Digital Intelligences and Urban InfoSystems in Territorial Re-Education

Chapter 69
Digital Intelligences and Urban InfoSystems in Territorial Re-Education

Raffaella De Marco
https://orcid.org/0000-0002-4857-3196
University of Pavia, Italy

Maurizio Marco Bocconcino
Polytechnic University of Turin, Italy

ABSTRACT

The relationship between education and urban environments identifies a process of societal impact through levels of exploration and knowledge of the territorial system. It emerges from pedagogical levels linked to the development of spatial knowledge as "vision" and "motricity," finalising education on the use and management of territory and urban space in classes of knowledge. In parallel, the increasing adoption of digital technologies has extended the contamination of digital twins to the existing instruments for territorial management, such as geographic information systems. Their features of representation have increased, and the resulting systems can focus on the opportunity to use virtual territories (cities and landscapes in digital form) as both objects and spaces of education. The chapter focuses on "territorial education" to highlight the potentialities of urban infosystems from advancements in digitisation practices, and their interaction with artificial intelligence to support the educational function of digital urban spaces in experience-based and situated learnings.

INTRODUCTION

The city constitutes a source of education when it recognises its learning tasks and directs its environmental principles towards the full enjoyment of the rights of life and growth of citizens, from every age. The reflection on the relationship between the city and education has today focused mainly on how the city can be at the same time an 'object' and a 'space' to convey learnings. This concept often takes the definition of 'territorial education' (Champollion, 1987).

At the same time, the scientific literature (psychological, sociological, urban planning) provides the image of a city that is increasingly inadequate to meet the needs of its citizens. The logic of specialisa-

DOI: 10.4018/978-1-6684-7366-5.ch069

tion of functions has ended up fragmenting the city into separate components and hierarchies, making it lose its original nature as a place for meeting and social exchange, and thereby weakening its ability to provide educational measures. The landscape of contemporary cities is changing in its dimension of a 'system' of 'systems', in which the multiple social sectors and active practices of citizenship are spatially fragmented even if intertwined with technological apparatuses guided by Artificial Intelligence (AI), with the aim of achieving a collective benefit for human and non-human components (Yigitcanlar et al., 2020).

In relation to the recent pandemic crisis, over more than two years physical distancing has affected the development of spatial interactions and skills in the use of urban space, especially by the younger generations. Restrictions on experience, perception and movement in city places have conditioned the development of 'cognitive mapping' and training skills related to the experience of the city, its signals and the behaviours it conveys. The development of degrees of exploration and knowledge of the territory in the stages from childhood to adolescence (Trisciuzzi et al., 1993) was abruptly interrupted by the pandemic. This thread needs to be re-knotted, also considering AI opportunities for learning mechanisms to facilitate relations between people, digital instancies and the same real world. It stimulates a renewed educational purpose, not exhaustively conducted with remote teaching methods, which can include the experience analysis of on-site sensorial data and establish an 'intelligent' learning challenge through AI simulations.

In this unprecedented scenario of COVID emergency, as highlighted in the technical report of the Italian Minister of Youth (Presidency of the Council of Ministers Italian, 2021), young people had serious consequences on their psycho-physical well being, penalised by the physical distance from urban space, precisely in that age stage of learning and orientation. The processes of developing cognition in the context of open physical space and sociality have been drastically interrupted, and for long periods they have lost contact with the city as an object of education. According to the UNICEF report (2021), children and young people could feel the impact of the pandemic on their mental health and well-being for many years to come: "*today more than ever, studying young people and the complex of phenomena affecting them is crucial: young people are in fact real agents of transition, catalysts for changes in consumption and lifestyles*" (UNICEF, 2021). Thereby, their impact involves also their parents and grandparents, and therefore the rest of the future population considering the impact of their growth and action as citizens.

The National Observatory for Childhood and Adolescence, set up in April 2020 by the Italian Ministry for Youth Policy, has approved intervention strategies for future education policies on childhood and adolescence, paying close attention to the causes of youth discomfort, including psychological ones (Lewin, 1936), and to the pandemic consequences. The debate pointed out that "*schools, which are historically burdened by critical points, including those of an infrastructural nature, are not in a position to fulfil, on their own, their role as the only educational and social agency in the area, arguing the need to promote actions capable of interweaving the plan of social policies*" (Presidency of the Council of Ministers, 2021).

With respect to the role of cities in this context of education, in 1991 the Italian Institute of Cognitive Science and Technology of the National Research Council (CNR) has already set up a research group to support and coordinate cities' impact on citizens' learning development. This gave rise to the International Laboratory 'The City of Children' for the recognition of children as citizens (not only future citizens). Among the tools that attempt to respond to the emergence of this issue, the Community Educational Pacts (Mulè, 2022) are specific agreements between the School Institutions and local education and training providers, as urban laboratories can be, with the aim of enriching the educational offer of the schools. Considering the first response to the lockdown in spring 2020 within Distance Learning (DAD), from

September 2020 educational actors moved on to the concept of Integrated Digital Learning (DID). Now these methodologies are finally seeing a return to 'proximity learning'.

From these premises, the educational function of the city identifies a process of societal impact, adopting levels of exploration and knowledge of the territorial system to affect the structuring of information and knowledge, in relation to spatial and cognitive components (Bernstein, 2009).

It emerges, from the pedagogical levels, the link to the development of spatial knowledge as both 'motricity' and 'perceptual map', finalising the education in the learning transition from 'sensory perception' (abstract) to 'formal thinking' (physical). It consolidates into classes of knowledge (social, green, recreational, cultural, artistic, relational) about the use and management of the territory and urban space (Nuzzaci, 2018). This exploratory activity can be intended at the same time as 'cognitive' (developing mental 'maps' of spaces and paths) and 'interpretive' (understanding the relationship between space, perception, and affective-relational impacts) (Nuzzaci, 2019).

Primarily, this concept involves the structuring of information and knowledge related to spatial and cognitive components of the urban system. In the present practices of documentation and analysis of urban assets, it is evident how the flow of information in cognitive cities has become multidirectional. In parallel, the increasing adoption of digital technologies has extended the contamination of complex 'Digital Twins' to the existing instruments for territorial management, such as in the development of advanced Geographic Information Systems (GIS) (Bocconcino, 2022). Their features of visual representation have been increased in relation to the conveying of multi-source and multi-scale information. The resulting systems can focus on Virtual Territories (cities and landscapes in digital form) as both 'objects' and 'spaces' for educational purposes (Schaeben, 2017; Brusaporci et al., 2020).

The implementation of 3D representation for territorial systems can further be related to the mapping of visual perception and semantic relations, from the first on-site contact to the reproduction of the experience of physical space in a digital dimension of learning involvement (Berta et al., 2016). In this way, a system of documentation can store and compare different phases of perception of the urban assets. It learns and adapts the flow of data by introducing the human factor in terms of cognitive, affective-relational and social components relating with cities. Thus, analysis and decisions can be advanced, such as based on an AI contribution, to the emotional data background (Li et al., 2016).

In this context, a new and important role is played by AI-tools applied to cartographic services (Bocconcino, 2023), through which data can be collected, selected and analysed, in order to gather useful information about the behaviour of users regarding the experience of city places (Silberman & Purser, 2012). Consequently, visual data in particular can be able to infer new levels of knowledge and trigger the acquisition of social perception skills (Ibrahim et al., 2020). From this experience, it is possible to proceed with methodologically structured and technologically integrated educational protocols. They support, on the one hand, to rationalise the educational process, applying the laws derived from scientific research in representation disciplines, and on the other hand, to emotionally and socially solicit public learning recipients.

The chapter will focus on the topic of 'territorial education' through the potentialities of Urban InfoSystems from the opportunities of advancement in digitization practices and virtual environments. It deals with the interaction between Digital Twins, as 2D/3D models, and AI-based tools to support the educational function of digital urban spaces in experience-based and situated learning. The aim is to respond to a reality-based educational and training perspective for citizenship. It aims to provide an opportunity for the development of urban Digital Twins supported by AI contribution to re-establish contact with the territory and space in social contexts. It is also considered in order to reformulate a city perspective in which the city itself can reaffirm as a place of learning and application of cultural paradigms representing cooperation between people, environments and technology.

The chapter highlights the opportunities of visual and survey data in the processing of AI tools linked to Geographic Information Systems for the representation of the urban context, its qualitative perception and documentation data. It provides theoretical critiques on the learning impact that these research opportunities can contribute to.

The scientific objectives pursued by the research are meant to:

- Contextualise the role of Vision and Movement in guiding the perception of components of visual 'attraction' located in the physical space, also monitoring cognitive reactions to physical scenes and citizens' responses in relation to the learning contents;
- Identify components of visual attraction in the public space (physical signs and shapes) related to cognitive and behavioural human factors, foreseeing the application of users' sensor tracking;
- Educate on bottom-up and top-down behavioural mechanisms of user's cognition on the visual space/urban scene;
- Integrate Urban InfoSystems with learning applications on the identification and solving of societal scenarios, acting virtually on the visual features that influence cognitive and behavioural mechanisms in the public space.

Solutions and future research directions will be discussed regarding data representations and AI-based analytics. They will call for educational learning paths on the topic of the city and the territory, to develop citizenship behaviour, cultural analysis and territorial sustainability. In particular, the topic of advanced Urban InfoSystems will be aimed to systematise visualising tools and analysis methods related to the correlation and use of quantitative data produced by urban environments (Clifton et al., 2008). Opportunities for the development of Urban Learning Analytics through interactive 3D virtual-learning environments will be addressed, to convey education on mechanical behaviours and sustainable practices through interaction with urban Digital Twins. In this way, the application of sensors (e.g., eye and human tracking) and the mapping of data flows (e.g., socials, apps) will be introduced to monitor the cognitive perceptions of target users in public spaces (Duarte & Ratti, 2019). Impacts are considered also for applying participatory public design to the regeneration of urban spaces, and pursuing the debate in national and European education through AI tools, encouraging soft skills for new attitudes and critical thinking sensibility on the city's design.

BACKGROUND

The chapter deals with a review of the state of the art related to the educational support of Urban InfoSystems, in the face of both the evolution of digital data and products, and their susceptibility to increasingly widespread critical and revelatory re-processing by means of AI. In this sense, the state of the art is declined on the connections that can be made explicit between 'Training' and 'Knowledge-based Intelligent Systems' toward an integration through the 'Support of AI'.

Through such cohesion, a significant framework of understanding of the reciprocal influences and possible communication channels for learning products, with respect to the required impacts on users, is addressed.

The contribution made by AI is introduced as a component of widespread reinforcement among these practices, and it is declined with respect to databases and information models, and their knowledge-based structure, in particular with a specific declination to artificial learning with respect to the expression of cognitive and perception mechanisms specific to human observation sensitivity (Heidi, 2018).

All the sections presented help to define the central concept of 'Urban Learning Analytics', understood as a discovery and communication process of significant patterns that can be found in urban data, to be empowered by AI-based tools for the development of learning workflows through Urban InfoSystems and Virtual Territories. These types of data processing are meant to continuously assess the potential of innovative solutions in the visual interpretation and correspondence of urban assets for educational and social impacts on citizens.

Training

The 'Training' section is addressed through the relevant argumentations on:

- Perception and qualification of urban assets to relate with users' education and involvement;
- Pedagogics in territorial education for social sustainability.

An urban space, as an environment of high perceptive quality, contributes to the social and psychological health of the people and communities (Mehta, 2013, p. 56), impacting on the quality of life. The urban form, in particular, originates from the reading and interpretation of historical structuring as a consequence of a process of mutation and planning in the architectural, geo-political, and social context (Cavallari Murat, 1968). Thus, the evaluation of people's emotional responses living in urban spaces represents a relevant step for actions of urban planning and regeneration of cities. Introducing an integrated support based on InfoSystems at the urban scale and techniques for tracking behaviours, habits, and participation in social life helps to critically assess the educational relationship between public space and people's behavioural responses (Han et al., 2022, Shuyan et. al, 2022). Urban design, as well, deals with the elements that can contribute to qualifying public space, such as building facades, parks, recreation spaces and public infrastructures. In a social perspective, it also declines as a concept of participative design. Tt is worth mentioning Gordon Cullen (Cullen, 1961), Kevin Lynch (Linch, 1960), Giancarlo De Carlo (De Carlo, 2019). Cullen addressed the themes of the urban vision, setting a peculiar aspect that involves and impresses the observer. The themes of sight and planning as an artistic form were developed in the book 'Townscape' (1961) and later in 'The Urban Landscape. Morphology and planning' (Cullen, 1976). Lynch focused his research activity on the study of people's perception of the urban landscape. His scientific contributions, as well as representing a turning point for urban theory, range in a wide conceptual field, from environmental psychology to the geography of perception. Lynch's most famous book, 'The image of the city' (1960) is the result of an investigation into the way city visitors perceive urban space and organize spatial information during their experiences. Finally, De Carlo was among the first to experiment and apply the direct participation of users in the design process in architecture (De Carlo, 2015).

