

Digital Innovations in Architecture,  
Engineering and Construction

Andrea Giordano  
Michele Russo  
Roberta Spallone *Editors*


# Beyond Digital Representation

Advanced Experiences in AR and AI  
for Cultural Heritage and Innovative  
Design

 Springer

# **Digital Innovations in Architecture, Engineering and Construction**

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The Architecture, Engineering and Construction (AEC) industry is experiencing an unprecedented transformation from conventional labor-intensive activities to automation using innovative digital technologies and processes. This new paradigm also requires systemic changes focused on social, economic and sustainability aspects. Within the scope of Industry 4.0, digital technologies are a key factor in interconnecting information between the physical built environment and the digital virtual ecosystem. The most advanced virtual ecosystems allow to simulate the built to enable a real-time data-driven decision-making. This Book Series promotes and expedites the dissemination of recent research, advances, and applications in the field of digital innovations in the AEC industry. Topics of interest include but are not limited to:

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Andrea Giordano · Michele Russo ·  
Roberta Spallone  
Editors

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Cultural Heritage and Innovative Design

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# Foreword

This book testifies to the joint effort of a group of professors in the Disciplinary Sector of “Drawing” who were able to make clear already three years ago a channel of research particularly interesting for the topics covered. The Digital first, the Virtual then and again Artificial Intelligence and the complex intermingling of computer science and visual communication show a liveliness of speculation and research all directed to new ways of fruition, understanding and enjoyment of our Cultural Heritage, often suspended between material and immaterial.

While information technology and technological innovation might at first have created inhibitions for those trained in the social sciences, between documentary analysis, surveying and the design of architectural spaces, the REACH-ID Symposia have been able to demonstrate how much the themes of Drawing, Representation, geometry and visual communication can be research opportunities that are always current and innovative.

It can be inferred from the pages of this volume how much the purpose of REACH-ID meetings is to solicit and expand human intelligence through new inputs from new technologies; these are occasions that tend to bring together contiguous cognitive universes, not only between different disciplinary fields but also within the same discipline.

From the editors’ introductory essay and the authors’ contributions, an epistemological framework has significantly changed since the 20th century. The scheme of the two cultures seems outdated because of the complexity and cultural hybridity that marks today’s knowledge society. We are far from the pattern of fifty years ago when the scientific and humanistic cultures were separated by “an abyss of mutual incomprehension” (Charles P. Snow 2005. *Le due culture*, Marsilio, Venice, p. 20).

However, the confrontation between the two cultures is far from exhausted since the field of Cultural Heritage, until yesterday the prerogative of the humanities and social sciences, today has also become one of the main targets of technological research; it is a common pivotal theme that protects collective memory and contributes overwhelmingly to the definition of community identity and awareness (see Horizon 2020, 8th Framework Program).

Given the above, the symposium chairs thought it appropriate to promote a national and international network of researchers (REAACH Association) interested in Heritage Science to propose an increasingly organic and conscious way line of research in the field of Cultural Heritage by exploiting IT skills and applying them to Cultural Heritage. All of this was with a view to multidisciplinary exchanges of knowledge and the enhancement of advanced transversal skills.

It is a volume that brings together valuable evidence ranging from different ways of accessibility to Cultural Heritage to the use of Artificial Intelligence and Augmented Reality to applications of Extended Reality and Gamification to enjoy the fantastic universe of Cultural Heritage in a diversified way.

May 2023

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# Preface: Introducing the Relationships Between Digital Representation and AR/AI Advanced Experiences

We are witnessing a rapid technological innovation, which in the space of two decades has completely subverted the panorama of the discipline of Representation: a panorama that now sees the involvement of interdisciplinary issues with findings, repercussions, and feedback in both theoretical and applicative fields. Furthermore, if the concept of Virtual Reality was already inherent in Representation also for artistic purposes—see in this regard the Renaissance pictorial works, precisely *ante litteram* attempts at Virtual Reality—today Artificial Intelligence (AI), fueled by Deep Learning, has made it possible to arrive at an Extended Reality (XR), which incorporates the adjectives of Virtual, Augmented and Mixed.

For this reason, Artificial Intelligence has proved to be a truly transformative technology, exploited daily in more and more areas, continuing to surprise us with its evolutions. Evolutions, however, must consider awareness. Awareness in both theoretical and practical terms is where training plays a significant role in engaging with a critical and constructive attitude. For this reason, it is unquestionably that an aware conceptual apparatus is at the basis of Artificial Intelligence and its relationship with Extended Reality, being able to relate to and describe entities directly suggested by the real and ideal world through more advanced conceptualizations. The definition of these concepts, with the awareness that interesting and ingenious considerations could be applied to them, is the first demonstration of the acute use of Artificial Intelligence for Extended Reality. Moreover, for this, we must consider the depth of thought that goes into the formulation of XR through the concepts of Representation and, subsequently, the skill with which these concepts are used.

Thus, the domain of reasoning becomes lawful and indispensable. It remains fundamental, for example, to be able to recognize an architectural surface in geometric and configurational terms to then have important effects in structural and constructive terms. Once these concepts have been acquired, implementing them through AI-XR increases the evolutionary scenarios, with enormous repercussions on the heritage (architectural/engineering/urban/landscape), whether existing or in progress.

