps
B. SECONDARY EXTERIOR ELEVATION
6. al-musasa stone
C. PASSAGEWAY

D. WATER DISPENSARY ROOM
7. stone walls with two-arm marble skirting
8. colorful marble floor
9. decorated wooden-beam ceiling
10. inscription frieze
11. shādharwān
12. drinking basin
13. basin of al-musasa stone
14. embedded pipes towards basin and al-musasa stone
15. wooden cupboards

E. SHOPS
F. ANNEX ROOM
16. well rim
G. TOMB
H. QURAN SCHOOL
I. PORTICO
J- CISTERN

Figure 2. An exploded 3D model of Sabīl wa Kuttāb of Ismaʿīl al-Maghlawī before its relocation

Figure 3. The exterior elevations after relocation

Figure 4. The water dispensary room after relocation

4.2 Acoustic reconstruction

This section details the methods used for collecting audio sources, audio convolution, and their integration into the game.

We divided audio sources based on their role in the game. There are non-player characters, sound effects, soundscape, and most importantly, the water ambiance of the sabīl. The non-player characters meet the player and narrate the story of each space. The sound effects result from the player's interaction with game objects. Being in the vibrant Khān al-Khalīlī Street, full of markets, and between two important mosques, al-Mashhad al-Ḫussaynī and al-Azhar, the soundscape is critical in providing the players with a sense of place. It includes prayer calls, marketplace sounds, and water carrier calls. Players can listen to the water's sound and feel the water's ambiance in different spaces, even in those that are not accessible or no longer exist.

Audio was generated with voice casting, sample libraries, and field recordings; this follows Gwen's classification of game audio [Guo 2020]. We used voice casting to enhance the narratives of non-player characters. The recording took place in a well-padded, semi-anechoic room, which enabled the recording of a clear, dry sound by absorbing other sounds [Murphy et al. 2017]. Sample libraries are online open-source prerecorded audio files [Guo 2020]. We used them to replace extinct sounds in the sabīl, like pouring water, dropping a bucket in the water, and for various other interactive game objects. Field recordings were mainly for ambiance sounds. Using the voice recorder application on a cell phone, we recorded the sound of markets, prayer calls, and other sounds.

The following section sheds light on the four phases we used in the acoustic reconstruction: acoustic survey, modeling and validation, materials for reconstruction, and auralization.

4.2.1 Acoustic survey

Measuring the impulse response (IR) is used to preserve and analyze the acoustics of the heritage building and reconstruct its IR, representing the unique acoustic room signature. The characteristics of IR depend on the room's volume, the absorption characteristics of the room's boundaries (materials' absorptions), relative humidity, and air temperature. Additionally, it contributes to various applications, such as auralization and spatialization in virtual environments [Stan et al. 2002].