The state of the art of research on the human perception of the built environment is based both on questionnaires and field observations of people interacting with the environment, and on the use of more frontier methods. These second ones are suggested to investigate the relationship between spatial characteristics and human senses, through tools that collect and process relevant data, including various sensors and social media. The aim is to investigate what types of places people find most comfortable (Girardin et al., 2009). Social sciences have introduced quantitative parameters and indicators, often labelled as computational social science (Lazer et al., 2009), related to environmental perception, feeling, emotion, social connection, previously limited to qualitative modes of investigation (Moretti 2016). In particular, the emerging network science that studies complex networks has made a significant contribution to field research (Borner et al., 2007). 'Network science' takes an exclusively spatial perspective on urban data, focusing on the relationships and interactions between people, places, institutions, at different scales of reading. Manuel Castells (1996) introduced in urban studies the concept that by abstracting cities as social spatial networks of interaction, network science helps to unravel common structural elements shared by most urban systems, allowing to set up cognitive and predictive models of development (Batty, 2013). In this way, infrastructuring the urban tissue with sensor networks has opened up to real-time representations of the state and condition of places. The growth of social media is leading to new forms of participation and activism, alongside the traditional forms of participation in the city's project. Thus, citizens voluntarily play monitoring and reporting roles, a phenomenon that has been defined as the increase of the 'expert amateur' (Kuznetsov & Paulos, 2010).

It emerges how the science of sensing, both as a visual and flux approach, can be structured to direct the purposes of Learning Analytics on the urban assets. It means to collect, analyse and translate data from urban experience, defining dynamic maps that can better support urban educational tools (Batty, 2005). In this way, it can be aimed at representing new scenarios - real and virtual - available to the actors involved in the cognitive processes of urban education of modern cities, reliably analysed through the perception of their inhabitants.

Pedagogy's reflection on the relationship between education and living environments is very ancient and, as far as the relationship between city space and the formation of individuals is concerned, can be traced back to Plato's Republic. Between antiquity and the modern age, for example, there have been many authors who have reflected on how the social environment of the city can be 'educational' or 'non educational' for the proper growth of young people.

In the 20th century, reflection on the relationship between the city and education has mainly focused on how the city can constitute an object and space of education. This is a pedagogical tradition ranging from Jan Amos Comenius to Friedrich Wilhelm Fröbel, from Henry David Thoreau to John Dewey and Maria

Montessori. It was in fact found that the vast majority of children and adolescents, in the advanced West as well as in developing countries, live in urban environments. This focus often takes the form of 'territory and social education' (Duhun, 2012).

Territory education stems from the realisation that development between childhood and adolescence also corresponds to the need to explore the reality in which one's place of life is included. It gradually broadens one's search beyond what are the spaces (such as the neighbourhood or the city) immediately pertinent to the area of residence (Løvlie, 2007). This exploratory activity is at the same time 'cognitive' (to construct mental 'maps' of spaces and paths) and 'interpretive' (y to better understand the relationship between surroundings, needs and states of mind). In the same way, it also concerns 'affective-relational' and 'perceptive' definitions..

In the pedagogical field, the relationship between education and urban environments identifies a process of training between the person and the environment that can be constructed through levels of exploration and knowledge, which develop in parallel with child growth (Trisciuzzi et al., 1993). From the first level, in childhood, linked to the development of knowledge as 'motricity' and 'perceptual map', to the fifth level, in pre-adolescence, which finalises the educational process in the transition between sensory perception, abstract and formal thinking (Ware, 2000) about the use and management of the territory and urban space.

The idea of addressing pedagogic practices on territorial education through the theme of InfoSystems for the city (exploring also the interaction between AI-based learning systems and urban models) supports the educational function of the city (Paciroli et al., 2020). It means to offer interpretative pedagogical tools of the city and adaptive solutions to meet the needs of users. These needs are considered from the co-creation of innovative educational and training tools related to experience-based learning, situated learning, the use of service-learning approaches, citizen science, participatory action research, and conflict mediation (Jenkins, 2008).

Considering the vision of "*giving the city back to the citizens*" (International Association of Educating Cities, 2020), many projects are currently spreading to develop "*educational cities, as cities that assume an intentionality and a responsibility about the education, promotion and development of all their inhabitants, starting with children and youth*" (Lerner & Silbereisen, 2007; UNESCO Institute for Lifelong Learning, 2021). In this perspective, it emerges the importance of acquiring specific skills that help young citizens to think and live as citizens, advocating for a more democratic society and an 'urban citizenship'. It means in preparing them to act as agents of change rather than mere observers of the change (Power et al., 2023). It requires the use of relevant and increasingly technologies to strengthen the individual's awareness of urban space, enable closer collaboration between groups, communities and institutions, and change the way people build 'civic spaces' (Adjapong & Emdin, 2015).

Urban spaces can rightly be transformed into decentralised smart classrooms on the ground (Saini & Goel, 2019), in which formal, non formal and informal contexts are combined with environmental and cultural resources in a lifelong learning perspective. It also makes use of 'situated' methodological approaches and always takes into account the contextual constraints currently acting on, in and around social and cultural networks. Thus, educational innovation and learning in urban and public space is developing towards structured strategies of sustainability between social approaches and environmental needs, also addressing digital languages and tools. In this perspective, concepts and methods are meant to identify challenges, gather information, generate potential solutions, refine ideas and test solutions, in an effort to strengthen the relationship between personal, individual, collective and institutional heritages with a view to participation and social cohesion.

This process is meant to involve five stages (Nuzzaci, 2017): discovery, interpretation, ideation, experimentation and evolution, involving the use of tools to enable citizens to support social processes and participatory urban design, combining formal and non-formal, virtual and object-based contexts.

Knowledge-Based Intelligent Systems

The topic on territorial education in a digital learning perspective assumes a founding reflection on interdisciplinary technologies to support the implementation of urban skills centred around elements of territorial 'permanence'.

Interdisciplinarity identifies an aggregation of the interactions that can occur between different areas of expertise regarding Urban Analytics. In this vein (Abbott, 2001) it constitutes a real opportunity to address 'urgent issues' and 'urban emergencies'. Coming to the training and educational processes (Nickerson & Zodhiates, 1988), technological innovations (in computers, tech-devices and their software) are integrated with increasing speed and pervasiveness.

The efficiency of computer-based technologies used in education is relatively low compared to the different facilities provided by modern integrated classroom and distance learning equipment. The reason is that only methods and instructions for computer-based learning are developed, but their modalities of knowledge and interpretation of learning contents for users are not investigated so far. That is why it is so urgent to implement a technological approach to learning and, above all, a learning approach that goes in the direction of the models developed around research focused on the processes of personalization and individualization (Chen, 2020).

Urban spaces can rightly be transformed into decentralised smart classrooms on the ground in which formal, non formal and informal contexts are combined with environmental and cultural resources in a lifelong learning perspective. They can also make use of 'situated' methodological approaches and always take into account the contextual constraints currently acting on, in and around social and cultural networks (Mitchell, 1996).

The topic of learning contents derived from the automatic or semi-automatic collection and survey of urban data requires a reflection on the synthesis knowledge-based models that such actions produce. It deals with different data sources, both for 'visualising' (e.g. point clouds, 3D models) and 'informing' (e.g. attributes) the urban systems and territorial apparatus (Lin et al., 2013; Brusaporci et al., 2019). It also includes the construction of an analytical method of validation of the quality of metadata and their actions of synthesis. More in general, it concerns the interaction between man, environment and data through the technological infrastructure of the Digital Twin, as Urban InfoSystem.

The themes of Big Data, Internet of Things and 'smart city' (Ofenhuber & Ratti, 2014; Dustdar et al., 2017; Allam & Dunny, 2019; Brusaporci, 2020) converge in a research challenge that aims to systematise these complex structures through visual interactive models. With regard to the possibility of expressing the 'city of tomorrow' (Ratti & Claudel, 2016), urban models bring the knowledge-based dimension into a 'virtual physicality' (Agugiaro et al., 2020).

The use of Virtual Reality (VR) has developed in quality and extension of services for perceptual immersion into simulated environments, where cognitive variables are connected (Jankowski & Hatchet, 2015). With VR, it is suggested a simulated 3D environment with exploring and interaction tools from a user perception, with an immersion in the virtual space that neglects the physical surroundings even stimulating the physical user's senses. At the same time, the platforms that host such environments are increasingly capable of interacting not only with geometric but also informational components associated with the elements (Parrinello & Picchio, 2017).

This is the direction of Augmented Reality (AR), where informational components are joined to the real-time perceptual experience of a 3D space. The purpose regards the overlap between physical and virtual perception features (with information applied to add or even mask the physical environment or a part of it), assuming at the same time an impact action towards the users, regarding decision-making purposes or entertainment goals.

The boundary between VR, AR and descriptive spatial InfoSystems (in particular, GIS and referenced geodatabases) is now increasingly blurred (Saygi et al., 2013; Vacca et al., 2018). Digital cartographic environments have developed in 3D urban components, with hybridised tools in Deep Learning, 3D parametric modelling and 3D Analyst components. This is based on the development of info-graphic possibilities enhanced by geo-referencing 3D data and information on complex spatial structures (Marr & Nishihara, 1978), in terms of density and geographical extension.

The components of InfoSystems, represented simultaneously by visual form and attributes, are enhanced precisely by the parallel parameterisation of geometries and the semantic relationships in their knowledge-based mechanism (Benner et al., 2005; Liu et al., 2006). This opens up to a field of ontological possibilities to the development of abacuses, not only at the level of 3D representation (Parrinello et al., 2020). It also considers the relation algorithms that can be established between the components to replicate in a Digital Twin a set of perceptual relations typical of the human cognitive component in the experience of urban space (Calvano et al., 2020).

In this way, the functions of InfoSystems maintain a suitable transfer of knowledge for the purposes of education and training (Psotka, 1995). Since the first overviews of intelligent tutoring and computer-based instruction (Nickerson & Zodhiates, 1988), this technology has broadly defined the ability of a user to perceive and interact with a real-world environment in a 3D simulation, expanding types of interaction and change of the virtual scene (Roussou, 2006). Educational research has shown an increased interest in VR technology because of its ability to simulate real-world conditions and perform effective user modelling (Katsionis & Virvou, 2008). Thus, its conjunction to GIS (El-Mekawi et al., 2012) for a potential in education and training activities (Geris & Özdener, 2020) is highlighted.

The application of VR to contexts of physical public spaces defines a unique tool to measure and influence the social responses to the territorial stimulus, as key elements affecting the sustainability of the physical environment (Maietti at al., 2020). The attempt to identify the characteristics of visual oppression in the spaces of the community through factor analysis can be performed within different levels of perception (Lee & Huh, 2020). In this way, InfoSystems combined with VR assets of interaction can adapt to re-educate an empowered sense of being and participation. This field highlights the need for a strengthened policy in the integration of digital knowledge in urban learning and analytics training, and the possibility to access digital resources and tools for interactive, dynamic and customizable analysis and representation.

Support of AI

Personalised education (Walkington, 2013) relates to the impact of relevant contexts on performance and learning outcomes (Aleven et al., 2017). In this way, the design of personalisation and individualization models is foreseen to combine with AI, from the analysis of the user's behaviours, developing an 'intelligent' educational environment.

The spread of digital learning environments involves a definition of the pedagogical dimensions of Learning Analytics (Johnson et al., 2016) in relation to the urban context of study. Considering the specific topic of territorial education, it needs to define and focus both urban education and critical connections expected from user training.

The application of AI-based tools in urban and spatial analysis today covers specific fields of research (Kamrowska-Załuska, 2021), two of which are relevant in the educational perspective.