This process, therefore, takes on a prodigious characterization, adapting the Representation to extensive/plural/multiple areas from a disciplinary point of view, with

repercussions on the scientific aspect of the adequacy of the codes and expressions of knowledge to broad branches of culture. In this way, the “frontiers” of Representation are widened. Thus, the relationship between Representation Space and the Representation of Space further expands and explains the relationship between Science and Art, between concept and creativity and between elaboration and realization.

The digital world and the Representation domain are strongly interconnected. Their long-established relationship has seen a major step forward in the past two decades. The ability to survey in space any kind of artifact, draw and visualize it with digital models at different levels of detail and reliability is now considered an established practice. At the same time, the sudden growth in the last five years of Artificial Intelligence (AI) and Augmented Reality (AR) research, especially, but not exclusively, applied in the field of Cultural Heritage, has required a deep analysis of the role of these technologies in the Representation domain. Specifically, “if and how” these tools, strongly leaning by expertise to the world of computer science, can find a declination in the research of Drawing.

The answer to such a complex question requires extensive and in-depth discussion among those who have had the opportunity to critically experiment with AI and AR in different scientific domains. This is the main motivation that led us to promote in 2020 (REAACH-ID 2020), and for the first time, a symposium dedicated to these issues. The articulated framework of research that such an event brought to light allowed us to begin a journey of maturation from which two different needs emerged: on the one hand, the repetition of the event, promoting annually and consolidating a place for discussion and updating on emerging technologies. From this point descended, the organization of the symposiums in 2021 (REAACH-ID 2021) and 2022 (REAACH-ID 2022). On the other, the definition of a new entity that could support from a scientific and organizational point of view the promotion of these issues on a national and international scale, encouraging the increase of networks among different scholars. From this choice came the founding in 2022 of the REAACH Association ([www.reaach.eu](http://www.reaach.eu)), which stands as a “bridge” between experts in different disciplines and some European research streams such as Heritage Science. The association promotes the symposium annually, nurturing interest in the issues and, at the same time, fostering that path of maturation toward an increasingly conscious use of emerging technologies.

The annual event presents an online format to maximize participation by both speakers and attendees. To encourage useful discussion, the authors present in-progress experimentation highlighting the pros and cons of the specific application. The definition of the paper occurs later, downstream of the meeting, reaching a more critical development of the contents. The articles, therefore, follow an autonomous path in which the symposium represents only a moment of critical feedback and comparison with similar research to understand the topic’s relevance, arriving at a more informed synthesis in the research domain. The book presented here promotes the results of research that were presented as a first idea during the 2022 symposium and then developed independently following the event.

The book is divided into parts that collect contributions that weave together the two main topics, i.e., the discipline of Artificial Intelligence and the technology of

Augmented Reality, with specific objects of interest from the discipline of Representation. The definition of these parts is partly driven by the topics proposed in the call for papers and partly guided by the authors' responses, who have brought to attention new and interesting theoretical developments and application possibilities. According to this logic, the book is divided into six main parts.

The part "AR&AI and Historical Sources" deals with the accessibility and communication of archival historical heritage mediated by virtual reconstruction using 3D models and the experimentation of the heuristic potential of digital modeling for the 3D visualization of consistencies represented in archival drawings. The opportunities offered by the digital revolution and specific technologies and simulations are explored in the part dedicated to "AR&AI and Museum", with the aim of increasing the community's knowledge and awareness of heritage, also in terms of inclusion. In the "AR&AI and Heritage Routes" part, experiences in archeological sites are presented through virtual reconstructions and "augmented" tours of existing architecture and landscapes acquired through digitally surveyed. The part "AR&AI and Classification/3D Analysis" is largely devoted to papers presenting general considerations with extensive references to the most interesting and richly developed Artificial Intelligence methodologies. "AR&AI and Education/Shape Representation" is the part that contains Artificial Intelligence and Augmented Reality methodologies and technologies for shape representation and innovative teaching, as well as Extended Reality and Gamification applications for the presentation of curriculum work. The monitoring of the built environment, both historical and contemporary, characterizes the "AR&AI and Building Monitoring" part. The state-of-the-art digital methodologies and technologies enable the development of effective and efficient monitoring systems.

Each part is organized starting with the papers that set out general theoretical considerations or that refer to broad application areas and is followed by the papers that develop specific case studies. The parts are preceded by a keynote lecture dealing with a recent digital initiative at the Montreal Museum of Fine Arts that strives to mimic the lost pleasure of tactility, as well as to address the physical limitations surrounding the display of miniature objects in a museum, in an attempt to subvert canonical museum hierarchies by rendering visible the often-invisible, including the artworks' tactility, materiality and craftsmanship, which would otherwise be left obscured by a traditional museum display.

More than 150 scholars have participated in the realization of this volume, consisting of 53 chapters, contributing to the establishment of the scientifically up-to-date state-of-the-art of international studies linking the discipline of Representation with Artificial Intelligence and Augmented Reality.