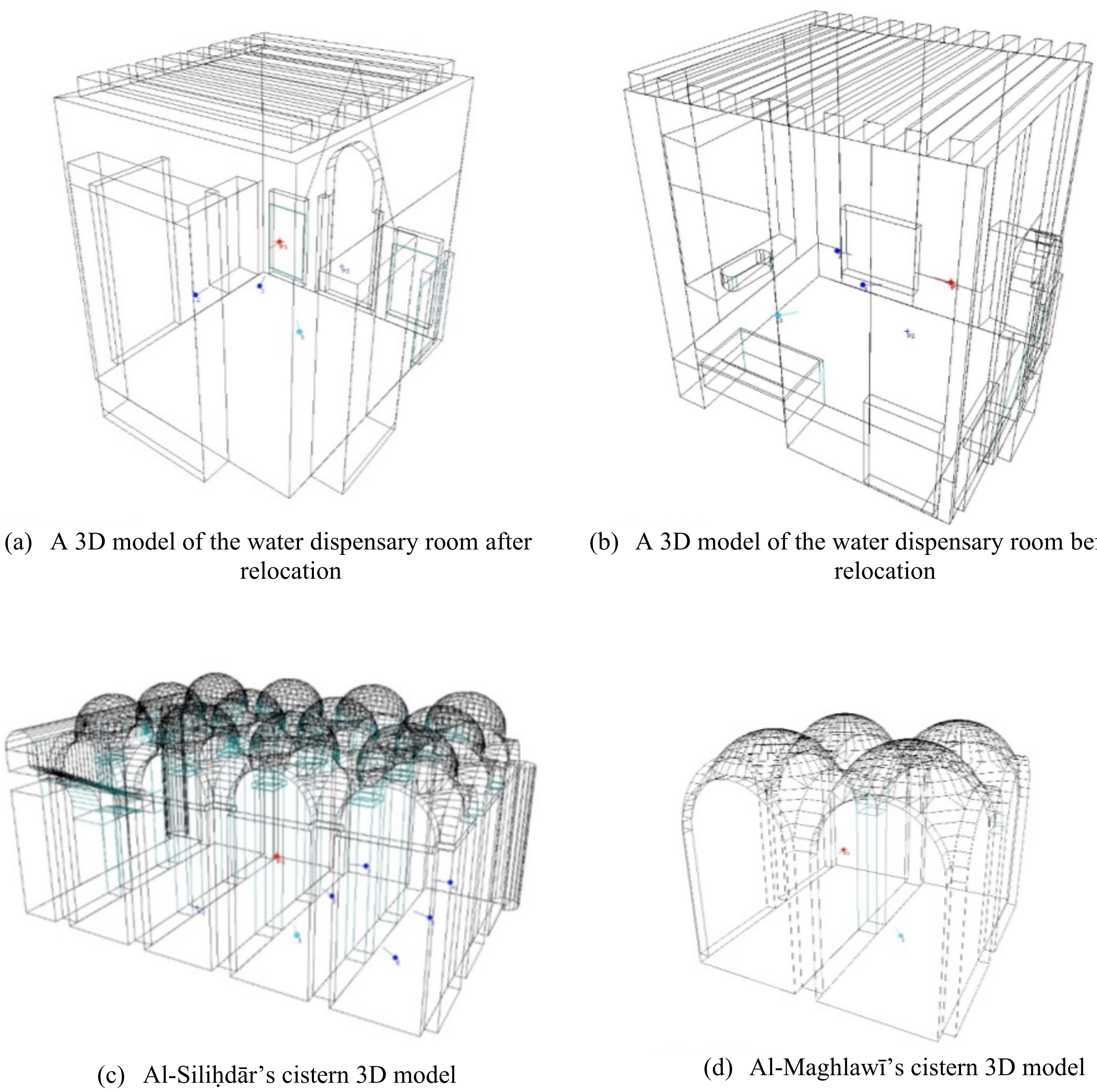
ISO 3382-1 standards define two methods to collect the IR: (1) the interrupted noise method and (2) the integrated impulse response (the impulsive) method [ISO 2009]. The interrupted noise method is more complex and requires special equipment and arrangement. Unfortunately, the Ministry of Tourism and Antiquities prohibits the entry of such complex equipment into the sabīl. Moreover, the sabīl has no power supplies for the equipment. Therefore, we used the simpler impulsive method. We located the sources and the receivers following ISO 3382-1 standards for an unoccupied room. We used the bursting of inflated, full-sized balloons (with a maximum diameter of about 300 mm) as a stimulus. Pätynena et al. discuss the pros and cons of utilizing balloon pops as a stimulus when recording room IRs [Pätynen et al. 2011], while Abel et al. conclude that the popping of large balloons can be "an inexpensive, convenient way to measure room acoustics" [Abel et al. 2010]. We collected signals as WAV files using a digital sound recorder (TASCAM DR-100 MKIII) and an omni microphone (Earthwork M30BX) [Elkhateeb and Eldakdoky 2021]. This omni microphone receives the reflected sounds from all directions after the impulsive, direct sound. **Error! Reference source not found.** lists the mean signal-to-noise ratio of the relocated water dispensary room. Its data is based on Odeon's standard list of materials, which was modified using GMO to validate the model. The table shows that the signal strength is sufficient for a good impulse, particularly in the mid and high-frequency ranges.

Table 1 The mean signal-to-noise ratio of the relocated water dispensary room

Frequency bands (Hz)	125	250	500	1000	2000	4000	8000
Mean signal-to-noise ratio (dB)	33	36.4	39.5	44.8	50.3	46.7	45.4

We conducted the acoustic survey of the original water dispensary room in the relocated one, considering the changes in its finishing materials and the absence of some elements. The relocated water dispensary room is almost square, with an area of 19.70 m2 (4.19 x 4.70 m) and a height of 5.3 m. Two locations for the sound source (popped balloons) were near the room's corners, and three locations for the receiver (microphone and recorder) were arbitrarily distributed across the room, one near the room's center and the others near the opposite room's corners.