The reflection on 'urban morphology and digital urban image' is central beyond the core of the history of architecture and art. It is recalled to involve settlement patterns, their stylistic and functional developments, urban mechanisms, and additional hierarchies related to urban apparatuses. In this field, architectural components, solids and voids, vegetation, infrastructure, up to the design-technological component and cultural expressive enrichment of the city are meant (Kucharczyk et al., 2020; Doria et al., 2021; Billi et al., 2023).

The reflection on 'behaviours of urban dwellers', in relation to the same hierarchical components of perception, is relevant in contributing to the teaching of individual perceptual and cognitive mechanisms in the urban space. It relates also to social conditions and spatial relations that can be the subject of participatory design from the community.

The conjunction of these two observations highlights the objective of urban sustainability (Rieder et al., 2023). Thus, the discussion is developed on the types of data to be trained from knowledge-based Urban InfoSystems through AI-based tools to support data analyst actions on significant components, otherwise set in manual mode (Doria, 2022).

With respect to types of data, the dualism between social sciences and documentation technologies is evident (Kandt & Batty, 2021). 'Sensors systems gathered data' for the 'tangible' physical urban component (e.g. LiDAR, UAVs) find association with 'users' generated content'. They assign relevance and 'sensible' variation to supporting physical components (e.g., perception of morphology, connectivity and accessibility between users, components' evidence, urban pattern). 'Historic data', linked to the urban object, its components or authors, is introduced in complementary and understanding terms to reveal significance to the specific spatial contexts of analysis (Croce et al., 2021).

With respect to AI-based tools, the objectives of spatial analysis and representation find correspondence in specific training of algorithms from reality-based data, instead of adopting abacuses to train the analyst networks (Casali et al., 2022). This condition fully expresses the complexities associated with the urban and territorial pattern, and its specific varieties of features that go beyond the typological classification of buildings, terrain and apparatuses. In the same way, it incorporates the many variations of perceptive associations and the critical learning responses (Azzam et al., 2020).

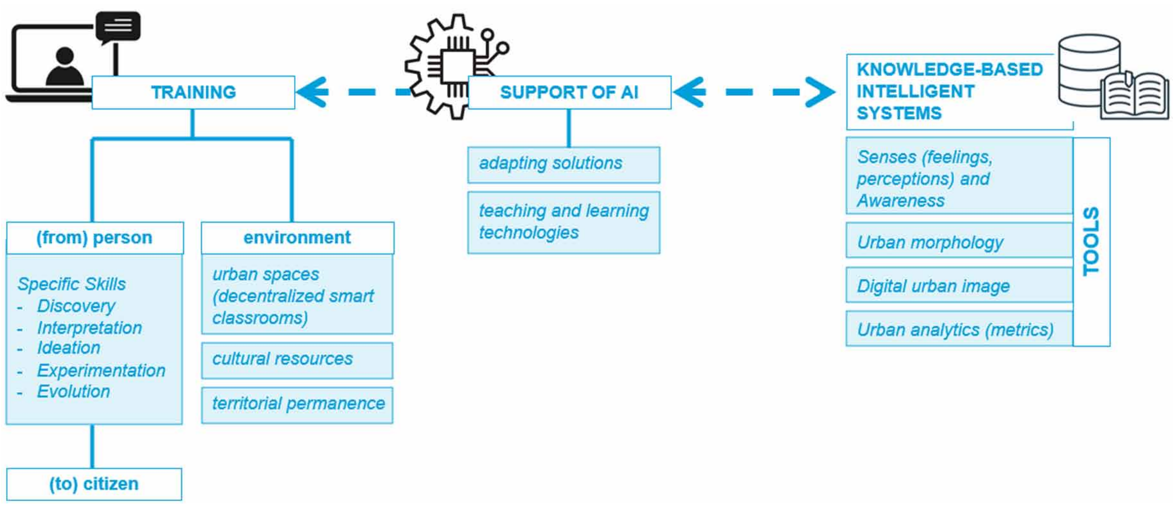
Machine Learning algorithms can improve their performance adaptively and proportionally to the development of Urban Learning Analytics and to the collection of data for their training, as the number of examples they learn from. In this sense, reference can be made to three main learning models, suitable for urban datasets and urban-related data for territorial education, according to which algorithms can be classified (Hoi et al., 2014):

- 'Supervised learning' by means of input and output examples with the objective of allowing the machine to identify a general rule that links the input data with the output data. Examples regard image and voice recognition, to recognize geometric features and spoken keywords, classify and associate them to semantic classes;
- 'Unsupervised learning' by means of input data supplied to the machine, with the objective of identifying in them a logical structure, without any indication of the output data; the lists of results returned by a search engine refer to this learning model; in this specific case, the algorithms supply as output the information considered pertinent to the search carried out through the analysis of the patterns, models and structures derived from the input data. Examples are the analysis of perception features from cluster groups, where the algorithms are focused to elaborate an association between attributes not-defined by the surveyor. It can regard the grouping of users in relation to urban perception preferences, basing not only on age classes but finding new correlations between profession, background, education and/or familiar urban pattern;
- 'Reinforcement learning' by assigning rewards when the desired results are achieved and punishments in the event of errors; the aim is to improve the machine's performance according to the results previously achieved; applications of this type are found in Intelligent Tutoring Systems. It is applied in contexts of predictive answers, summarization of contextual frameworks, image processing to identify objects and evaluate their correct association to already classified features or meanings in the field of urban analysis and perception.

Specific considerations regarding territorial education related to AI consider learning modalities and facilitated, linked to social and emotional factors, open/informal/blended environments and visualisation methods, to understand representation mechanisms and clearly link them to real learning mechanisms (Chassin et al., 2021). The visual engagement of the user can be explored through urban virtual environments (Brusaporci, 2019), to allow the participants to be placed in VR daily scenarios, experimenting with 3D perception and cognitive decision in a real and multisensory environment (Croce et al., 2020).

Problems of elaboration of educational technologies joining digital practices and AI must be analysed from a methodological and theoretical point of view, as the mere existence of technological tools is not sufficient to guarantee their adoption and use in learning practices. The use of VR and augmented data, also, has several advantages. The removal of confusion factors is relevant in the objective responses of users (Parrinello & De Marco, 2022), as they can be strongly influenced by environmental conditions such as temperature and light (ESUM, 2017).

Figure 1. Conceptual flow chart relating 'training' purposes to AI contribution, finalised to the definition of controlling tools in Urban InfoSystems related to digital processing and territorial dimension in the medium of Knowledge-based intelligent systems



SOLUTIONS AND RECOMMENDATIONS

In order to investigate AI-based integrations to the urban learning mechanisms, a qualitative methodological approach is assumed in the presented chapter. The aim is to present a panorama of challenging and on-going opportunities through the analysis of 3D data from digital urban survey to involve analyst practices and AI applications for the interpretation of urban scenes in learning purposes. The proposal of updated versions of Urban InfoSystems addresses future research.

'Perception', as a visual approach to the urban scene and its classified elements, is addressed to collect, analyse and translate data from physical space to virtual assets, as mediums of learnings on the urban experience. Urban Learning Analytics are meant as measurement, analysis and reporting of data about learners in a specific virtual context. Well-being and social valorisation are assumed for the mapping of data and the critical considerations from users.

The ambition regards the advancement of a system to guide a learning user through defining digital maps that can better support urban practices and participatory design, revealing social mechanisms related to the elements of the urban scenario. In this way, it is aimed at enabling those cognitive skills for building a representation of new scenarios - real and virtual - in the sustainable processes of urban education.

The use of 'feature recognition', 'segmentation' and 'deep-learning' applications on 2D and 3D digital databases of the urban scene presents as an increasingly common and accessible practice, despite IT skills level. Indeed, it is highlighted that not only image analytics platforms but also GIS platforms are increasingly integrating deep-learning algorithms and processors into their geoprocessing toolkits.

Vision and Movement as Preliminary Perception Concepts to the Territorial Re-Education

Educational practices for territorial learnings, supported by the advances in digital technologies, have to address a sensorial analysis of real and practical needs, as directly perceived from the physical and anthropological societal space.

The relevance of visual data, as collected through an 'eye-sight' in both physical and digital mediated ways (Nugrahaningsih at al., 2013; Cantoni et al., 2014; Cantoni et al., 2016), can improve the public education to act, design and preserve cognitive and emotional relations with the physical spaces (i.e., schools, parks, squares, public buildings). The experience of the territory and of public spaces can be conceived more deeply through spatial and sensitive needs that require, in particular after the pandemic isolation, updated learning skills from their direct contact. In this way, the digital translation can adopt the impressive value of perception analytics to establish 'intelligent' learning challenges through virtual simulations. It refers to addressing advanced cognitive and socio-behavioural skills in relation to ways of interaction of citizens in a certain type of physical space, urban or even public, where the desire is to find a well-being of presence, accessibility and community's collaboration for the public sustainability. The possibility to supervise the evolution of users' attention and interaction in learning approaches with the urban public space (both as observers and participants) advances AI-based tools for a sustainable education to physical perception, territorial awareness and exploration.

Along with 'Vision', also 'Movement' perception comes central in this analysis process (Zhang et al., 2020). The interpretation of the 'eye-based' data is entered in the urban scene, highlighting visual analysis classifications from urban living spaces, and proposing them for parametric databases. Thus, the translation from qualitative to quantitative repositories can lead to a practice of 3D virtual modelling of urban space, to interact with sensor tracking and VR simulations, not excluding AR and other immersive contents. On the other hand, the analysis of 'movement-based' data within the urban and cultural environment derives from the recording of different visualisation lapses in time. It highlights the development of perception mechanisms in guiding people to orient themselves and act as citizens in physical places. In this way, both visual and movement data of interpretation of the urban scene can be linked by algorithms of machine learning to quantify parameters on flows and public interest (Gòmez et al., 2020). These data can be set by users features to concretize dynamic maps of perceptual urban characterisation.

Targets of Visual Attraction to Classify the Experience of the Urban Environment

The issue of reliability and communication of physical spaces involves elements and hierarchies of spatial representation and 3D modelling address at the scale of the territory (La Placa & Doria, 2022). Typically, the disposition of digital replicas of public spaces, to establish educational paths and cognitive maps, is set from standard libraries, statistics and census documentation. Usually, the complexity of elements and relations from the physical space is re-modulated through the attribution of simplified semantics (Cordts et al., 2016). In an educational perspective, they are not sufficient to represent those flexible relationships of learning information coming from real cognitive/behavioural states linked to the true well-being experience of a physical context.

The development of an information base, collector of visual attraction data, can be processed from sensors' contribution in visual and motion tracking. It can allow the measurement of a metropolitan perception where educational urban indicators can highlight the quality of spaces, developing a chain in which these data, born from real architecture as a set of 'subjective descriptors', are evaluated in the analysis of urban space, as corresponding to measurable 'objective attributes'. Through tracking strategies and open-source data analysis, sensory information on the urban environment can be linked through algorithms, flow maps and abacus to model an 'intelligent' virtual form of the city, as a first act of reflection for educational purposes and skills development on urban policy.

The participation of school users can be used as a coaching method of the AI Knowledge-based system, collecting unreleased sensory data of the human relationship with the city (Marr, 1982), and for the structuring of an educational atlas, which will systematise this information to identify behavioural and training patterns. The AI contribution can be combined to the lines of 'Eye' ('perception') and 'Movement' ('mobility') data tracking and analysis, declining and sensitising the use of sensors to the perception of the urban ecosystem by users. According to sensors' measurement, appropriate parameters should be linked to a repository of urban forms, and the AI tools will be trained to correspond data, element and educational advice associated with tracking device data. At the same time, the tracking will be associated with the intelligent scanning of networks in the digital system, to extract information from age-classes of users and put them in spatial and temporal correlation.

Integrating AI-Based Tools to Data From Urban Survey, Behavioural Data and Urban Infosystems

Currently, Deep Learning workflows already see wide application in the field of GIS. Deployment is prevalent on imagery data, where categorised tool packages within Image Analyst extensions allow geoprocessing of raster data. The workflows involve the processing of imagery data, prepared as 'training data' for 'detection' applications: object detection, pixel detection or classification, and object classification models. The workflows consist of three fundamental phases: Prepare Training Data, creating training samples and converting the samples into deep learning training data; Train a Model, through deep learning frameworks adopted from the information system (as PyTorch for ArcGIS) or from third-parties; Use of the trained Model, applying the AI contribution in the processing of additional input datasets, where the operator's action is limited to the review and validation of results, and the computation of accuracy.