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# **AR&AI and Building Monitoring**

# Dataspace: Predictive Survey as a Tool for a Data Driven Design for Public Space



Massimiliano Campi , Marika Falcone , and Giacomo Santoro

## 1 Introduction

The decision-making process based on the interrogation and prediction of Big Data is a research topic that has animated the interest of many fields of investigation in recent decades. Among these, the architectural field has also participated in this widespread interest involving, in particular, the disciplines of Drawing and Representation. In this context, technological progress has transformed the way of knowing and investigating architecture with research approaches characterized by a multidisciplinary vision. The use of these new technologies has in fact developed new ways of thinking about architecture while representing, at the same time, a key factor in the process of analogy-digital transition still underway. In this mixture of physical and digital fits the theme of city models that follow development strategies based on Artificial Intelligence and Internet of Things applications that allow for the processing and analysis of the enormous volume of data they generate. The definitions attributed to these cities are different: from wired city [1] to cyber city [2], from digital city [3] to intelligent city [4] up to the more recent and well-known ones of smart city [5], sentient city [6] and senseable city [7]. Each of these terms has been coined to explore the relationship between Big Data and the city itself, analysing the effects that information and communication technologies produce on urban form and public space. It is from this assumption that this contribution aims to analyse the quality

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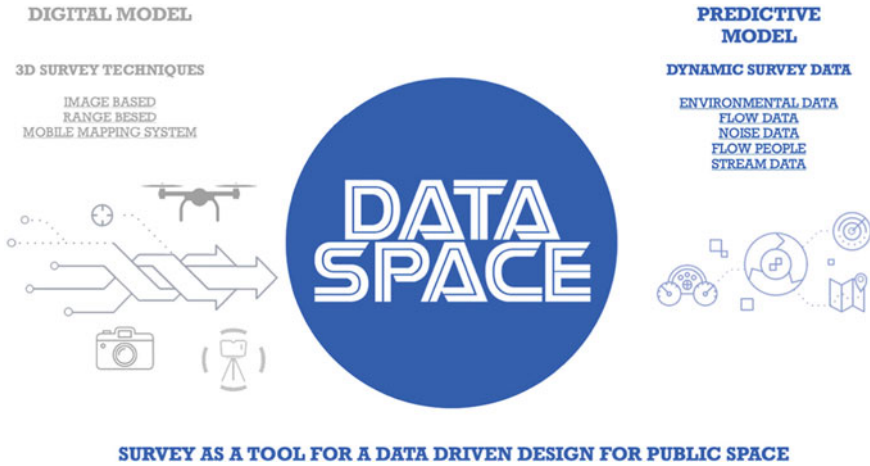
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of public space by defining, through survey techniques, a three-dimensional model in which to simulate a series of heterogeneous data collected through field surveys. The aim is to define a future sensors system to support a design based on real data and, therefore, a prototype of a forecasting model. Topics that are trendy in the predictive survey that associates morpho-metric information with a continuous flow of heterogeneous data obtaining what is commonly called Digital Twin. In this vision, the survey is understood, in its broadest sense, as a modification of the reality of the subject that reflects the research attitude of the group. The limitations of 2020 have certainly changed our lives for better or for worse. The Covid-19 pandemic has highlighted the weaknesses of the places we live in, and the introduction of the concept of social distancing has forced mankind to think about public space in a different way. What has changed in the use of spaces in our cities? Can we make the most of it in everyday life? The aim of this thesis work is to understand the quality of public space by defining—through survey and representation methodologies—a three-dimensional model in which to simulate a series of heterogeneous data collected through field surveys. The aim is to imagine a future sensor system to support a design based on real data. The scope of this work is potentially enormous. From maintenance, through restoration, urban redevelopment, construction from scratch—but also the simple monitoring of spaces or interactive management. The application possibilities are many. This model, however, needs to be fed by a huge amount of data, so often, to date, there are not even collection tools. The output of this thesis wants to be the definition of a method, understanding which tools are currently available and which ones would be needed to collect these data and put them into a coherent and usable system [8]. On the basis of the premises mentioned above, the methodology used saw the identification and distinction of four operational phases. The first phase concerned the analysis of the sources, linked to the necessity to understand how the urban context of our cities has been influenced, during history, by pandemic events and which kind of lessons have been learnt on the way. The second concerned the direct knowledge of the public space through the acquisition of morphometric data. In this case, the investigation campaign was conducted using image-based technologies, with the combined and integrated use of LiDAR techniques. The third phase concerned the creation of a digital model on which a series of interpretations were developed. Instead, the fourth phase was dedicated to the design and implementation of the model with a simulation of methodology (Fig. 1).

## 2 Analysis

Humankind is not new to pandemics, and Covid-19 will not be the last event of this kind. The concept of pandemic (from the ancient Greek *pándēmos*, what affects all people, public, general) is of recent introduction, used in the modern age to indicate the exposure of the entire world population to a common disease [9]. The spread of these diseases on a global scale has been the consequence of a progressive process of globalization which has made possible the contagion between different



**Fig. 1** From digital model to predictive model for public space. *Editing arch. M. Falcone and arch. G. Santoro*

peoples; the story is scattered with examples which have brought suffering, death, even the disappearance of entire civilizations [10]. Some diseases have struck rapidly, others have acted in lethal waves over the years but all, for better or for worse, have profoundly changed the social fabric and the urban layout of our cities. Covid-19 could be again—as it happened before—a watershed for rethinking our cities to make them ready for the challenges of the future [11]. A barrier to the risks deriving from pandemic and epidemic events can be found within some tools developed in recent years at a global level. The UN 2030 Agenda for Sustainable Development outlines, among other things, the 17 Sustainable Development Goals. From the fight against poverty, through the protection of the environment and the development of clean energy sources, the objectives recognize an important role for health (objective 3) and the development of safe and sustainable cities (objective 11). These goals go hand in hand: today half of humanity, 3.5 billion people, live in cities and by 2030, almost 60% of the world’s population will live in urban areas. This transformation will lead mankind to face new challenges (Figs. 2 and 3).