The extinct cistern was a challenge. Surviving cisterns of the same period are either damaged or submerged in water. Consequently, we used Mosque wa-Sabīl wa-Kuttāb Sulaymān Aghā al-Siliḥdār cistern, constructed in 1839, to reference the materials' absorption coefficient. We based our choice on several aspects. The building belongs to the same Ottoman period and is accessible and water-free. However, al-Siliḥdār's cistern is seven times bigger in volume than the original al-Maghlawī's cistern. It has twelve shallow domes, an area of 304 m2, and a height of 12 m from the floor to the dome's center. Following ISO 3382-1 standards for an unoccupied room, we collected the IRs in the al-Siliḥdār's cistern using two locations for the sound sources and six locations for the receivers.



(a) A 3D model of the water dispensary room after relocation

(b) A 3D model of the water dispensary room before relocation

(c) Al-Siliḥdār's cistern 3D model

(d) Al-Maghlawī's cistern 3D model

Figure 5. 3D models of the rooms imported in Odeon with their IRs

We used the acoustic measurement software DIRAC (ver. 6) to analyze the collected IRs and deduce the variable acoustic indicators. This software allows us to comprehend the acoustic characteristics of the space before progressing to the simulation. Furthermore, it helps in obtaining the reverberation time (T), the time needed for the sound level to decay by 60 decibels (dB) after the source of the sound has stopped, for validation. This validation takes place by comparing (T) from DIRAC to (T) simulated in the room acoustic simulation software Odeon (ver. 13), discussed in the following section.

4.2.2 Modeling and validation

We developed 3D models for the three rooms: al-Maghlawī's water dispensary room before and after relocation, al-Siliḥdār's cistern, and al-Maghlawī's cistern (Figure). Then, we used Odeon to generate a digital IR that resembles the actual (measured) IR using the Genetic Material Optimizer (GMO) [ODEON Room Acoustics Software 2021], which is a specialized new tool in Odeon that automatically adjusts materials' absorption coefficients to get a closer match with the measured IR. The digital IR was later convoluted with the sounds required in the game.

Additionally, we validated the 3D model of the water dispensary room before its relocation with the measured IRs from the acoustic survey of the water dispensary room after its relocation.

4.2.3 Materials for reconstruction

As discussed, several changes occurred in the three rooms, including the water dispensary room's marble skirting and floor and the water basins. The materials' absorption coefficient determines a material's absorptivity (and, consequently, its reflectivity), which depends on several factors, such as materials' thickness, density, and flow resistivity [Cabrera et al. 2012]. The acoustic reconstruction uses two categories of materials. For existing materials, we used GMO to produce the absorption coefficient, which resulted from the acoustic survey's IR (Table 1).

Table 1: Reconstruction of existing materials

Room	Material	Reference of material's absorption coefficient	Reference
Water dispensary room	Stonewall	IRs from the acoustic survey in the relocated water dispensary room of Sabīl al-Maghlawī	The endowment document [Elghezawi 1996]
	Wood (ceiling and cabinetry)		

For non-existing materials, we used materials listed in Odeon in addition to the absorption coefficient from the acoustic survey's IR from the cistern of Sabīl al-Siliḥdār (Tab. 2). GMO enables the alteration of materials' absorption coefficients to correspond to the measured impulse responses.

Table 2: Reconstruction of non-existing materials

Room	Material	Reference of material's absorption coefficient	Reference
Water dispensary room	Marble (floor, skirting and basins)	Listed in Odeon	The endowment document [Elghezawi 1996]
	Water	Listed in Odeon	[El-Hosseiny 1988]
Cistern	Plaster (walls)	IRs from the acoustic survey in the cistern of Sabīl al-Silihdār	The endowment document [Elghezawi 1996]
	Stone (floor, arches and domes)	IRs from the acoustic survey in the cistern of Sabīl al-Silihdār	The endowment document [Elghezawi 1996]
	Water	IRs from the acoustic survey in the cistern of Sabīl al-Silihdār	[El-Hosseiny 1988]
Annex room	Stone (walls and floor)	Listed in Odeon	The endowment document [Elghezawi 1996]
	Marble (well rim and basins)	Listed in Odeon	The endowment document [Elghezawi 1996]
	Water	Listed in Odeon	[El-Hosseiny 1988]

4.2.4 Auralization

Auralization enables the reconstruction of audio clips according to their spatial aspects [Suárez et al. 2018]. It depends on the convolution between the simulated IRs and the dry sound waves in Odeon as obtained either from the anechoic room or from open audio sources. After generating the IRs and the required audio files, we performed the convolution and exported MP3 auralized audio files usable in the game engine Unity (ver. 2020.3.42f1).