The 'Training' phase represents the key step of reflection in terms of automation and 'intelligence' for Urban Analytics: the selection of the types of 'features' or 'objects' is representative of the theories of perception and visual attraction attributable to urban space with respect to the sensitivity of territorial education. Similarly, the type of survey data (2D, 3D), in terms of coverage, resolution and accuracy, is relevant to the institutionalisation of training features. For the application of convolutional neural networks or deep learning models to the action of 'urban data' detection, it is necessary that the definition of the source data is sufficient to allow the system to classify it. This demand is compared with multiple assumptions and developments in the field of digital documentation at the urban scale. The expeditiousness of survey action by fast survey applications (Mobile scanning, SLAM, UAV photogrammetry or 360° photogrammetry) is being confronted with the resolution of datasets, not limited to building volumes. Openings, vegetation, secondary spaces, apparatuses of technological infrastructures (e.g., lighting, air conditioning) and socio-cultural structures (e.g., temporary structures, urban design, signage and other recreational apparatuses) define a specialisation in the classification of the overlayers of the urban scene, detailing the factors of public perception and the related psycho-metric mechanisms.

The integration of these concepts in a research design focused on Urban Learning Analytics is aimed to develop Urban InfoSystems in the direction of interactive 3D virtual-learning environments, where AI-based protocols are considered to integrate and direct the visual interpretation of urban scenes. Visual analysis can be applied to convey the education on sustainable practices for the community's physical places, acting on social, relational and urban levels. In this way, the segmentation and classification of features in an urban scene can permit the analysis of its taxonomic structure and to monitor the cognitive perceptions of target users into public spaces. Their processing within data representations and AI analytics are related to map cognitive relevance and, at the same time, to understand which missing concepts of citizenship behaviour, cultural analysis and territorial sustainability can be improved in the present educational practice with respect to classes of knowledge on the urban space (social, green, recreational, cultural, artistic, relational).

Exploitation of Taxonomic Classes of Urban Information in the Interaction With Urban Infosystems

Less attention is usually given to implementing the 3D representation of urban contexts through the mapping of the mind processes of visual perception into semantic relations, from the first on-site contact to the reproduction of the experience of physical space in a digital dimension of learning involvement. Thus, two key topics are considered:

- The potential of digital skills and VR structures for societal education and training simulation;
- The measuring of visual perception and elements of attention to establish taxonomic relational classes.

Despite their digital skill levels, citizens are now regularly exposed to 3D scenes and digital twins as non-expert users, thanks in particular to the development of more intuitive techniques to interact with digital 3D objects. The availability of interaction with such environments encourages their adoption for purposes of social education to the territory.

In the technical sphere, the main relevant concepts for the taxonomic definition of the 3D digital scene concern: data (of a multi-source type but declined around a single digital medium), users (by class, age and cognitive capacity for communication) and representation, as decisive in the choice of style and interaction in the communication of information, and to limit the risk of inappropriate learning practices.

At the same time, the benefits brought about by geo-visualisation in the VR sphere are considered central, facilitating 3D communication by working both on the semantics of products and on the modalities of immersion and interaction. A democratisation practice in accessing and understanding content on the analysis of urban space, its structures and the cognitive approaches it guides is addressed. Interactivity encourages users to explore the 3D scene by choosing personal perspectives, and thereby enhancing the perception and understanding of features (e.g. depths, heights, distances, proportions) between spatial positioning and cognitive significance or perceptual comfort. The stimuli addressed by the interaction are translated into user behaviours (e.g. orientation, hesitation, performance, impulses).

Relevant features to guide taxonomies for urban education through digital tools are addressed to allow users to visualise urban assets (such as at the neighbourhood scale) in three dimensions with the support of data collection, both from close-range survey and sensor spatial reference. Users are expected to interact with the scene and modify it, adding elements, functions and services for the public space, in relation to the topics of ecology, energy, mobility, leisure and culture. In this way, a structure of taxonomic classes can be proposed, about the categories of accessibility, economy, productivity, ecology, social interaction. The user-player can therefore interact with a design proposal and visualise its impact, understanding the level of complexity of each decision related to the urban space and the different needs related to different functions.

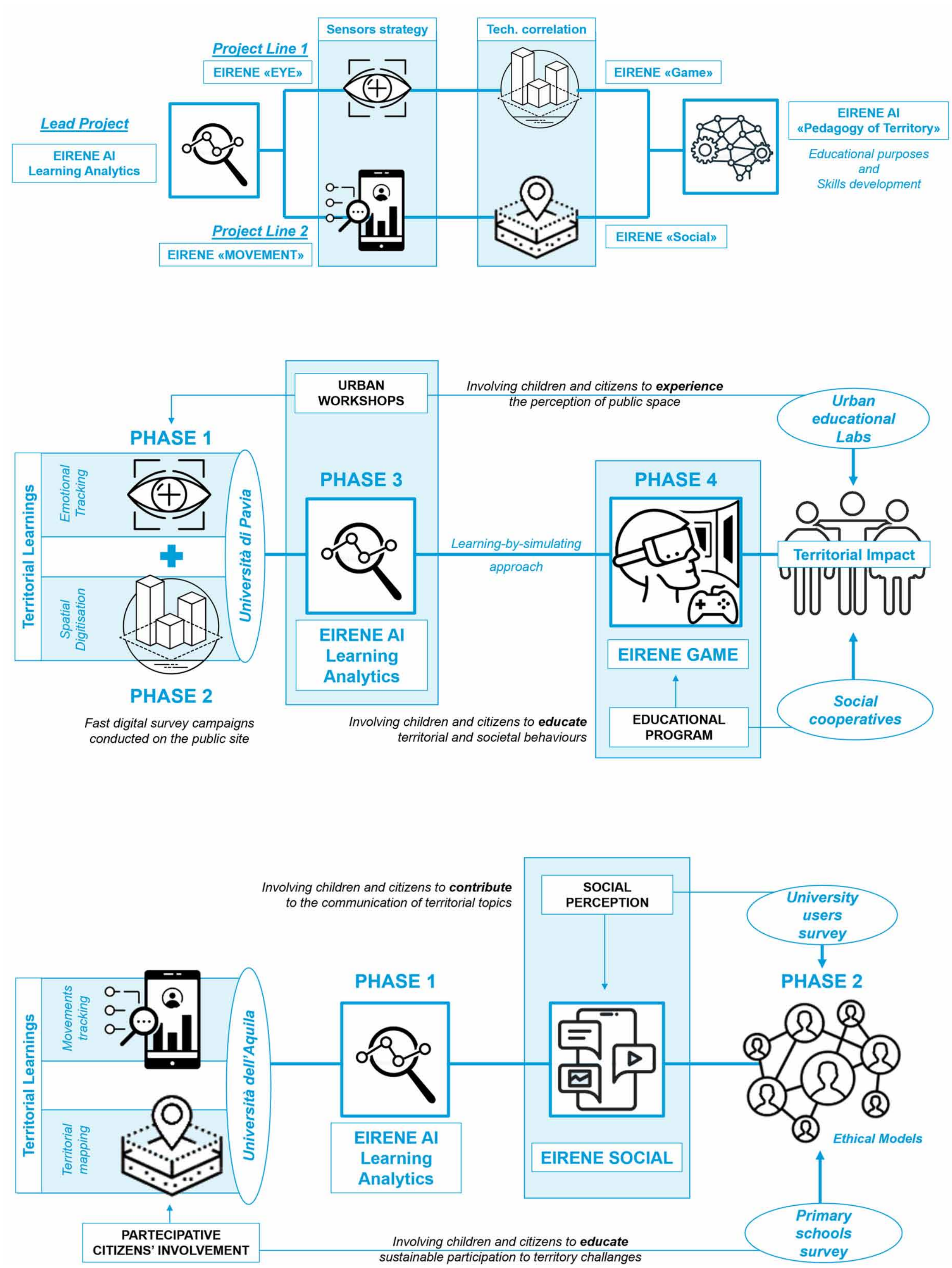
The VR representation proposal is imagined to be integrated in a web platform exploitation, collecting the data of users' session in a server, building a database about the citizens' desires, needs and proposal and allowing the data visualisation and analytics in a dashboard, accessible to citizens, architects and public entities. Objectives are:

- To structure a three-dimensional repository of the urban Digital Twin, attributing formal compositions and behavioural significance to the sensory data.
- To dispose of a learning system to involve users, from children, adolescents, till parents and adults, in developing cognitive maps on the urban space, and to disseminate the impact of urban practices.
- Realisation of a platform (dynamic digital atlas) for analysis and communication of collected data.
- Reasoned multilingual vocabulary aimed at overcoming urban barriers and linguistic stereotypes to be used in the educational field to counter urban violence in the construction of communication, to deconstruct prejudices and to strengthen the exchange of information using appropriate channels.
- Implementation of a crowdsourcing platform based on interactive education and training tools prepared in the two lines 'Eye' and 'Movement' (podcasts, simulation game app, escape rooms, training content, social app), offering adaptable tools and solutions to ensure participation.
- Use of the platform in an educational way, with specific visualisations dedicated to different user profiles.

A Pipeline Proposal: EIRENE Project Design and "Eye" Line

A project design proposal is presented, under the acronym of 'EIRENE - Effective Intelligence for RE-education to cogNitive, relational and social city spacEs'. A focus line 'Eye' is related to the integration of cognitive-perceptual data from the eye-gaze. It is meant to coordinate, with spatial data from 3D close-range surveying, a semantic reading of urban space that relates each hierarchical component to

Figure 2. Conceptual workflows designed for the EIRENE research proposal on the development of learning analytics for urban analysis and territorial education. Above, general workflow, below, detail on the workflows for the two complementary research lines 'Eye' and 'Movement'.



social meanings and critical solutions for improving urban liveability for its citizens. It is oriented to an AI-based translation of sensory data and 3D semantics into learning paths on the interaction of citizens with the territory, through an Urban InfoSystem applied as a 3D immersive urban scenario.

The methodology of development is based on the collection and measurement of sensorial (perceptual maps from eye tracking) and spatial data (3D reality-based databases) from real public spaces. The data are applied for the AI training to recognize the level of knowledge of users, and to perform for each of them a learning mechanism of contents and simulated interactions in the VR space, userful for the training on societal responses.

The projected outcome, 'EIRENE Game', is meant to present a VR environment for the education on the territory and public physical space, where the user will move into the 3D virtual space, simulating a learning experience linked to the real physical one. While exploring the digital replica of the public space, the user will find questions and puzzles to solve through a point-and-click interaction. Behavioural suggestions and best-practices to be adopted in the societal field will be provided, educating the young users to topics of urban experience, public 'green deal', community behaviours in the public domain, arts and cultural public influence. The goal of the game is to make the user solve quests and completing the challenge, stimulating a decision-making process that directly influences his/her gaming experience, thus enhancing his/her participative active role in the public knowledge and sustainability of territory.

A double format of EIRENE Game can be foreseen:

- A VR immersive version, for educational activities conducted by territorial partners. This version can be performed with a 1st person navigation mode, enabled through VR visors.
- A Smart-Device version, for remote educational activities, available for other users through a shared platform. This version can be accessible from users' personal devices (i.e. tablets, smartphones), and it will be performed with a 3rd person navigation mode.

PHASE 1 Method: Mapping of Visual-Emotional Interaction Within Eye-Tracking

Real-time tracking of visual pathways of users, engaged in a sensory and emotional experience, will provide immediate feedback and reliable mapping data to guide the territorial learning process. The response to public space stimuli and the mapping of attention distribution will allow comparative evaluations of behavioural mechanisms. Eye movements occur as sudden (almost instantaneous) saccades, followed by fixation periods of about 100-600 milliseconds. Fixations correspond to stages of relative stability during which the gaze is focused on a specific area of the visual scene.

Eye trackers are devices able to measure and trace the user's gaze behaviour. Remote eye trackers will be set in a fixed position, thus allowing to obtain information about the gaze behaviour of a person while observing a specific scene/urban sight. A free, unconstrained scene can be considered, provided that the user's eyes can be correctly detected. 'Totems' (or kiosks) will be installed, incorporating eye tracking devices which will detect and record the gaze of people in front of them (one at a time). Since the eye data recorded by a specific totem will be from the same scene for all the people who interacted with it, it will be possible to obtain precise information about which elements are the most observed and which are instead ignored. Information about the exploration sequence of the scene will be derived, which can provide hints about people's perceived logical/emotional connections with elements and societal behaviours in the scene. Wearable eye trackers will be included, to be worn by a person in movement to track the gaze in a totally unconstrained scene. They are sort of 'glasses' endowed with infrared cameras (to detect eye movements) and with a frontal ordinary camera (to record the observed scene). It will be possible to assess more complex behaviours, involving people's physical movement.