## 2.1 State of Art

In a global context in which 63% of the global mortality rate is linked to chronic diseases, many of which are linked to risks from urban environments, what can we do to make cities not places where we get sick but active organisms that cure and are adapted to the historical context to avoid the risk of new pandemics? First through maximizing the use of data. Making decisions based on scientific evidence, collecting both historical data and real-time data streams regarding the environment,

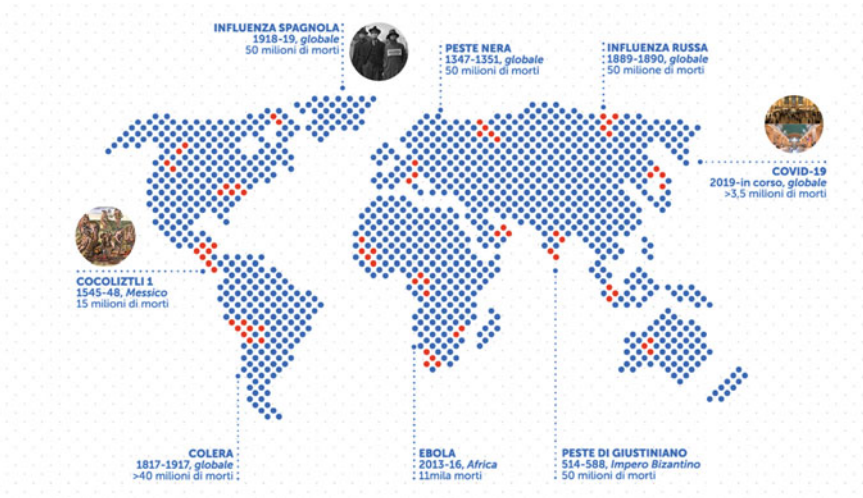


Fig. 2 Pandemic and epidemic events in the history. *Editing arch. G. Santoro*



Fig. 3 The 17 goals of United Nation (on the left). Healthy and unhealthy urban space (on the right). *Editing arch. G. Santoro*



**Fig. 4** The project of Norman Foster in Trafalgar Square, London. *Editing arch. G. Santoro*

health, can help establish an even closer link between the built environment and the well-being of citizens. The use of data in the field of architecture, therefore of the survey and understanding of city spaces, is not new and examples in this sense already exist from the beginning of the 2000s. In fact, at the end of the 90s, the British architect Norman Foster’s studio was commissioned to define a masterplan called *World Squares for All* for the improvement of the public space of Trafalgar Square, considered insecure and unpleasant. The definition of the project was supported by a series of analyses on space carried out by the Space Syntax studio: in particular, both pedestrian and vehicular traffic flows were analysed, through observation periods which led to the definition of a highly developed analysis model for the era. The collected data helped to define a new design of the square, still existing and widely appreciated. Although this project was a forerunner in the use of data to support design, the data used was far lower than what it would be possible to do today; despite the mass of heterogeneous data of our day—designing using data is an approach that has never become canonical. In recent years, the greatest contribution to this research field has been made by the Senseable City Lab of MIT in Boston, led by the Italian architect Carlo Ratti. With more than 50 research projects developed, the Senseable City Lab stands as an ambitious experimenter in the field of data use, maintaining a multidisciplinary approach that relies not only on architecture or urban planning, but also on physics, biology and sociology. Notable projects include the recent *Desirable Streets*, for which thousands of pedestrian trajectories—obtained from the GPS signals of mobile phones—were used to build a desirability index of Boston streets (Fig. 4).

## ***2.2 The Use of Data and the Importance of Survey***

But how to collect this data? The extraction of knowledge from Big Data and their use for the improvement of decision-making are subordinate to the definition of processes that allow to efficiently manage and transform datasets that grow rapidly

in volume and variety. In addition to the variety of formats and structures, Big Data also has a variety of sources. In particular, we are talking about human generated data (those coming from the internet, social networks, blogs, etc.) and machine generated (extracted through the use of technological sensors). The acquisition, for both types, can take place both using specific software and by accessing the APIs made available by the web services, relying in any case on technologies present in everyday life. The combined use of everyday data flows from these technologies—equipped with low-cost sensors—and data taken with field investigations, can help build an unprecedented analysis framework. The key to all of this is survey. Through digital representation procedures and tools, it is nowadays possible to support the interpretation of data; understanding the structure of cities, its buildings and activities helps to understand how urban space works and could work better, according to the maxim of “if you can’t measure it, you can’t manage it”. Digital photogrammetry (in particular, Close-range Photogrammetry) has been the most suitable tool to pursue these objectives. An accurate urban survey allows to obtain dimensional data, geometric proportions of the spaces, analysis of the materials, favouring a typological, structural and functional knowledge of the building (Fig. 5).