We explored different simulation scenarios to enhance the players' interaction with the water sound in the game. In one of the scenarios, the players enter the annex room and drop the bucket into the cistern to bring water. They also could reach inside the cistern and see it being filled with water. Thus, we simulated water audio in both the cistern, at different water levels, and in the annex room at the well rim, which connects this room with the cistern (Fig. 6).

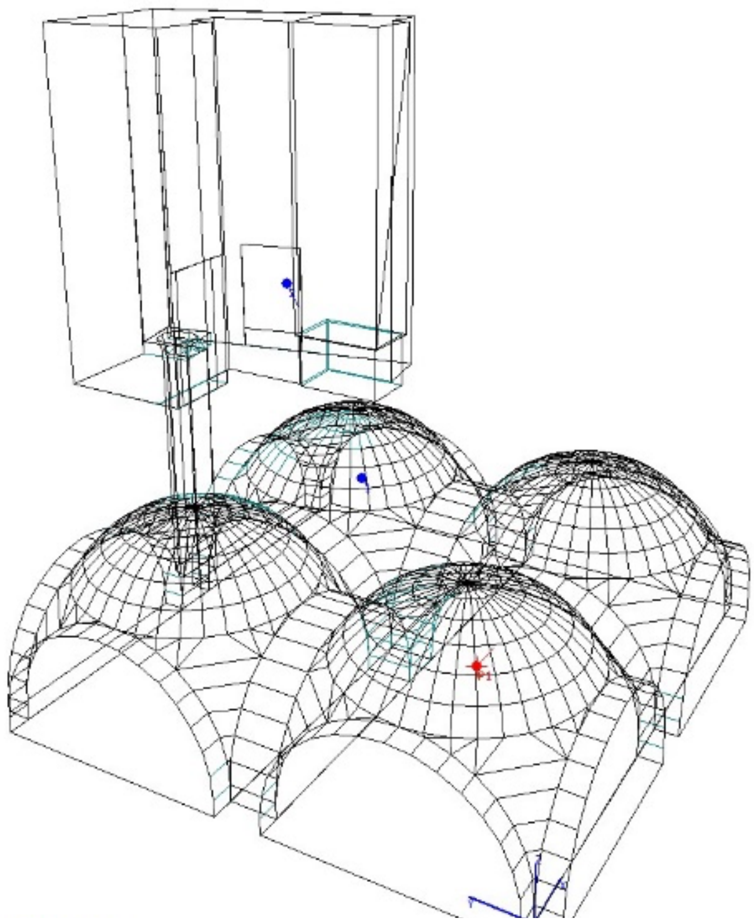


Figure 6. The model used in the simulation and convolution of "dropping the bucket" audio inside the cistern with the water level at 4 m from the cistern's floor

4.2.5 Audio in Unity

After importing the auralized audio clips in Unity, we added an "Audio Source" component to game objects with sounds. We used the "Steam Audio" plugin to provide sound occlusion by adding "Steam Audio Source" to these objects and "Steam Audio Geometry" to the 3D environment. Afterward, we added "Steam Audio Listener" to the first-person shooter avatar's main camera.

4.3 The game

This first-person player-character game lets players freely navigate the virtual environment. They can explore the sabīl's architecture, interact with its characters, and follow the water path. As they move through this space they can listen to ambient and auralized interior sounds enhancing the spatial experience. We published the game on the Itch.io web platform to make it available and accessible to the public. Players can play it online or download a larger file for a better acoustic experience (https://aliaa-el-dardiry.itch.io/back-to-the-roots).

The Ottoman style of Sabīl wa Kuttāb of Ismāʿīl al-Maghlawī inspired us to use Ottoman miniature art for the game's user interface (UI) (Figure 3). The art's abstract features simplify complex information in a simple painting [Özcan 2005]. Therefore, the design of the game's non-player characters (NPCs) is based on Abd al-Aziz Abdu's illustrations in "Legends of the House of the Cretan Woman" [Kretli et al. 2001].