In both kinds of experimental settings, eye-tracking data (gaze samples, fixations, pupil size, blinks, etc.) will be analysed to derive information about: 1) most observed areas in a static or dynamic scene; 2) common exploration patterns; 3) distribution of people's visual attention; 4) potential 'emotional states'; 5) people's cognitive load (e.g. associated to the execution of specific tasks). It will be possible to carry out similar experiments and investigations with VR simulations, both in the non-immersive case (using a screen and a remote eye tracker) and in the immersive situation (for example using a wearable device such as Oculus Rift enhanced for eye tracking).

PHASE 2 Method: Physical Space Documentation With Fast Digital Survey Technology

Mobile solutions of 3D digital survey will be applied on site, in a fast survey approach, overcoming critical factors linked to accessibility or wider extensions of public space. In particular, SLAM technology defines a solution of 'simultaneous global localization and mapping' that is moving nowadays to specifically integrate the perspective of spatial machine intelligence systems (SMIS). Thus, more automation and self-management of SLAM technology is allocated for the acquisition of scene geometry and the transposition of space semantics. This technology can also include multi-camera vision systems (as BLK2GO from Leica) to increase the quality of acquired spatial data.

Inside the project line, SLAM survey technology will be applied as a fast acquisition system on the physical context of analysis, defining a digital background and declining the point cloud databases to different data analysis through a representation calibrated for Levels of Detail (LoD). It will define a reality-based digital replica of the real context, including paths, volumes, open spaces, architectural details, and other elements of urban scene, even integrated when necessary by other survey campaigns (e.g. ultra-light UAVs for high levels, static LiDAR for smaller spaces or details).

PHASE 3 Method: AI Processing From Background Learning to Machine Learning in the 3D Scene

The acquired and processed databases of information will be composed by a wide and complex extent of different data, divided between sensorial maps and spatial hierarchies. The application of EIRENE Learning Analytics will permit to structure an approach of semantic labelling for the repository at the basis of EIRENE Game, identifying "instances" and "annotations" in relation to parameters and query information that define them. Based on the semantic labels, objects in different categories are reconstructed with domain-specific knowledge, and linked to educational relations.

The translation of various data on public space perception (sensorial and visual) validates an essential methodological aspect of cognitive classification of digital data for educational purposes. The multi-level coexistence of elements increases the difficulty of training of AI processes, for a semantization of perception maps linked to the VR space. The implementation of an integrated acquisition protocol will set a classification in semantic classes (Berta et al. 2016), giving a Repository structure connected to the AI system also for subsequent implementation of data in the game.

EIRENE Learning Analytics will be incorporated in the Machine Learning (ML) approach. ML sets will process the acquired sensorial-spatial data, training the system to interpret behavioural associations:

- **Supervised learning:** Examples of input information and related output, to set specific training models. E.g. observation of stylistic features on historical elements -> education to artistic/cultural characters.
- **Unsupervised learning:** Series of input information that conditions the choice of output learning of AI. E.g. sequence/observation/attention of public damages -> education to green environment behaviours.
- **Reinforcement learning:** Correspondence of points and rewards to correct behavioural mechanisms. E.g. correct pedestrian behaviour in a simulated walking path -> gadgets, scores or tricks in the game.

PHASE 4 Method: Visual Design and Validation of the Gaming Devices

Guidelines for the development of video games semiotics will be adopted, to foresee a structure of the gaming platform according to a tree macro-scheme. It will be possible to act from the simulated VR environment on the real behavioural dimension, influencing it in educational terms.

The visual design of the game will be established, according to source data, results of Machine Learning processes, and the brand identity of the EIRENE project. 3 coding phases will be performed: the coding of 3D virtual space levels, the coding of information maps, and the coding of avatar's interactions.

The choice of the engine platform for the development of the game environment (i.e., Unreal Engine, Unity, Godot) will be evaluated as preliminary action, to calibrate all the subsequent design and implementation activities of the educational simulated environment. In particular, they will be developed:

- A segmentation of the 3D scene, according to the levels of functionality of the VR gaming platform, and to the technical capability of loading of the selected engine platform.
- The gaming scripting of Blueprint and Canvas elements, to set the User Interface (UI) between components and data, considering the most effective mechanism to recreate the user's involvement and the educational actions in the VR environment. The implementation of contents in 'overlapping' (overlaying the scene) or 'word-space' (inside the 3D space) mode into the scene will be considered.
- A graphic line and multimedia integration, according to its influence in the learning-by-simulating process, to the management of survey data and to the brand identity of the results. In this way, it will consider the integration of textures, environment details, dynamic effects, and sounds.
- Navigation modes, considering the perception of first/third person involvement of the user (controlled by the scripting of user's virtual camera) to appreciate the AI design of measured interactions between the eye and the gaming interface (i.e., gaze pointing, gaze gestures, gaze as observation and analysis information to assist and support the user during the learning-by-simulating process).

AI-Based Integration to Digital Documentation Data: Tools Tested on 2D and 3D Datasets From Urban Survey

2D and 3D visualisation of data processed by AI promotes processes of 'visual computing', for the study of large amounts of data in rapid times and accessible tools, to allow users to choose and create customised software images.

The majority of developments and algorithms tested for the most efficient automation of the taxonomic representation of urban contexts focus on 'Feature Extraction' toolboxes for two-dimensional documentation. In particular, the use of photographic data, acquired from elevated viewpoints or even better from aerial cameras such as drones, constitute an opportunity for expeditious processing on urban datasets at multiple time intervals.

Experiments in this field have been conducted with reference to a geospatial image analysis application (specifically ENVI from NV5 Geospatial). The datasets used involved 2D photographic data from aerial cameras, with constant photographic quality parameters equal to the camera's maximum resolution (48MPixel for 1/1.3-inch CMOS camera mounted on DJI Mavic 3 Mini). Two different contexts in terms of density and urban morphological complexity were adopted for the experimentation. In both cases, the photographic material was acquired with an orientation at 45° to the nadiral axis. A further experiment was conducted on photographic documentation material acquired at the inner plane of urban space use, with a 360° spherical camera mode. The photographic quality (23MPixel Ricoh Theta Z1 camera) maintained a high sharpness in the RGB product, with distinction of both the fixed components of the urban scene and the dynamic occlusion elements present in the scene (e.g., people, vehicles, moving objects).

Feature Extraction was applied to raster data to identify objects from imagery based on spatial and texture characteristics. The Example Based mode, by selecting training data (samples of known identity) to assign objects of unknown identity to known features, has been performed. The process is based on two main algorithms, a Segmentation algorithm and a Merging algorithm. The Segmenting algorithm is set to the Edge mode for detecting those features associated with morphological edges of the urban elements in the scene, based on the RGB visuality of the data from the survey, and corrected to the appropriate reading scale. The Merging algorithm combines adjacent segments with similar spectral attributes, and must be set with reference to the type of ontological classification desired for scene analysis. With reference to the Learning Analytics goals and educational purposes drawn from the cognitive relationships between scene elements, the Full Lambda Schedule mode is preferred for the merging of over-segmented areas within larger, textured portions such as trees or clouds, while retaining those classes desired for analysis correlation with perception related to the graphical picture.

Following, the Select Training Data process allows the integration of the operator's critical manual condition to the AI algorithm applied by the system, completing the association of segmentation with a defined class ontology. It is in this step that Urban Analytic's intelligence is confirmed, and from this moment on it can be adopted as Ground Truth Data with reference to the repetition of the segmentation and classification process.

The comparison between the 3 study datasets shows how the Feature Extraction approach from 2D photographic material can be applied to different actions of analysing and classifying urban scenes in order to establish a taxonomy protocol aimed at education. At a macro scale of aerial visualisation, segmentation by edges allows for the definition of those sets of built space, infrastructures and composition elements of the settlement system that allow for the mapping in analytical terms of the otherwise perceived pattern on the territory. At the same time, at a closer scale of observation and focus on the hierarchy of the components of the same category (e.g., conglomerate of building units, correlation of gaps of openings, complementary elements of urban structures), Feature Extraction tends to lose that capacity of critical segmentation useful for scene analysis, focusing more on the isolation of the same border entities, as boundaries, more than on the areas corresponding to them.

Opportunities for taxonomic reading of urban layout data are also possible through dedicated processing for 3D modelling. In this case, the Urban Analytic process is developed by the dedicated tools not as a stand-alone process for producing critical analyses, but as a technical means for the semi-automated extraction of 3D volumes. Given the additional spatial dimension, the system allows for a more technical intervention in the calibration of parameters specific to the dataset's scene reading. In this sense, it is correct to consider the data as Training Data from the very first training step of Urban Analytics, where the action between operator and AI is not unrelated and consecutive, but occurs in an integrated and dynamic way, with a continuous input and response of the system to the interpretation of the data.

Still through a geospatial application (ENVI from NV5 Geospatial), it is possible to interact from the toolbox in the LIDAR section, dedicated to the specific processing of dense 3D data. The Urban Analytic options offer a choice output section linked to the classification structure established by the American Society for Photogrammetry and Remote Sensing (ASPRS) for LAS formats. In terms of relevance to the semantics of urban space and its social education objectives, the system is limited to the macro categories of 'buildings', 'trees' and 'terrain'. Subsequently, the macroscopic extraction of 3D space features, processed by the AI, detailed on a limited set of Production Parameters and by extraction formats. The latter are mainly grouped around image formats (.jpg, .tiff, .png) or vector formats for recording geometric identities and their associated information (.shp).

The AI application proceeds to analysing and recognising features from the imported dataset, subdividing it into regular meshes, and proceeding to the ontological interpretation of the data according to the defined list of classes. The Urban Analytics process produces as output both a classification of the source point cloud data and a critical reconstruction of 3D vector data, predominantly buildings of recognisable 'box contour', main vegetation and soil. Architectural features are not distinguished by the system, but a minimum area and planar tolerance is allowed to help interpret the continuity and density of points according to the ontologies of the AI system.

The dataset adopted was produced by a photogrammetric process of aerial photographic material. The source data corresponds to a dense point cloud format with RGB properties, filtered for a uniform density of maximum point range of 0.015 metres. The resolution of the data allows a recognisability of the main built edges of the urban layout, reading the building volumes and the main typological characteristics at the architectural scale (openings, roof geometries, projecting elements of the main fronts).

The observation of the processing results highlights how Urban Analytics based on AI tools can semanticize the point cloud for a 3D reconstruction, defining the box-like volumetry of the building units, the terrain and infrastructure as vector entities. Other extraction components, such as the contour lines of the DEM, are defined as 2D entities, while others still maintain a type of positional data associated by the system to a semi-automated abacus of elements, parameterised in an automatic manner to allow the match with the features identified and established by the system, as in the case of the data associated with the 'vegetation' class. The result is that even a series of out-of-scale urban components (such as towers, bell towers, minarets) can be identified by the AI through features more in keeping with the categorisation as vegetation. There remains, therefore, scope for manual verification and correction of the classification of particular elements of the urban scene, after critical analysis, and their manual modelling.

FUTURE RESEARCH DIRECTIONS

The scope for the development of Digital Intelligences suitable for supporting Urban InfoSystems is addressed along two lines, for which interdisciplinary and specialised focus in platforms and processing modes is foreseen in the future:

Figure 3. Experimentations for AI-based tools application to the analysis and classification of urban scenes from 2D and 3D datasets (conducted through ENVI-NV5 Geospatial software). Above, test on 360° HD photos in Jerusalem, Jaffa Gate/Bab al-Khalil area in the Old City. Below, test on 3D point clouds from UAV survey, Artas village, West Bank.

- The Interpretation of the Eye entering the urban scene (eye-tracking), adopting sensors that acquire data from urban living spaces to parametric databases. It includes the translation into qualitative repositories, leading on 3D virtual modelling of urban space to express the perceived experience (simulated in VR/AR result systems).
- The Analysis of Movements and flows of citizens within the urban and cultural environment (human tracking). Open source data of communication are linked by algorithms to quantify parameters on flows and public interest. These data will be set by users features to concretize dynamic maps of urban characterisation.

