



# Beyond the Smart City. The Urban Digital Twin for the Augmented City: The *Vox Hortus* Project

Romano Fistola<sup>1</sup> and Ida Zingariello<sup>2</sup>(✉)

<sup>1</sup> University of Naples Federico II, Naples, Italy

<sup>2</sup> University of Sannio, Benevento, Italy  
izingariello@unisannio.it

**Abstract.** The Urban Digital Twin (UDT) represents an innovative new dimension for urban planning capable, not only, to replay the corresponding physical twin in all its properties but also and specially, to implement the interaction with our cities through the addition of any type of information content. Thanks to the tools of City Information Modeling and Augmented Reality technologies, the information content of the UDT can be interrogated, updated and shared among planners and political decision makers, and with citizens. Based on the type of information content, the UDT makes various planning actions possible and allows to start of different perceptive experiences, such as the prefiguration of urban transformations; the virtual recombination of historical heritage; the augmented use of the city with a new way to polarize tourist flows as well. With regard to this capability of the UDT, the present work intends to describe how it is possible to regenerate an urban context by using augmented reality. The case study is focused on one of the most iconic spaces inside the city of Benevento: the *Hortus Conclusus*. This little open-air space, inside the inner city, contains the artworks of the famous modern artist Mimmo Paladino that are been geolocated inside a project called *Vox Hortus* which allow the visitors to listen to the voice of the masterpieces through an augmented reality audio application.

**Keywords:** Smart City · Urban Digital Twin · City Information Modeling · Augmented Reality

## 1 Introduction

Technology assumes a central role in supporting informed knowledge and decision-making processes, which are indispensable to orient the urban system towards a sustainable evolution compatible with the available resources. It is necessary to consider new paradigms for understanding urban dynamics and to adopt technological innovation in the knowledge processes, interpretation, modelling, planning and management of the city.

In this sense, it appears useful to note that, from a theoretical-methodological point of view, it is necessary to overcome the rhetoric on the smart city and develop a new reflection on the technological paradigm applied to urban planning. The main element

of incongruence of the smart city lay in urban planning practices that saw technologies “added” to the city and not “adopted” by the processes of governance of territorial transformations. Technology should not be instrumentally added, but introjected for the redefinition of urban planning methods and procedures [1]. From this awareness it is necessary to start a new reflection for a disciplinary redefinition that adopts technological innovation in all phases of the urban planning process in order to govern the evolution of the complex urban system in a sustainable way.

## 2 The Urban Digital Twin, Beyond the Smart City

The discourse surrounding the concept of urban digital twin has reached a mature stage in research, marked by numerous global experiments. Major cities worldwide are currently constructing their digital twins based on models that accurately replicate the functioning of urban systems. Similar to historical trends, where urban scientists analyzed city transformations to develop theories describing past urban developments (such as the emergence of smart cities), we are now at a juncture where we can propose a methodological approach to comprehend the phenomenon of urban digital twins.

A digital twin is commonly defined as a virtual representation of a physical system, including its environment and processes, which is continually updated through information exchange between the physical and virtual realms [2]. In the context of a city model, this implies the creation of a digital environment that mirrors the city’s physical space. Furthermore, adhering to a systemic approach to city interpretation, it is evident that cities can be conceptualized and depicted as complex dynamic systems [3].

The concept of urban digital twins builds upon previous research in urban modeling, spanning from the works of Christaller to Wilson, extending beyond the scope of the smart city model. As recently stated, “Urban digital twins have the potential to revolutionize the smart city concept and propel urban models to new heights” [3]. The digital modeling of urban space can occur through both the virtual reconstruction of the urban system in an electronic simulation and, in a sense, by incorporating digitalization within the physical urban space. In other words, it is possible to envision another dimension of digital twin modeling, built within the spatial context and through the creation of a network of hybrid digital spaces [4].

This reflection leads to proposing two distinct types of urban digital twins:

- UDT exogenous
- UDT endogenous

Both typologies are based on the reference to the urban system and owe their effectiveness to the speed of digital information processing.

The first type is the UDT which is currently being defined or already developed in many international urban contexts. This model is essentially built through a computer programming structure that connects data from urban sensors with expert system modules capable of formalizing the state of the system and suggesting potential governance actions, either autonomously or with human intervention [5].

As previously emphasized, a significant number of “classic” UDTs have been developed, either as prototypes or are currently under development. Among these, we can

mention the UDTs of cities such as New York, Tokyo, Vienna, Helsinki, and so on (see Fig. 1).