The game allows players to choose between three scenarios: Ismāʿīl al-Maghlawī, the water carrier, and al-Mizammilātī (Figure 4). The first two scenarios are currently under construction and provide information about the spatial-temporal transformation, as well as the historical background of water and water carriers, respectively. The third scenario, al-Mizammilātī enables players to experience the sabīl, its soundscape, and spatial practices, before its relocation. The game includes three interactive game objects, the "golden flower," the "shiny gene" and the "water droplet petal." The first one is responsible for announcing the quest. The "shiny gene" provides information about characters and the sabīl's elements. The "water droplet petal" is the award given to the players after finishing the quest.

Players are free to experience any room from the sabīl's three rooms: the water dispensary, the annex, and the cistern. Each room has its own quest. For instance, in the water dispensary room, players help reconstruct the missing elements of the water dispensary room to reveal its water flow path. In the annex room, they don al-Mizammilātī's character and bring water from the cistern to fill the basins. In the cistern, they learn about the Islamic endowment system and help collect its income to finance the sabīl's operations.

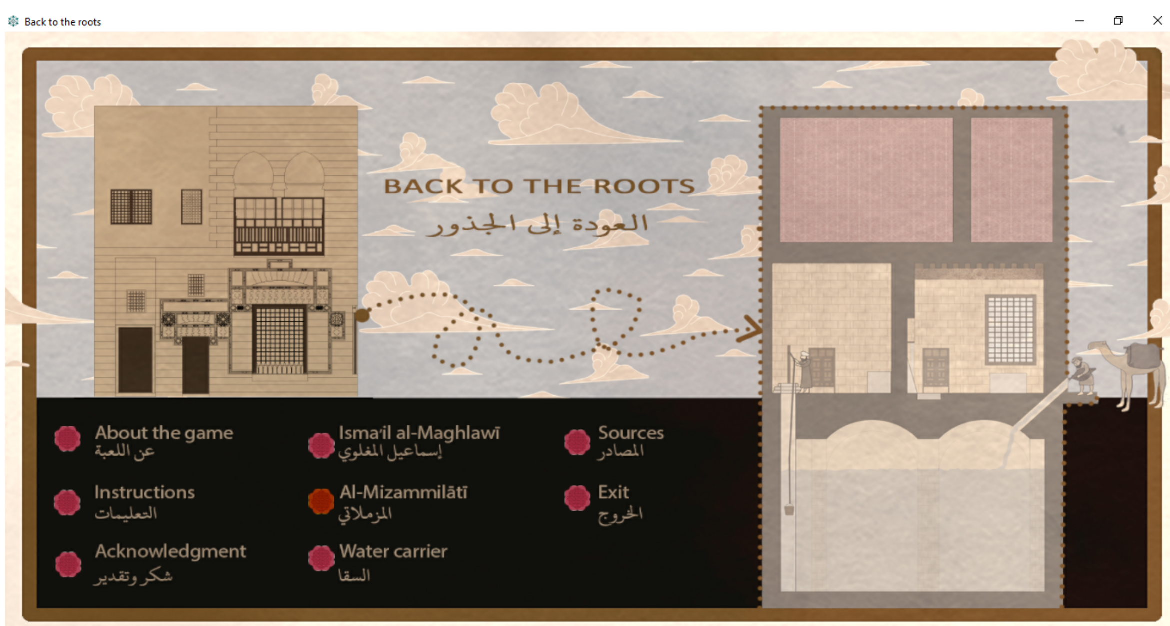


Figure 3. User interface (UI) of the game

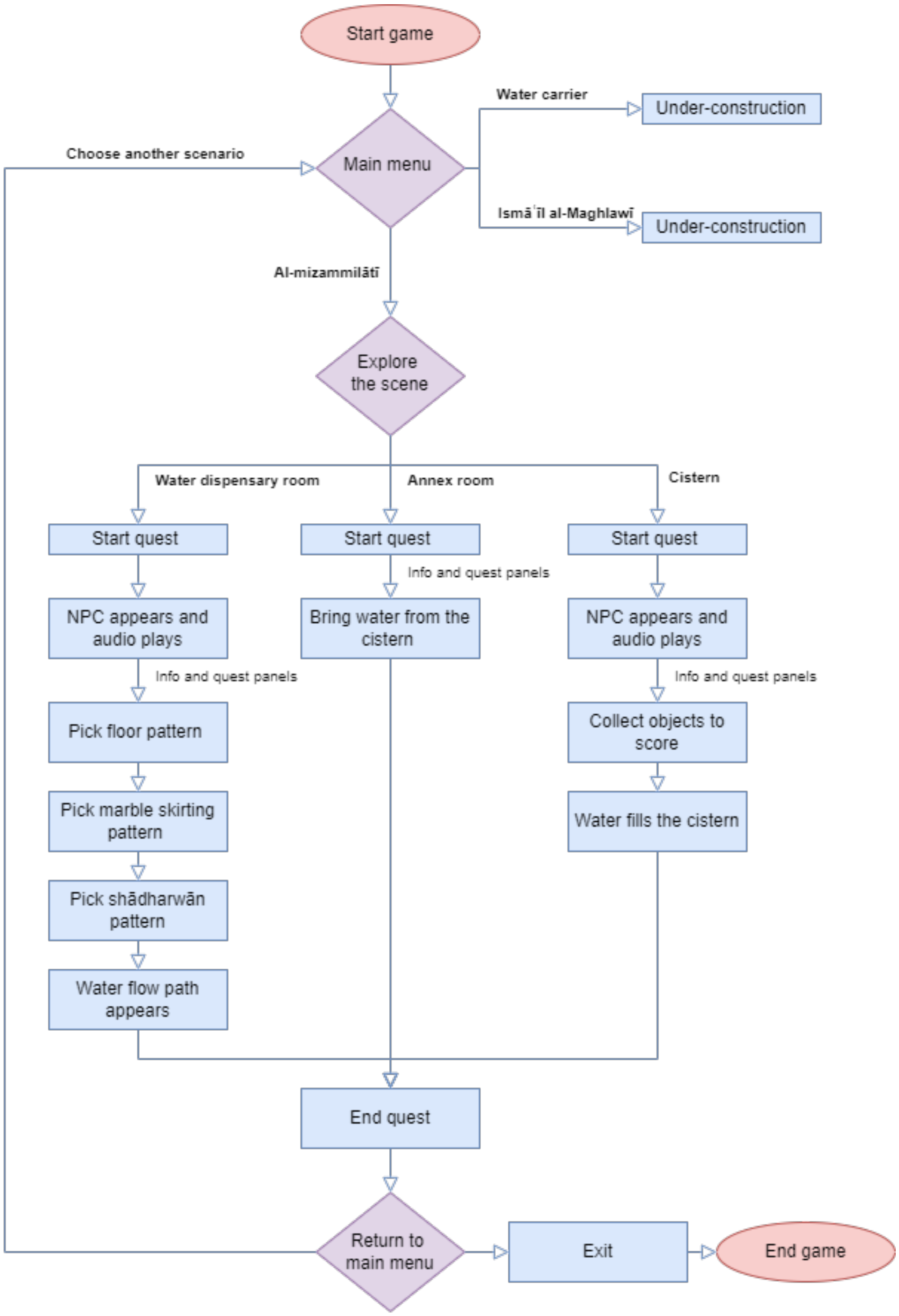


Figure 4. The flow chart of the game

5. DISCUSSION