The horizon is to direct the Machine Learning process based on real experience data collected on site; this will make it possible to identify unique relationships between the heat maps of the eye tracking sensors (significant of the recognisability and attention given by each user to an element/component of the public space and territory) and the degree of cognitive awareness characteristic of the learning candidates (an aspect to be updated with respect to the literature studies following the unusual components of experience that have occurred in recent years of pandemic and digital conversion in remote physical-spatial contacts).

Starting from the recognition in classes for cognitive features, learners will be classified by levels of experience already gathered towards the territory and public space, and they will be guided towards a customised training path. Accepting the pluralism and divergences in the relationship with the territory and public space that can be expressed by the young citizens, each user's training within the EIRENE Game will be specifically designed by the AI system on the user's reality-based factors, optimising the pedagogical and training offer developed by EIRENE.

The research contribution aims to suggest future directions of development and involvement between the fields of education and representation at the urban scale, to provide qualitative and quantitative information in relation to the cognitive knowledge and interpretation of the physical space, in particular considering children and minors as young classes of citizens to be educated to territorial perception. It is central to stress the evolution of human perception through AI processing to an interpretation of sustainable "citizen education" and "societal-spatial response".

AI is foreseen for a development of the information base, collector of all the data received by the planned sensors, allowing the measurement of a metropolitan polycentrism that urban indicators can highlight for the urban quality of spaces. The aim is for developing a chain in which these data, born from real architecture as a set of "descriptors" that are evaluated central to the analysis of urban space, find a correspondence in measurable "signals". Through tracking strategies and open-source data analysis, sensory information on the urban environment is addressed to be linked with algorithms, flow maps and abacus to model an "intelligent" virtual form of the city, as a first act of reflection for educational purposes and skills development on urban policy.

The main application cases are projected on the double urban scale and the level of perception, and they are presented as a preliminary consideration for the development of future research lines with a on-site action on pilot sites:

- **Public Space Scale:** The measurement carried out by the sensors of a resting point, in a defined place, evaluated in an area of a certain radius and on other parameters such as timing and grouping, can be linked by appropriate parameters to a repository of urban forms. According to these set parameters, the Urban InfoSystem will choose a symbolic urban form corresponding to an element of interest, an equipped area or a green zone (adopting VPL visual programming languages associated with tracking device data). At the same time, the tracking and measurement of people's "walking" movements could be associated to the intelligent scanning of the network in the digital system, in order to extract information on public events of various kinds and to identify them geographically on the city-city map in order to put them in spatial and temporal correlation with the measurements.

- **Neighbourhood Scale:** The intelligent system will be able to propose to the smallest scale a virtual urban model, again drawing on structured schedules (on the basis of appropriate documentation and surveys carried out, also drawing from different areas of the city or other metropolis and establishing comparisons), and will formulate a conceptual master plan based on appropriate reflections of the study groups and urban design.
- **Perception level:** The digital information models elaborated will be used for the reconstruction of public space and buildings (urban scene), exploring intervention simulations for "art elements", street furniture, functions. In the same way, simulations of absence and presence of the same and correlations with the mutation of visual attitudes, mood, perception, evaluation of the quality of that same space in different configurations, user questions/answers, will be explored. The communication of 3D scenarios and multi-level, multi-dimensional, dynamic and interactive thematic maps will deepen and access the experimentations in a diversified and specialised way for the users involved. In particular, it will define a support to professionals of the urban dimension. It will pursue a main result of lifelong training that addresses the urban transformation through the professional careers and skills involved, including young designers and experienced urban designers.

In order to calibrate results deriving from eye perception and flux data, questionnaires regarding awareness and AI applied to a georeferentiation of public events and manifestations (in open-air spaces or in buildings) will be set up. Therefore, systematic investigation of the effects of interdisciplinarity will not be neglected both organizationally and in terms of engagement and benefits by integrating into a coherent set of distinct methodologies and methodological traditions across domains and recombining them into a common vision and design to produce innovation.

A specific issue regards promoting the impact both on-site (direct involvement) and off-site (remote, e.g. webinar) as a 360° participatory form of the new professional educational model; integrative modalities of traditional didactics with live links to the fields of surveying is one of the milestones. An example can be the introduction of remote interaction modes between "traditional classroom with teacher" and real-time connection to survey areas and specialist survey teams that show the acquisition procedures live and then reach the students in the classroom for data processing. This mode is especially useful for numerous courses and very crowded city environments (places where it is complicated to keep the focus on the instrumentation for the measurement and their use).

Finally, one of the possible further research developments is the design of an open source video game for smartphone and tablets, a tool for designers and public entities to engage citizens in the design of the public space, to educate to sustainability and inclusiveness, and to collect data about citizens' needs, desires and proposals, a flexible tool that can be applied to different neighbourhood. Citizens who are not specialists, architects or designers, already have tools today to design and visualise a proposal for the urban space, usually very poorly integrated with tools for capillary detection of individual and group behaviours and attitudes.

CONCLUSION

A hybrid methodological pathway is proposed, aimed to acquire transdisciplinary competences involving the study and application of knowledge as an organic integration of technology in urban education, to increase knowledge on the history, theories, languages and digital technologies that produce paradigmatic changes in urban assets. The aim is to pour the scientific, technological and cultural knowledge on the social tissue with the aim of promoting the collective growth of the territory, so that the comparison, the study and the reflection are tools of active knowledge to obtain cultural, political, experiential benefits of continuous training and public engagement.

The challenge that will be followed concerns the material and thematic densification of the city and the contextual loss of quality of the common space resulting from the rapid and disorderly growth. The analysis of these phenomena must constantly update the urban policy knowledge for design objectives, by deciphering changes just as quickly.

A possible solution is the introduction of training methodologies and tools in urban design teaching, with an AI-based implementation for educational purposes on urban projects. Specific objectives related are:

- Systematise visualising tools and analysis methods related to the correlation and use of quantitative data produced by urban environments, experimenting with algorithmic and parametric relationships between sensory and visual data (perceived or simulated);
- Apply participatory public design to the regeneration of urban spaces, visualising the sensory stimuli produced by them in a virtual scenario;
- Define a supervision tool (an "explore"" database, collector of urban sensory data) as enhanced digital competence for Turin's urban designers;
- Pursue the impact of national and European education through AI tools, both towards students and young professionals, as soft skills for new attitudes and critical thinking sensibility on the city's design in the long term, and for expert project figures oriented on a re-skilling program that directs technical skills towards new services with a medium-short term training.

The foreseen impact expected from the project line, considering the purposes, methods and outcomes expected in the project design is also summerized. In particular, the development of EIRENE is foreseen on 4 classes of impact, which will act on the educational needs identified by territorial partners through the research promotion/application.

- Impact on the LEARNER_Impact on the students' users from the application of EIRENE Game through the educational program provided by territorial partners. With EIRENE Game, customised instructions and learnings will be provided to users, acting on the education of territorial issues and improving the post-pandemic territorial approach through a direct virtual awareness-raising experience to trigger the learning-by-doing mechanism.
- Impact on the TEACHER_Impact on the teachers involved in the application of EIRENE Game inside the educational program provided by territorial partners. The teachers involved will take part in the brainstorming on EIRENE training content related to learning about territory, taking part in the methods of integrating AI methodologies for the education on public space, accessibility and simplification of teaching, and taking the opportunity to re-propose them.

- Impact on the DIGITAL EXPERT_Impact on the scientific community in charge of digital applications to simplify the citizens' contribution and collaboration to the common territorial sustainability. Digital experts will learn how AI and EIRENE Learning Analytics components can be applied to disseminate and influence societal mechanisms and best-practices via interactive gaming spaces.
- Impact on the SCIENTIFIC TOPIC OF AI_Impact on the social community/citizens of the contribution of AI to the sector of education and to the simulation of VR space for enabling social behaviours. EIRENE Game will bring the citizen closer to understanding the dynamics and levels of interaction with the territory, using AI as a tool for expansion and intelligent learning of territory perception by citizens.

The research impact aims to address an effective attention to the urban and territorial asset both as educational source and tool, extracting a critical view on planning behaviours. To achieve this objective, the goal is to apply an educational protocol on the digital transposition of the levels of analysis and perception of urban spaces, involving a taxonomic classification and relation between classes from the training and validation of AI tools, focused on the pedagogical and educational evidence. The experimentation of solutions and recommendations aims to introduce possible pipelines and typological results oriented to the elaboration of 'interactive urban atlas', a synthesis of visualising and mapping data. They are meant to be elaborated and tested into education protocols, integrating the participatory practices of territorial laboratories in contact with both education bodies and territorial administrations.

Future directions of development from the processing of AI on urban digital assets and virtual environments are intended towards the modalities of communication and users' involvement. In this way, the integration of perception sensors (e.g., eye, motion trackers) as well as the development of VR gaming can contribute to set pipelines for the continuous AI self-training and improvement of digital intelligences in InfoSystems, with the goal to generate Urban Learning Analytics directed to territorial education. In order to support this knowledge-based principles of survey, representation and communication, data processing and analysis processes need to be established.

In this perspective, the project increases the complexity of the urban system; this must be managed because "*complexity is directly related to connectivity. As connections or interconnections proliferate, complexity expands and, correlatively, information increases*" (Taylor, 2002): the map of connections and interconnections is populated, the diversification of the urban environment and the city experienced expands and, in parallel, the virtual environment increasingly interacts with the real environment.

Through the use of appropriate analytical techniques, these data can be translated into key elements for urban planning and thus make cities more liveable and within reach, increasing well-being and quality of life. In order to be able to visualise, analyse and study complex phenomena, such as the behaviour of groups of people, their preferences and how to intervene on the built and the project to be implemented in order to improve it and make it on a human scale, it will be possible to create a virtual environment within which the geometries and data collected will be synthesised, in order to develop typical behaviours, catalogable and 'translatable' into sustainable urban planning actions.

ACKNOWLEDGMENT

The paper presents some in-depth methodological aspects related to the joint research project "EIRENE - Effective Intelligence for RE-education to cogNitive, relational and social city spacEs" between Politecnico di Torino (Maurizio Marco Bocconcino, Giorgio Garzino, Mariapaola Vozzola), University of Pavia (Sandro Parrinello, Raffaella De Marco, Virginio Cantoni, Marco Porta), University of L'Aquila (Stefano Brusaporci, Antonella Nuzzaci, Pamela Maiezza), San Raffaele University of Rome (Edmondo Grassi), University of Torino (Davide Vannoni, Marina Di Giacomo), Centro Studi Italia Canada (Paolo Quattrocchi, Roberta Cosentino), Urbanlab Turin (Valentina Campana, Giulietta Fassino), and Cooperativa DOC (Mario Ferretti). The research activity is included in the project funded by the European Commission "MOEBHIOS – Multi-attribute values' OntologiEs to improve Built Heritage InformatiOn assessment in cluStered territories" (Project n° 101064433). The project is funded through the Horizon Europe programme, Marie Skłodowska-Curie Actions - Post-doctoral Global Fellowship (Principal Investigator: Ph.D. Raffaella De Marco). The project is coordinated by the University of Pavia (Italy) and developed in partnership with the Al-Quds University in Jerusalem (Palestine) and the European University Viadrina in Frankfurt Oder (Germany).

REFERENCES

Abbott, A. (2001). *Times matters - On theory and method*. University of Chicago Press.

Adjapong, E. S., & Emdin, C. (2015). Rethinking pedagogy in urban spaces: Implementing hip-hop pedagogy in the urban science classroom. *Journal of Urban Learning, Teaching, and Research*, *11*, 66–77.

Agugiaro, G., González, F. G. G., & Cavallo, R. (2020). The City of Tomorrow from… the Data of Today. *ISPRS International Journal of Geo-Information*, *9*(9), 9. doi:10.3390/ijgi9090554

Aleven, V., McLaughlin, E. A., Glenn, R. A., & Koedinger, K. R. (2017). Instruction based on adaptive learning technologies. In Handbook of Research on Learning and Instruction (2nd ed., pp. 522–560). Routledge.