	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reference number	
User	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Citizens	
																							Public administration	
																							Asset owners	
																							Asset managers	
Life-cycle stage					X																		Researchers	
	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Planning	
	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Construction	
	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Operation and maintenance	
																							End-of-life	
Modelled systems	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X	X	Physical city model	
	X	X	X	X	X																		Meteorology	
																							Climatology	
				X	X						X	X	X	X	X	X	X	X	X	X	X	X	Atmospheric pollution	
				X	X																		Noise pollution	
	X	X				X										X							Flooding	
	X	X				X																	Sewage	
																							Road infrastructure	
																								Wireless network coverage
																								Electrical network infrastructure
																								Electricity supply
																								Natural gas supply
																								Heat supply
	X	X																						Water supply
																								Energy demand
																								Electricity generation
																								Renewable energy resources
																							Mobility	
																							Public transport	

**Fig. 1.** The urban digital twin referred to specific features of the urban system (source: Ferre-Bigorra et al., 2022).

The second type of UDT is one that incorporates digital spaces within the physical context of the city. This second typology does not strictly represent a model of the city, but it can be useful for testing localized modifications of the urban space where such changes are anticipated.

In this sense, the endogenous UDT is configured as a Digital Twin Instance (DTI) understood as a digital instance connected and federated to its physical twin. The DTI is identified as a digital content that can be activated live and on demand in the urban context to which it refers by means of augmented reality tools and envisages the direct involvement of the urban community in decisions concerning the transformation of the city.

The endogenous UDT can be implemented in various ways in the spatial contexts of the city and can become an innovative tool for the enhancement of the territory capable of satisfying the needs of a new multi-sensorial urban tourism.

The endogenous UDT, thanks to AR tools, has the potential to significantly increase the use of urban spaces for tourism [6]. The advantages of AR in the field of tourism enhancement are multiple: a greater emotional involvement of the visitor, a greater and differentiated fruition of space, a multi-level knowledge.

On the basis of these considerations, it is possible to affirm that endogenous UDT can serve as a functional catalyst triggering new processes of interactive tourist fruition as illustrated in the case of the Vox Hortus project described below.

### 3 The *Vox Hortus* Project

The *Vox Hortus* project, with the support of the Municipality of Benevento and the supervision of the well-known artist Mimmo Paladino, aims to ‘give voice’ to the artworks through the realization of an audio augmented reality application for the urban space of the *Hortus Conclusus* in Benevento, which houses the works of the Samnite artist, one of the leading exponents of the Italian Transavantgarde. Paladino’s *Hortus Conclusus*, designed in 1992, is located within one of the gardens of the Convent of San Domenico, and evokes, in its urban conformation, the classic medieval garden of small dimensions, surrounded by high walls, a protected and silent place within the chaos of the city. In this place, which takes the form of an open-air museum, are the numerous works of the master Paladino, among which the Bronze Horse and the enormous Shield stand out (see Fig. 2).



**Fig. 2.** Photo of the urban space of the *Hortus Conclusus* taken from a drone (source: Aurus Research Group - [www.aurusricerca.it](http://www.aurusricerca.it)).

Starting out from this urban context, the *Vox Hortus* project aims to make the sculptures “speak” by creating a sound path through which the visitor can walk through the space of the *Hortus Conclusus*, grasping, in an integrated perception, not only the spatial values of the works, but also the audio-emotional stimuli linked to the individual artwork. The audio does not provide an explanation of the work to which it is connected, but proposes a short sound (voice and music) that the visitor can listen to, with incremental volume, as he approaches the artwork itself, so as to define a path, not necessarily guided, between the artworks.

In other words, each work is associated with an informative content in the form of sound input that can be enjoyed, in full autonomy, by each individual visitor thanks to their smartphone. Once the *Vox Hortus* app has been installed and the marker has been framed with the smartphone, each visitor is offered the possibility of listening to

the audio content associated with each work, the volume of which becomes louder and louder as one approaches the work and lower and lower as one moves away from it. Moving within the urban space of the *Hortus*, it is possible to move from one sound content to another simply by approaching the individual works, deciding independently which itinerary to follow (see Fig. 3).