Our proposed game allows players to visit the partially extinct Ottoman Sabīl wa Kuttāb of Ismāʿīl al-Maghlawī (Figure 5). It virtually reconstructs the sabīl's signature soundscape, otherwise lost to visitors of the current relocated (and closed) building. This soundscape includes the voices of water carriers and their animals, the sound of water filling the cistern, or water running on the shādharwān. This is in addition to the bustling urban context comprising markets, a caravansary, and large mosques, just to name a few. These sounds and voices represent the lost intangible heritage of the Cairene sabīl.

Games afford the integration of multi-modal (visual and auditory) experiences, interactive gameplay, and narrative elements. Our proposed game enables players to revisit the acoustic experience of the building. In addition, it allows players to learn about the role of al-mizammilātī, water carriers, and other characters. The game provides the building's floor plans before and after its relocation and informs the players about the changes in the sabīl. The water dispensary room's quest introduces its functionality, corresponding to its architectural space and elements. The quest encourages players to freely choose and reconstruct the missing marble floor, marble skirting, and shādharwān (Figure 6). Their reconstruction depends on precedents from other Ottoman and late Mamluk buildings.

Being in al-mizammilātī's shoes at the annex room quest, the players conceive of the connection between the room's elements, the cistern, and the water dispensary room (Figure 7). The quest shows the interaction between lifting water from the cistern and its acoustics.