Allam, Z., & Dhunny, Z. A. (2019). On big data, artificial intelligence and smart cities. *Cities (London, England)*, *89*, 80–91. doi:10.1016/j.cities.2019.01.032

Azzam, R., Taha, T., Huang, S., & Zweiri, Y. (2020). Feature-based visual simultaneous localization and mapping: A survey. *SN Applied Sciences*, *2*(2), 1–24. doi:10.100742452-020-2001-3

Batty, M. (2005). Agents, cells, and cities: New representational models for simulating multiscale urban dynamics. *Environment & Planning*, *2005*(37), 1373–1394. doi:10.1068/a3784

Batty, M. (2013). *The New Science of Cities*. The MIT Press. doi:10.7551/mitpress/9399.001.0001

Batty, M. (2017). Data about cities. In R. Kitchin, T. P. Lauriault, & G. McArdle (Eds.), *Data and the city*. Routledge. doi:10.4324/9781315407388-3

Benner, J., Geiger, A., & Leinemann, K. (2005). June, Flexible generation of semantic 3D building models. In *Proceedings of the 1st international workshop on next generation 3D city models*. EuroSDR.

Bernstein, J. H. (2009). The Data-Information-Knowledge-Wisdom Hierarchy and its Antithesis. In *Proceedings North American Symposium on Knowledge Organization*. ISKO C-US.

Berta, M., Caneparo, L., Montuori, A., & Rolfo, D. (2016). Semantic urban modelling: Knowledge representation of urban space. *Environment and Planning. B, Planning & Design*, *43*(4), 610–639. doi:10.1177/0265813515609820

Billi, D., Croce, V., Bevilacqua, M. G., Caroti, G., Pasqualetti, A., Piemonte, A. & Russo, M. (2023). Machine Learning and Deep Learning for the Built Heritage Analysis: Laser Scanning and UAV-Based Surveying Applications on a Complex Spatial Grid Structure. *Remote Sensing, 15*(8), 1961. doi:10.3390/rs15081961

Bocconcino, M. M. (2022). "nD" maps that show what cannot be seen, for an imagination of the concrete - Information systems and future perspectives that are already the present. In S. Parrinello (Ed.), 3D BETHLEHEM Management and control of urban growth for the development of heritage and improvement of life in the city of Bethlehem (pp. 166-183). Edifir Firenze.

Bocconcino, M. M. (2023). Information Systems and Models for Territorial and Cultural Heritage. In S. Parrinello & R. De Marco (Eds.), *Digital Strategies for Endangered Cultural Heritage: Forthcoming INTERSPECIES) - Handbook of Research on Strategies and Creative Interdisciplinarity for the Digitization and Safeguard of Endangered Heritage* (pp. 52–63). Pavia University Press.

Börner, K., Sanyal, S., & Vespignani, A. (2007). Network Science. In B. Cronin (Ed.), *Annual Review of Information Science & Technology 41*. American Society for Information Science and Technology. doi:10.1002/aris.2007.1440410119

Brusaporci, S. (2019). On Visual Computing for Architectural Heritage. In S. Brusaporci (Ed.), *Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modeling, and Representation*. IGI Global. doi:10.4018/978-1-5225-8054-6.ch024

Brusaporci, S. (2020). Toward Smart Heritage: Cultural Challenges in Digital Built Heritage. In G. Pavlidis (Ed.), *Applying Innovative Technologies in Heritage Science*. IGI Global. doi:10.4018/978-1-7998-2871-6.ch013

Brusaporci, S., Maiezza, P., & Tata, A. (2020). Advanced Heritage: From the Virtual Copy to a Virtuous Image of Reality. In E. Cicalò (Ed.), *Proceedings of the 2nd International and Interdisciplinary Conference on Image and Imagination IMG 2019*. Springer. 10.1007/978-3-030-41018-6_73

Brusaporci, S., Maiezza, P., Tata, A., & Ruggieri, A. (2019). From point cloud to cloud heritage. A framework for a participatory approach to study, knowledge and enhancement of historical cantres. In G. Granado Castro & J. Aguilar Camacho (Eds.), *APEGA 2019 De la línea a la nube. Actas XIV Congreso Internacional Expresión Gráfica aplicada a la Edificación*. Editorial Círculo Rojo.

Calvano, M., Cirelli, M., & Lo Turco, M. (2020). Display the Invisible. Automated Algorithms to Visualize Complex Phenomena. In *Proceedings of the 2nd International and Interdisciplinary Conference on Image and Imagination*. Springer.

Cantoni, V., Merlano, L., Nugrahaningsih, N., & Porta, M. (2016). Eye Tracking for Cultural Heritage: a Gaze-controlled System for Handless Interaction with Artworks. In *Proceedings of the 17th International Conference on Computer Systems and Technologies 2016*. Association for Computing Machinery. DOI:10.1145/2983468.2983499

Cantoni, V., & Porta, M. (2014). Eye tracking as a computer input and interaction method. In *Proceedings of the 15th International Conference on Computer Systems and Technologies*. Association for Computing Machinery. 10.1145/2659532.2659592

Card, S. K., Mackinlay, J., & Shneiderman, B. (Eds.). (1999). *Readings in Information Visualization: using Vision to Think*. Morgan Kaufmann.

Casali, Y., Yonca Aydin, N., & Comes, T. (2022). Machine learning for spatial analyses in urban areas: A scoping review. *Sustainable Cities and Society*, *85*, 104050. doi:10.1016/j.scs.2022.104050

Cavallari Murat, A. (Ed.). (1968). Forma urbana e architettura nella Torino Barocca. Dalle premesse classiche alle conclusioni neoclassiche. Unione tipografico-editrice torinese.

Champollion, P. (2015). Education and Territory: A Conceptual Framework. *SISYPHUS Journal of Education, 3*(2), 12-27.

Chassin, T., Ingensand, J., Christophe, S., & Touya, G. (2022). Experiencing virtual geographic environment in urban 3D participatory e-planning: A user perspective. *Landscape and Urban Planning*, *224*, 104432. doi:10.1016/j.landurbplan.2022.104432

Chassin, T., Ingensand, J., Touya, G., & Christophe, S. (2021). How do users interact with Virtual Geographic Environments? Users' behaviour evaluation in urban participatory planning. *Proceedings of the ICA*, *4*, 1–8. doi:10.5194/ica-proc-4-19-2021

Chen, C. (2020). *A Survey on Deep Learning for Localization and Mapping: Towards the Age of Spatial Machine Intelligence.* arXiv:2006.12567

Clifton, K., Ewing, R., Knaap, G. J., & Song, Y. (2008). Quantitative analysis of urban form: A multidisciplinary review. *Journal of Urbanism*, *1*(1), 17–45. doi:10.1080/17549170801903496

Cordts, M., Omran, M., Ramos, S., Rehfeld, T., Enzweiler, M., Benenson, R., Franke, U., Roth, S., & Schiele, B. (2016). The cityscapes dataset for semantic urban scene understanding. In Proceedings of the IEEE 2016 Conference on Computer Vision and Pattern Recognition. doi:10.1109/CVPR.2016.350

Croce, V., Caroti, G., De Luca, L., Piemonte, A., & Véron, P. (2020). Semantic annotations on heritage models: 2D/3D approaches and future research challenges. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *43*, 829–836. doi:10.5194/isprs-archives-XLIII-B2-2020-829-2020

Croce, V., Caroti, G., Piemonte, A., & Bevilacqua, M. G. (2021). From survey to semantic representation for Cultural Heritage: The 3D modeling of recurring architectural elements. *Acta IMEKO*, *10*(1), 98–108. doi:10.21014/acta_imeko.v10i1.842

Cullen, G. (1961). *The Concise Townscape*. Butterworth-Heinemann.

Cullen, G. (1976). *Il paesaggio urbano: morfologia e progettazione*. Calderini Editore.

De Carlo, G. (2015). *L'architettura della partecipazione*. Quodlibet.

De Carlo, G. (2019). *La città e il territorio. Quattro lezioni*. Quodlibet.

Doria, E. (2022). Automation of urban technological census. The historical centre of Bethlehem. *AGATHÓN | International Journal of Architecture, Art and Design*, *12*, 178–189. doi:10.19229/2464-9309/12162022

Doria, E., Carcano, L., & Parrinello, S. (2021). Object Detection Techniques Applied to UAV Photogrammetric Survey. In A. Giordano, M. Russo, & R. Spallone (Eds.), *Representation Challenges: New Frontiers of AR and AI Research for Cultural Heritage and Innovative Design*. FrancoAngeli. doi:10.3280/oa-845-c233

Duarte, F., & Ratti, C. (2019). Designing cities within emerging geographies: the work of Senseable City Lab. In T. Banerjee & A. Loukaitou-Sideris (Eds.), *The new companion to urban design*. Routledge. doi:10.4324/9780203731932-56

Duhn, I. (2012). Places for pedagogies, pedagogies for places. *Contemporary Issues in Early Childhood*, *13*(2), 99–107. doi:10.2304/ciec.2012.13.2.99

Dustdar, S., Nastić, S., & Šćekić, O. (2017). *Smart Cities. The Internet of Things, People and Systems*. Springer.

El-Mekawi, M., Ostman, A., & Hijazi, I. (2012). A unified Building Model for 3D Urban GIS. *ISPRS International Journal of Geo-Information*, *1*(2), 120–145. doi:10.3390/ijgi1020120

ESUM. (2017). *Human perception of urban environment.* https://www.esum.arch.ethz.ch

Geris, A., & Nesrin, Ö. (2020). Design Models for Developing Educational Virtual Reality Environments: A Systematic Review. In G. Guazzaroni & A. S. Pillai (Eds.), *Virtual and Augmented Reality in Education, Art, and Museums*. IGI Global. doi:10.4018/978-1-7998-1796-3.ch001

Girardin, F., Vaccari, A., Gerber, A., Birderman, A., & Ratti, C. (2009). Quantifying Urban Attractiveness from the Distribution and Density of Digital Footprints. *International Journal of Spatial Data Infrastructures Research*, *4*, 175–200. doi:10.2902/1725-0463.2009.04.art10

Gómez, J. A., Patiño, J. E., Duque, J. C., & Passos, S. (2020). Spatiotemporal Modeling of Urban Growth Using Machine Learning. *Remote Sensing*, *12*(1), 109. doi:10.3390/rs12010109

Heidi, S. (2018). *Non-Spatial Statistic for Analysing Human Perception of the Built Environment*. ETH Zurich.

Hoi, S. C. H., Wang, J., & Zhao, P. (2014). LIBOL: A Library for Online Learning Algorithms. *Journal of Machine Learning Research*, *15*(1), 495–499.

Ibrahim, M. R., Haworth, J., & Cheng, T. (2020). Understanding cities with machine eyes: A review of deep computer vision in urban analytics. *Cities (London, England)*, *96*, 102481. doi:10.1016/j.cities.2019.102481

International Association of Educating Cities. (2020). *Charter of Educating Cities*. https://www.edcities.org/en/charter-of-educating-cities/

Jankowski, J., & Hachet, M. (2015). Advances in Interaction with 3D Environments. *Journal of the European Association for Computer Graphics*, *34*(1), 152–190.

Jenkins, H. (2009). *Confronting the Challenges of Participatory Culture: Media Education for the 21st Century*. MIT. doi:10.7551/mitpress/8435.001.0001

Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A., & Hall, C. (2016). *NMC Horizon Report: 2016 Higher Education Edition*. The New Media Consortium.

Kamrowska-Załuska, D. (2021). Impact of AI-Based Tools and Urban Big Data Analytics on the Design and Planning of Cities. *Land*, *10*(11), 1209. doi:10.3390/land10111209

Kandt, J., & Batty, M. (2021). Smart cities, Big Data and urban policy: Towards urban analytics for the long run. *Cities (London, England)*, *109*, 102992. doi:10.1016/j.cities.2020.102992

Katsionis, G., & Virvou, M. (2008). Personalised e-learning through an educational virtual reality game using Web services. *Multimedia Tools and Applications*, *39*(1), 47–71. doi:10.100711042-007-0155-2

Kucharczyk, M., Hay, G. J., Ghaffarian, S., & Hugenholtz, C. H. (2020). Geographic Object-Based Image Analysis: A Primer and Future Directions. *Remote Sensing*, *12*(12), 2012. doi:10.3390/rs12122012

Kuznetsov, S., & Paulos, E. (2010). Rise of the Expert Amateur: DIY Projects, Communities, and Cultures. *Proceedings of the 6th Nordic Conference on Human Computer Interaction: Extending Boundaries*. 10.1145/1868914.1868950

La Placa, S., & Doria, E. (2022). Reliability of Dtms Obtained with Mobile Fast Surveys Techniques. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *46*, 299–306. doi:10.5194/isprs-archives-XLVI-2-W1-2022-299-2022

Lazer, D., Pentland, A., Adamic, L., Aral, S., Barabási, A., Brewer, D., Christakis, N., Contractor, N., Fowler, J., Gutmann, M., Jebara, T., King, G., Macy, M., Roy, D., & Van Alstyne, M. (2009). Computational Social Science. *Science*, *323*(5915), 721–723. doi:10.1126cience.1167742 PMID:19197046

Lee, Y. W. & Huh, J. H. (2020). Evaluation of Urban Landscape Outdoor Advertisement Signboards Using Virtual Reality. *Land*, *9*(5), 141.