The accessibility of technologies, through the use of reality-based sensors, and specifically of image-based techniques, can allow the reconstruction of accurate three-dimensional models that can recreate, with the implementation of data, digital twins of the context taken into consideration, within which to hypothesize possible transformation scenarios through predictive analysis. The Digital Twin, for the definition of which survey and representation play a fundamental role, is constituted as an interactive digital container, within which is possible to pour a series of heterogeneous data fundamental to the management, conservation and monitoring of the urban context [12]. The city, after all, is a complex system in which a great deal

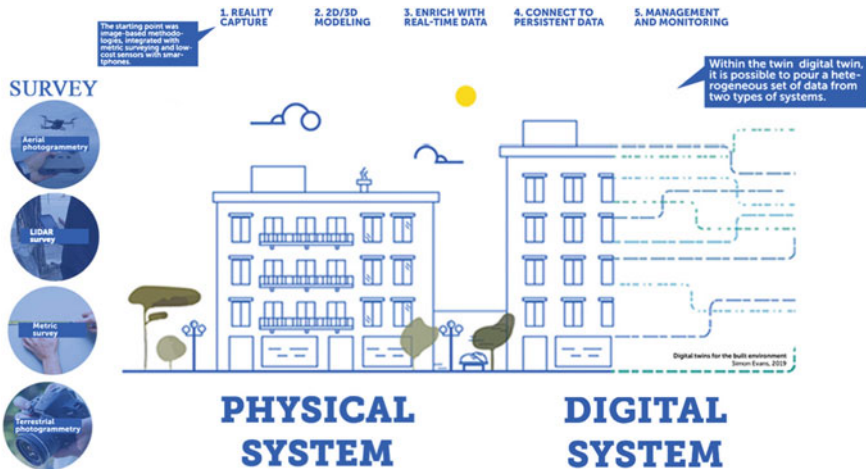


Fig. 5 The technologies of 3D survey and the definition of digital twin. *Editing arch.* G. Santoro

of information and data is generated and used to determine its characteristics. In the examined case study, the data are the result of a mixed digital-physical system: the smartphone, considered as a low-cost sensor, acts as a data collection element linked to environmental (noise, tree species) and/or dimensional factors, also thanks to the development of increasingly performing integrated cameras; field surveys, on the other hand, serve to integrate data for which there is no specific instrumentation [13].

### 2.3 *Public Space*

The assessment of the public space fits within this framework. Public space plays a fundamental role within the city. During the 2020 lockdowns, forced indoors, we realized how important it was, coming to find alternative solutions to replace it and when it was finally possible to go out, the decision to go out or stay at home was strongly influenced by how the city is designed, due to social distancing restrictions. The pandemic has presented itself as an opportunity: an opportunity resulting from the need to rethink the spaces that we collectively live in every day, based on real data [14]. How can we experience these spaces and respect such restrictions if cities are not designed for the purpose? The theme of public space rests on very solid theoretical foundations. Only in recent years, innovative methods started to develop in the urban environment and the city dwellers have started to become the protagonists within the urban public space. An approach that focuses on the search for a relationship between the environment and the human perception of spaces is the one supported by the theories of Reijndorp and Hajer in the book in search of the new public domain. Based on an analysis of the cultural structure of the city, the authors believe that the value of the public domain is conditioned by the intensity, diversity, overlapping and the interaction between uses and users. But an impactful role in this research was given by two personalities: first Jane Jacobs and later Jan Gehl, who concentrated their studies on improving public life, reorienting the design of cities towards a more humane scale and rejecting the policies undertaken until that moment.

In *The Death and Life of Great American Cities*, Jane Jacobs details the quality of urban life and the liveliness of the city, highlighting the limits of modernist planning, regarding the separation of the uses of the city and the emphasis on the individuality of buildings, which would put an end to urban space and life in the city, making it lifeless and deprived of people. Jane Jacobs' observations, activism and writings have had a significant impact on generations of architects, planners, politicians and activists. Jacobs saw cities as an integrated system with its own logic and dynamics, capable of changing over time according to the way it is used, promoting higher density in cities, smaller city blocks, small businesses and mixed uses [15]. Jan Gehl fits into the tracks traced by Jane Jacobs and the two would often confront each other in the years to come. Graduated in 1960, he undertook a change of pace in his profession when he married a psychologist and became interested in the borderland between architecture and the social sciences, in what people did in public spaces and how the shape of



**Fig. 6** Architect Jan Gehl and the 12 criteria of Public Space. *Editing arch. G. Santoro*

those spaces influenced the life of the people who used them. For a short time in the 1960s he moved to Italy to study its squares: how they worked, why they worked, what worked, which didn't. These early studies converged in the book *Life Between Buildings* and in the development of 12 criteria for defining quality public space. These criteria are a tool for understanding how public spaces are experienced by their users. They are used to evaluate whether the different characteristics of a public space are protective, comfortable and pleasant for the people who spend time there. The thinking behind these three categories is as follows: (1) without basic protection from cars, noise, rain, and wind, people will generally avoid spending time in a space; (2) without features that make walking, using a wheelchair, standing, sitting, seeing and conversing comfortable, a place will not invite people to stay; (3) large public spaces tend to offer positive aesthetic and sensory experiences, take advantage of the local climate and provide human-scale elements so that visitors do not feel lost in their surroundings [16]. The approach for using this tool, and others developed by Gehl and used in the analysis phase, is based on the observation and perception of spaces (Fig. 6).

### 3 Survey

#### 3.1 Case Study

The application of this process had to be done, obviously, on a case study. The decision to use a specific site within a district of our hometown (Salerno, Italy), was not dictated by a simple obligation due to travel restrictions: the city is known for being “mountainously marine”, as defined by the Salerno poet Alfonso Gatto, squeezed between the mountain and the sea with a population density far higher than the already high one of the region in which it is located. A context with such a high population density was an indispensable prerequisite to be sure of finding the right mix of characteristics in a few square meters of space.