Figure 5. The reconstruction of the sabīl and its context

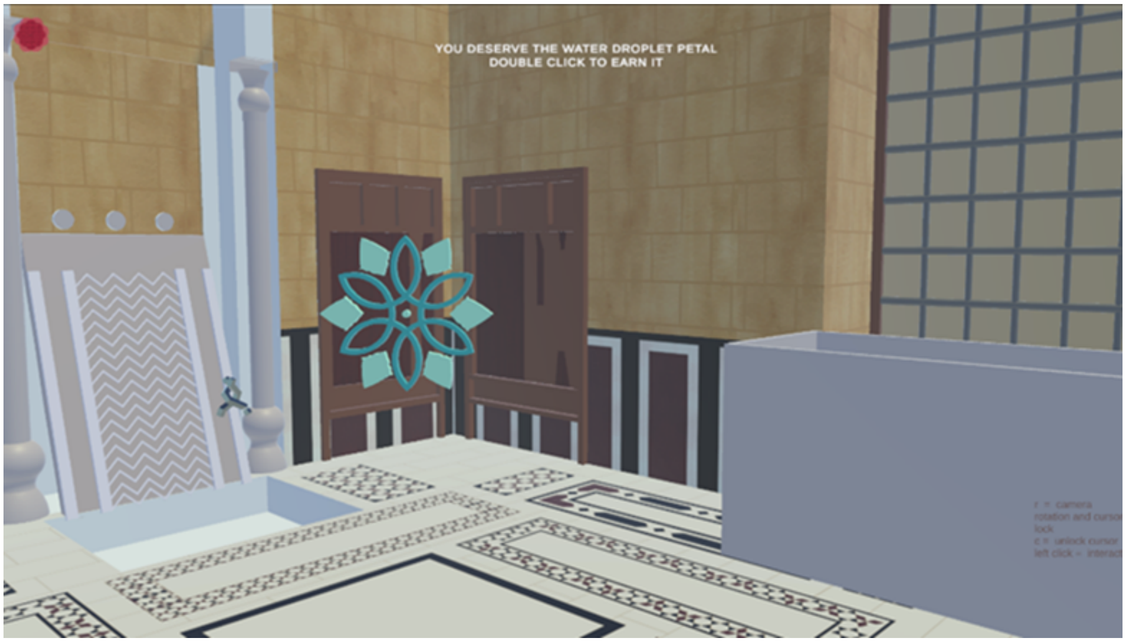


Figure 6. water dispensary room, after reconstruction

Figure 7. The players bring water from the well's rim and pour it into the basin.

This paper sheds light on the importance of exploring the acoustics of heritage buildings that played a crucial role in the everyday life of the past. In previous research, auralization is mainly limited to listening to auralized audio clips, connecting these clips to a 2D architectural plan, or allocating audio spheres in plain 3D modeling. Our proposed game integrates the architectural and acoustic reconstruction with the social aspects of the sabīl using narrations and quests. It stresses the significance of the sabīl's acoustic fingerprint and the role of acoustic occlusion in auralization. Players could listen to the soundscape and interior auralized audio clips corresponding to their space's architectural form and materials. For instance, the players can distinguish between the reverberation of al-Shihabi Ahmad's voice in the shallow-domed cistern and that of al-mizammilātī in the rectangular water dispensary room, thanks to the acoustic reconstruction process.

6. CONCLUSION

This paper proposes a serious game that digitally integrates the architectural and acoustic reconstructions of the Ottoman Sabīl wa-Kuttāb of Ismāʿīl al-Maghlawī. The architectural reconstruction builds on the Comité bulletins, endowment documents, contemporary literature, and site visits. The acoustics reconstruction depends on acoustic surveys in the relocated sabīl and the Sulayman Agha al-Siliḥdār cistern, which was auralized (simulated) and validated. We integrated the sabīl's 3D reconstruction and auralization into a game engine and applied acoustic occlusion to the building model. The resulting game is available online to the public. It goes beyond the typical ocular-centrism of historical reconstructions and offers its users the unique acoustic experience of the sound of water as it runs through the sabīl's different spaces. Adding NPCs and narrations, the game attempts to enrich the users' experiences with knowledge about the spatial practices and everyday life of the people associated with the sabīl in the 17th century.

For future work, we would like to broaden the game's scope to integrate, for example, the Quran school. We would also like to document and reconstruct the transformation of the sabīl into a coffee shop and inn in 1906. Last, we would like to conduct an evaluation analysis concerning public engagement with the game.

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