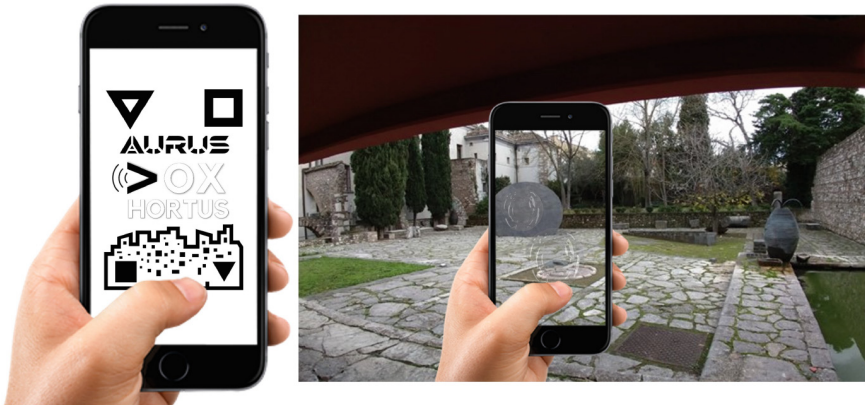


**Fig. 3.** *Vox Hortus* project mockup (source: Aurus Research Group - [www.aurusricerca.it](http://www.aurusricerca.it)).

The realization of the *Vox Hortus* project involved four consecutive phases:

1. The relief of the urban space of the *Hortus Conclusus*.  
The exact position of each work within the garden was identified, as well as the reciprocal distance between the individual works; the point where the marker capable of activating the geolocation of the works within the app was also chosen.
2. The design of the AR app in Unity using the ARCore and AR Foundation platforms.  
A scene was created in the Unity environment to simulate the space of the *Hortus*. Each artwork in real space was associated with a 3D object in Unity's virtual space to which an audio track was added with a linear roll off and a maximum distance beyond which the audio will not be heard.  
The app takes advantage of AR Foundation's image tracking, so once a tracking image was chosen to work as a marker, individual 3D objects were associated with it. Finally, the app was built in APK format for Android devices that support AR Core (see Fig. 4).
3. The choice of sound information content to be associated with each artwork.  
Currently, in order to test the app, generic music tracks have been associated with the works. The objective is to produce texts or musical contents, which are representative of the artwork, but not, explanatory or descriptive of it.
5. The 'augmented' use of the urban space of the *Hortus Conclusus*.

The app has been tested but is not yet usable by Benevento citizens and tourists. Once the audio content has been chosen, also under the supervision of the master Mimmo



**Fig. 4.** *Vox Hortus* project mockup (source: Aurus Research Group - [www.aurusricerca.it](http://www.aurusricerca.it)).

Paladino, the AR app *Vox Hortus* will be available to every citizen with an android device. Every visitor will be able to enjoy the ‘augmented’ space of the *Hortus Conclusus*; that is, to enjoy both the physical space with its artworks and the audio content. The *Vox Hortus* project aims to further increase the already high artistic and cultural value of the *Hortus Conclusus*, enhancing its touristic value through a further attractive dimension in “augmented” form, by triggering an innovative process of urban requalification.

## 4 Conclusions

The UDT will soon become one of the new backgrounds in urban planning and, more broadly, in the governance of urban transformations. What is important to underline is that the UDT must be a system capable of addressing the needs of the city [7], particularly the functional and socio-anthropological requirements of the urban system. Furthermore, as briefly demonstrated in the overall exploration of the topic, it is possible to envision different types of UDTs. These include not only the ones created for benchmark modeling of the city without involving urban actors but also those that emphasize the interaction that citizens can have with a virtual urban space.

Thanks to studies on Embodied Cognition [8], it has come to be understood how the individual’s knowledge is generated by the subject’s interaction with the surrounding environment and the elements that structure it. In other words, it is the interaction with an object that enables its perception by the individual regardless of the nature of the object itself.

On the basis of these reflections, it is possible to state that if a digital instance is inserted into a physical space of the city with which an individual can interact through appropriate extended reality devices, the individual will perceive the entire context as real without distinguishing between physical objects and virtual objects. The space generated by the interaction between real and digital entities is called ‘hybrid digital space’ (HDS). It is the DTI’s own information content that appropriately associated with real entities is able to digitally hybridise the physical space. The insertion of a DTI within a physical

space is capable of triggering a series of interactions between the real and the immaterial in which HDS is substantiated. In other words, an HDS is only possible if different digital contents are included in the physical space; it is through this grafting that the real space is configured as HDS [9].

Through this process, by the *Vox Hortus* app, the space of the *Hortus Conclusus* takes on the new configuration of a HDS, an environment in which the user, being able to establish an indistinct interaction with the real entities (the artworks) and the virtual ones (the sound content), triggers a new augmented cognitive process [10].

As a result of the above, it is evident how the adoption of technological innovation in the redefinition and re-functionalisation of urban contexts now allows the development of new dimensions of anthropised space that can be activated by extended reality tools.

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