From the choice of the city we moved on to a neighborhood scale. Usually, this type of analysis can be carried out on a larger scale (neighborhood), medium (a block) or small (a public place). The choice fell on the latter scale as it allows us to understand how the space works and is used. Once in the public space, are people invited by the street furniture, landscaping and planning to stay and enjoy it? A robust set of tools that measure public life and public space can help answer these questions and enable urban planners and decision-makers to set higher standards for public life. Thanks to the use of data from social network locations, we were able to identify the most popular public spaces. This was possible by searching a series of squares and extracting the number of user registrations, for an indefinite period of time. This led to selecting, among the various neighborhoods, Pastena as a case study. The choice was also confirmed by a qualitative observation born from a spontaneous planning during the 1900s, at present it seems to express the concept of liveliness better than other areas, a term that can be considered a sort of benchmark of evaluation which includes all the characteristics that qualify the public space. In particular, in Piazza Caduti Civili di Brescia, the place with the highest number of location registrations on social media, there are elements—such as the diversity and mix of activities and the presence of pedestrian and vehicular traffic—useful for making multiple assessments (Fig. 7).



Fig. 7 The focus on the *Piazza Caduti di Brescia* in Salerno. Editing arch. G. Santoro

### 3.2 Survey Process

Once the location of the case study was determined, an indirect survey campaign was conducted with a terrestrial and aerial photogrammetric approach using a Nikon D3100 digital camera and a DJI Mini 2 drone.

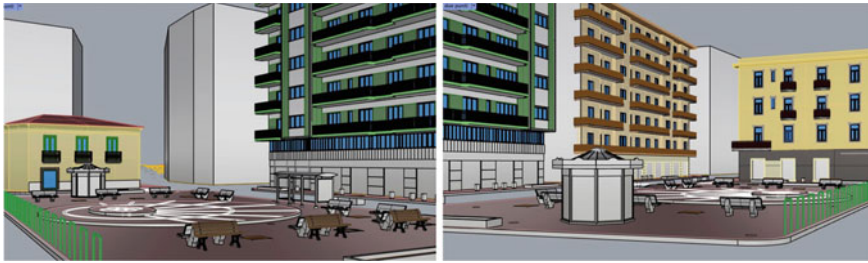
During the shooting phases, 1111 frames were recorded, in which it was guaranteed an image overlap of approximately 60%. In relation to the conformation of the spaces, it was decided to set the focal length to 24 mm with shooting with parallel axes. The acquisition of the spaces of the square, on the other hand, was carried out through a video taken with a drone, from which the frames were extracted using the 3DF Zephyr application. Subsequently, the processing of the images was carried out with the Agisoft—Metashape structure from motion application where medium quality parameters were set in all phases of the work. After the alignment phases, the dense cloud of 93,807,336 points was extracted. With the recognition of homologous points, it was possible to obtain, with dense image matching algorithms, the textured polygonal model, consisting of a triangular mesh of 6,699,696 faces. Finally, the orthophoto used for the critical interpretation phases was elaborated from the texturized model. From the orthophotos was then extracted the elevations of the buildings (Fig. 8).

From the export of the polygonal model, better known as a mesh, the three-dimensional modeling process began which was performed directly in the 3D CAD environment, and specifically in the Rhinoceros software, exploiting the use of NURBS modeling (Non-Uniform Rational B -splines).

The street furniture was also analyzed and was carried out with the support of a classic photogrammetric process, compared with a survey with LiDAR technology, using an iPhone 12 PRO which integrated this type of sensor. LiDAR—(acronym for



Fig. 8 The survey techniques used. *Editing arch.* G. Santoro



**Fig. 9** The reconstruction of 3D model with rhinoceros. *Editing arch.* G. Santoro

Light Detection and Ranging or Laser Imaging Detection and Ranging) is a remote sensing technique that allows to determine the distance of an object or a surface using a laser pulse—it has been used for years in the field of survey but through large machinery (Fig. 9).

The introduction of a version of reduced dimensions, in a device possibly within everyone’s reach, opens the door to a greater use of this instrument in the field of surveying. The two extrapolated point clouds were compared using the CloudCompare application to understand the actual accuracy of the data. Once the clouds were aligned using the ALIGN command—using the homologous points of the objects (in this case the markers) it was possible to calculate the distances between them.

This made it possible to understand that the maximum distance between the two clouds, in most of the model, is less than a centimeter. Decisive factor to positively evaluate the accuracy of the LiDAR sensor in the field of urban and architectural survey Both the urban context and the furniture elements, thereby, have been digitally rebuild—both as 2D and 3D outputs—to analyse them and start the interpretation phase.

### 3.3 Interpretation

The 12 quality criteria for public space elaborated by Jan Gehl have made it possible to define a framework in which to move for the collection and interpretation of data useful for understanding the space. In particular, proceeded to an analysis of the elements that contribute to the definition of the public space: the facades of the buildings—to be considered as a scenography of the public space—with qualitative analyses and the square and surrounding sidewalks with both qualitative and quantitative analyses.

These analyses determined outputs that are both objective and subjective, but which together can contribute to the definition of the characteristics of the space. By definition, a square is an enclosed place. The buildings that surround it help to define its characteristics and the perception by those who live around it. For this reason, all the characteristics that define them contribute to making public space a pleasant place.

The study of materials and colors plays a fundamental role in this understanding, having a strong psychological impact. It is also a question of scale; the study of heights makes it possible to highlight the scale characteristics of the buildings and their relationship with the surrounding space. According to Gehl's research, contact between the building and the streets is possible below five floors (or 13.5 m), beyond this limit, contact with the urban space is quickly lost. This comes from the way human vision develops, which allows us to see primarily horizontally, with limited upward and downward angles. Low-rise buildings, therefore, conform to the human sensory apparatus unlike tall buildings. Our horizontal field of vision indicates that when we stand along the facades of buildings, only the ground floors can offer us interest and intensity. If the ground floors are full of variations and details, our walks in the city will be full of experiences. In a good urban neighborhood, the ground floors of buildings work symbiotically with the surrounding sidewalks and public spaces. Together they provide a continuous network of active, safe, comfortable and engaging paths and experiences, creating a sort of funnel between the private sphere (the apartments) and the public sphere (the square and the sidewalks). It is no coincidence that Gehl defines different types of ground floor, evaluated based on their qualities and the experiences they can offer. The ground floors surrounding Piazza Caduti Civili di Brescia, although characterized by small businesses and largely with high visual permeability between inside and outside—and therefore comparable to lively ground floors—could fall into the monotonous category due to the presence of repetitive commercial activities which contribute little to the quality of the public space. In terms of materials, the square is characterized by porphyry and gneiss bolognini, materials not of local origin but imported from Northern Italy (Fig. 10).

The concept of the visual field also applies to the square space; In *City for People*, Jan Gehl describes the field of social vision by inscribing it within a radius of 100 m. This distance allows observers to stand in a corner and have a general view of what is happening in the square and, approaching 60–70 m, to recognize the faces of the people who frequent it. This relationship is reflected in the size of most of the old squares of European cities which rarely exceed a width of 100 m and an overall size of 10,000 m<sup>2</sup>. A close look at the invitations to participate in public life reveals a relationship between public life and public space. If there's no place to sit, people will not sit down. If there is no tree canopy to manage high temperatures or create visuals of interest, walking will be less pleasant and therefore less prevalent. Without inclusive programming, some people will never find a reason to spend time in the public space. This data layer helps uncover the relationships between the built environment and a place's ability to foster social mixing.

The tools developed by Gehl over the last 50 years make it possible to understand and analyse the behaviour of people in public spaces. These observational analyses help to understand if spaces work, what doesn't work and what could work better, defining an essential basis for any future projects that could take this data into account to design public spaces of quality. The analyses were carried out after choosing an observation point from which to write down all the necessary data, during a weekday and a holiday in the time slot between 8 in the morning and 18 in the evening, with observation times lasting 20 min. The cross-use of the tools developed by Gehl



Fig. 10. 2D representation with metric, material and colorimetric data. *Editing arch.* G. Santoro

People Moving Count, Stationary Activity Mapping and Gender + Age Tally has made it possible to collect a varied number of data relating to the type of user and their reasons for using the places, highlighting how the square is a place frequented mainly by elderly people who spend long periods of time socializing.

This socialization is more frequent when the seatings are placed in such a way as to favour conversation. It is no coincidence that the architect Ralph Erskine spoke of Talkscape, a systematic way of conceiving the conversation space, introducing in all his projects two corner benches with a small table in front, so that people could both talk and use the table. These observations were enriched with environmental analyses in relation to the noise level of the places and the presence of urban green areas. Trees generate shade and contribute to creating a pleasant microclimate, but the choice of the correct types can bring even more benefits: greater biodiversity, barrier from vehicular traffic, less maintenance; In the case study of Piazza Caduti Civili di Brescia, the prevalent presence of Mediterranean pines certainly contributes to create pleasant, shaded areas, but this specie cannot be considered suitable for an urban context due to its invasive root system. Furthermore, since it is a tall tree, it cannot offer the benefit of acting as a filter—both visual and aerial—between the public space and the driveway. Noise, in fact, is another factor of vital importance.

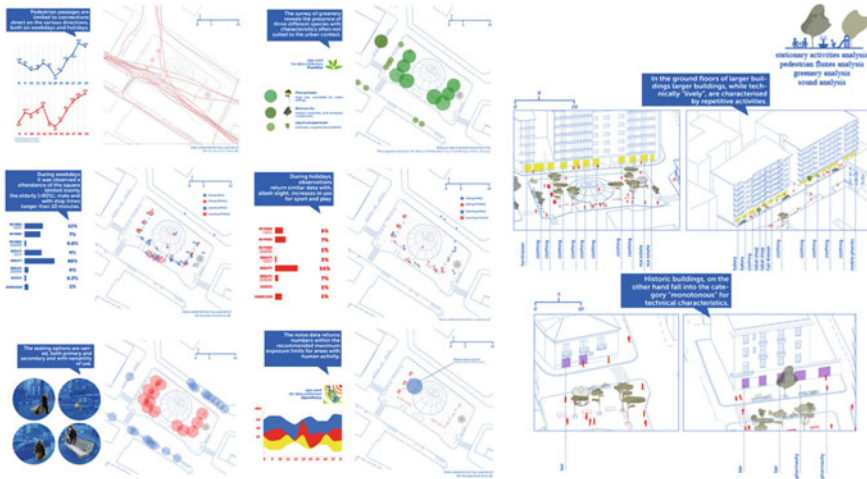


Fig. 11 Qualitative analysis. *Editing arch.* G. Santoro

According to Gehl, the cities where it is simple and pleasant to meet are those which offer good opportunities to hear, see and speak. These are fundamental aspects for human relationships but often the high noise levels due to car traffic and the high concentration of people and activities make them difficult. According to studies, the optimal background noise level should not exceed 60 dB; with levels equal to or lower than this it is possible to have a conversation between individuals while maintaining a distance that does not violate the personal space of others. In the case study, the noise levels recorded can be considered normal, with less than a few isolated peaks. These analyses helped to draw some conclusions: the square is mainly seen as a place of passage, the square lacks attractive elements that favor a greater variety of users (by gender and age) and the lack of continuity with the surrounding pedestrian areas reduces the perception of safety for the little ones. These conclusions could, ideally, be a starting point for a redesign of the space in order to meet quality criteria in the future (Fig. 11).

### 4 Simulation

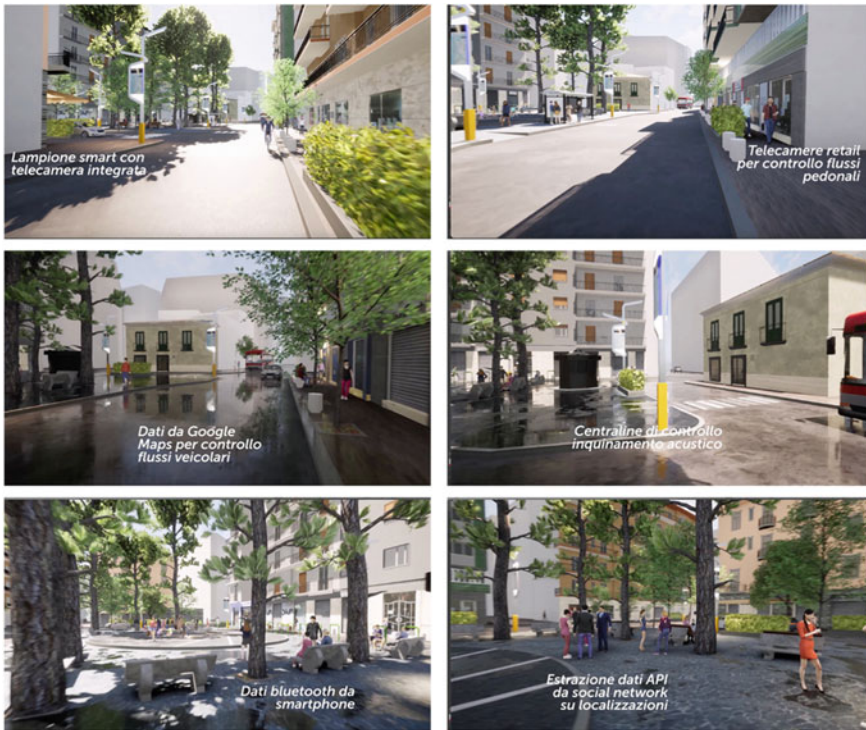
The last phase of the work consisted of the simulation phase in which the data collected through field surveys became the starting point for the embryonic development of the digital twin. Although at this stage it has already been possible to draw some conclusions based on the observed data deriving from the physical system (which would allow the introduction of redevelopment interventions of public space), the implementation of an advanced sensor system would allow to have a much richer and more reliable pool of information and data to be merged into a database to support

the decision-making process. To evaluate the potential of this system, a scenario of the current Piazza Caduti in Brescia in the year 2030 was simulated with the help of the TwinMotion application. Inside the scene, a series of above-ground sensors were virtually installed: audio control units, solar panels, cameras, thermal imaging cameras, data streams from mobile phones, satellite data, etc. that would monitor the physical changes of the case under consideration with a new level of knowledge of the problems related to urban space. The simulated model is nothing more than a predictive model, according to which surveying and Artificial Intelligence take on a key role. In this field of investigation, Machine Learning and Data Mining techniques applied to three-dimensional mappings allow to obtain data on traffic, air quality, neighborhood as well as possible scenarios to be adopted at an architectural and urban level. For example, the analysis of cameras or thermal imaging cameras would make it possible to monitor the movement of pedestrians and passing vehicles as well as to detect the use of public space by different stakeholders at different times of the day. As the performance of these sensors improves, so does our understanding of environments. In fact, in recent times, the technological evolution that has been achieved in the field of the Internet of Things has made possible the integration of reality-based and AI technologies. The relationship that is established between these two realities opens up new operational scenarios, supporting architects, designers and planners to design responsive urban environments [17] (Fig. 12).

However, there are various gaps against which it is necessary to codify a methodological process of investigation aimed, on the one hand, at the continuous acquisition of heterogeneous data obtained from sensors useful for training AI algorithms, on the other, at the management and systematization of information, through the structuring of a database for storage and prediction of phenomena in progress.

## 5 Conclusions

The virtual monitoring/management experience conducted for this contribution showed the results of survey methodology based on the analysis of urban space. In this context, the dynamics of the management and design of these spaces were addressed, starting from the three-dimensional survey, the digitization processes, and the integration of the various information. The possible benefits of this operational workflow today concern multiple fields of investigation such as maintenance, restoration, urban regeneration, and this is a great strength. Starting from this assumption, the course of study was articulated along two lines: from qualitative and quantitative analysis derived from the survey to the simulation of heterogeneous data. The goal was to prefigure a sensor that uses low-cost sensors and AI to structure a forecast model.



**Fig. 12** Simulation of 3D data and definition of sensor. *Editing arch. G. Santoro*

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