Lerner, R. M., & Silbereisen, R. K. (2007). Approaches to Positive Youth Development. *Sage (Atlanta, Ga.)*.

Lewin, K. (1936). *Principles of topological psychology*. Edizioni OS. doi:10.1037/10019-000

Li, X., Hijazi, I., Koning, R., Lv, Z., Zhong, C., & Schmitt, G. (2016). Assessing Essential Qualities of Urban Space with Emotional and Visual Data Based on Gis Technique. *ISPRS International Journal of Geo-Information*, *5*(11), 218. doi:10.3390/ijgi5110218

Lin, H., Gao, J., Zhou, Y., Lu, G., Ye, M., Zhang, C., Liu, L., & Yang, R. (2013). Semantic decomposition and reconstruction of residential scenes from LiDAR data. *ACM Transactions on Graphics*, *32*(4), 1–10. doi:10.1145/2461912.2461969

Liu, Y., Xu, C., Pan, Z., & Pan, Y. (2006). Semantic modelling for ancient architecture of digital heritage. *Computers & Graphics*, *30*(5), 800–814. doi:10.1016/j.cag.2006.07.008

Løvlie, L. (2007). The pedagogy of place. *Nordic Studies in Education*, *27*(1), 32-36.

Luusua, A., Ylipulli, J., Foth, M., & Aurigi, A. (2022). Urban AI: Understanding the emerging role of artificial intelligence in smart cities. *AI & Society*, *30*, 1–6. doi:10.100700146-022-01537-5 PMID:36196366

Lynch, K. (1960). *L'immagine della città*. Marsilio Editore.

Maietti, F., Di Giulio, R., Medici, M., Ferrari, F., Ziri, A. E., Turillazzi, B., & Bonsma, P. (2020). Documentation, Processing, and Representation of Architectural Heritage through 3D Semantic Modelling: The INCEPTION Project. In C. M. Bolognesi & C. Santagati (Eds.), *Impact of Industry 4.0 on Architecture and Cultural Heritage*. IGI Global. doi:10.4018/978-1-7998-1234-0.ch009

Marr, D. (1982). *Vision. A Computational Investigation into the Human Representation and Processing of Visual Information*. Freeman & Company.

Marr, D., & Nishihara, H. K. (1978). Representation and Recognition of the Spatial Organization of Three-Dimensional Shapes. In *Proceedings of the Royal Society of London. Series B, Biological Sciences*. The Royal Society Publishing.

Mehta, V. (2013). Evaluating Public Space. *Journal of Urban Design*, *19*(1), 53–88. doi:10.1080/13574809.2013.854698

Mitchell, W. J. (1996). *City of Bits*. MIT Press.

Moretti, M. (2016). *Senso e paesaggio. Analisi percettive e cartografie tematiche in ambiente GIS*. Franco Angeli.

Mulè, P. (2022). The Inclusive School as an Educational and Educating Community between the Family, the Territory and the Third sector: New Pacts of Educational Co-responsibility to be Redefined and Consolidated. *Formazione & Insegnamento*, *20*(I), 107–115. doi:10.7346/-fei-XX-01-22_10

Nickerson, R. S., & Zodhiates, P. P. (1988). *Technology in education: Looking toward 2020*. Lawrence Erlbanm Associates.

Nugrahaningsih, N., Porta, M., & Ricotti, S. (2013). Gaze behaviour analysis in multiple-answer tests: An Eye tracking investigation. *Proceedings of 12th International Conference on Information Technology Based Higher Education and Training (ITHET)*. doi: 10.1109/ITHET.2013.6671020

Nuzzaci, A. (2016). Promoting and supporting the methodological skills of teachers and trainers for the successful of the teaching and the quality of the training [Scienza dell'insegnamento, formazione e competenze metodologiche degli insegnanti e dei formatori: Dalla progettazione alla valutazione]. *Formazione & Insegnamento. European Journal of Research on Education and Teaching*, *14*(3), 17–36.

Nuzzaci, A. (2017). Technological skills and initial teacher training: An exploratory research on attitudes of the future teachers towards ICT. *International Journal of Digital Literacy and Digital Competence*, *8*(3), 39–54. doi:10.4018/IJDLDC.2017070103

Nuzzaci, A. (2018). Formazione degli insegnanti e 'pensiero pedagogico scientifico': un insegnamento orientato dai 'venti della ricerca' [Teacher training and 'scientific pedagogical thought': a teaching oriented by 'research winds']. *Formazione & Insegnamento. European Journal of Research on Education and Teaching*, *16*(2), 133–151.

Nuzzaci, A. (2019). Instructional design e assessment in contesti interculturali. In E. M. Bruni (Ed.), *Una pedagogia possibile per l'intercultura*. FrancoAngeli.

Ofenhuber, D., & Ratti, C. (2014). *Decoding the City: Urbanism in the Age of Big Data*. Birkhäuser Basel. doi:10.1515/9783038213925

Panciroli, C., Rivoltella, P. C., Gabbrielli, M., & Zawacki Richter, O. (2020). Artificial Intelligence and education: new research perspectives. *Form@re, 20*(3), 1–12.

Parrinello, S., & De Marco, R. (2022). Experiences of Digital Survey Data Applied for the Involvement of Societal Smart-Users in Cultural Heritage Awareness. In F. M. Ugliotti & A. Osello (Eds.), *Handbook of Research on Implementing Digital Reality and Interactive Technologies to Achieve Society 5.0* (pp. 344–386). IGI Global. doi:10.4018/978-1-6684-4854-0.ch016

Parrinello, S., De Marco, R., & Galasso, F. (2020). An urban modelling protocol through catalogues and technological modules. From digital survey to the 3D Information System for the historic center of Bethlehem. *Dn, 2020*(6), 52–69.

Parrinello, S., & Picchio, F. (2017). Databases and complexity. Remote use of the data in the virtual space of reliable 3D models. *Architecture and Engineering*, *2*(2), 2017. doi:10.23968/2500-0055-2017-2-2-27-36

Power, K., Almeida, S. C., & Cowan, N. (2023). Adaptation of environmental and sustainability education during the COVID-19 pandemic. In *Research and Teaching in a Pandemic World: The Challenges of Establishing Academic Identities During Times of Crisis* (pp. 157–169). Springer Nature Singapore.

Presidenza Italiana del Consiglio dei Ministri. (2021). *Pandemia, disagio giovanile e Neet*. https://www.politichegiovanili.gov.it/media/gmghlnp0/relazione-tecnica_pandemia-disagio-giovanile-neet.pdf

Psotka, J. (1995). Immersive training systems: Virtual reality and education and training. *Instructional Science*, *23*(5-6), 5–6, 405–431. doi:10.1007/BF00896880

Ratti, C., & Claudel, M. (2016). *The City of Tomorrow*. Yale University Press.

Rieder, E., Schmuck, M., & Tugui, A. (2023). A Scientific Perspective on Using Artificial Intelligence in Sustainable Urban Development. *Big Data and Cognitive Computing*, *7*, 1–3. doi:10.3390/bdcc7010003

Roussou, M., Oliver, M., & Slater, M. (2006). The virtual playground: An educational virtual reality environment for evaluating interactivity and conceptual learning. *Virtual Reality (Waltham Cross)*, *10*(3-4), 227–240. doi:10.100710055-006-0035-5

Saini, M. K., & Goel, N. (2019). How smart are smart classrooms? A review of smart classroom technologies. *ACM Computing Surveys*, *52*(6), 1–28. doi:10.1145/3365757

Saygi, G., Agugiaro, G., Hamamcioglu-Turan, M. & Remondino, F. (2013). Evaluation of GIS and BIM Roles for the Information Management of Historical Buildings. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, *2*(5), 283–288.

Schaeben, C. (2017). *People's Perception of Urban and Architectural Features* [Master Thesis, ETH Zurich]. ETH Zurich Research Collection.

Shuyan, H., Dexuan, S., Leiqing, X., Yu, Y., Shurui, Y., Feng, S., Yuhao, Z., Xiaodong, L., & Hu, D. (2022). Behaviour in public open spaces: A systematic review of studies with quantitative research methods. *Building and Environment*, *223*, 109444. doi:10.1016/j.buildenv.2022.109444

Silberman, N., & Purser, M. (2012). Collective memory as affirmation: People-centred cultural heritage in a digital age. In E. Giaccardi (Ed.), *Heritage and social media: Understanding heritage in a participatory culture* (pp. 13–39). Routledge.

Taylor, M. C. (2002). *The Moment of Complexity: Emerging Network Culture*. University of Chicago Press.

Trisciuzzi, L., Nuti, L., & Viaggi, M. (1993). *Il territorio come libro di testo*. Giunti e Lisciani.

UNESCO Institute for Lifelong Learning. (2021). *ESD implementation in learning cities*. https://unesdoc.unesco.org/ark:/48223/pf0000379535?posInSet=10&queryId=84896d88-79b6-4a07-92a4-82a6352fa98d

UNICEF. (2021). *The State of the World's Children, On My Mind: Promoting, protecting and caring for children's mental health*. https://www.unicef.org/media/108161/file/SOWC-2021-full-report-English.pdf

Vacca, G., Quaquero, E., Pili, D., & Brandolini, M. (2018). GIS-HBIM Integration for the Management of Historical Buildings. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2*, 1129–1135. doi:10.5194/isprs-archives-XLII-2-1129-2018

Walkington, C. A. (2013). Using adaptive learning technologies to personalize instruction to student interests: The impact of relevant contexts on performance and learning outcomes. *Journal of Educational Psychology*, *105*(4), 932–945. doi:10.1037/a0031882

Ware, C. (2000). *Information Visualization: Perception for Design*. Morgan Kaufmann.

Yigitcanlar, T., Butler, L., Windle, E., Desouza, K. C., Mehmood, R. & Corchado, J. M. (2020). Can Building "Artificially Intelligent Cities" Safeguard Humanity from Natural Disasters, Pandemics, and Other Catastrophes? An Urban Scholar's Perspective. *Sensors*, *20*(10), 2988.

Zhang, C., Lv, R., Chen, X., & Jiang, Y. (1570). Research on Virtual Roaming Technology of Urban Scene Based on Multi-mode Human-Computer Interaction. *Journal of Physics: Conference Series*, *1*, 012096.

KEY TERMS AND DEFINITIONS

Close-Range Digital Survey: Digitisation technology used for a variety of purposes, including mapping, surveying, and forensics. It can be used to create three-dimensional models of objects, which can be used for a variety of purposes, including engineering and design. In its processes, it uses photography and geometric calculations to create an accurate 3-dimensional model of an object or environment.

Community Educational Pacts: Introduced in the 2020-21 School Plan by the Italian Minister of Education, start from the concept of a specific law for the enhancement of the school as an active community. It is a tool introduced to give the possibility to local authorities, institutions, public and private, third sector realities and schools to sign specific agreements, thus strengthening not only the school-family alliance, but also that between the school and the whole educating community and to experiment with new forms of teaching that lead children to learn by doing: in museums, laboratories, companies. The school becomes a space for the participation of the whole local community, for the consolidation of the identity of a territory, to strengthen belonging to a community.

Decentralised Smart-Classrooms: Educational institutions are envisioned as principal agents for addressing the current sustainability challenge that society is facing. Education for Sustainable Development (ESD) is transformational and concerns learning content and outcomes, pedagogy and the learning environment in itself. ESD entails rethinking the learning environment (physical and virtual) in line with sustainable development, which implies classrooms' transformation towards learner engagement, formative assessments and active methodologies. The concept of Decentralised Smart Classroom shows a high level of adequacy for using problem and project-based learning, case study and cooperative inquiry methods because of its characteristics in terms of technology developments, environmental conditions and processes.

Digital Twin: It defines a virtual model developed to duplicate a physical object or space. The purpose of replication is not limited to the physicality of the object/space, its geometry, texture and perception features. It regards more widely also the information apparatus linked to the object/space, involving qualitative and quantitative values of performance. In this way, a unique relation can be established between a physical object and its Digital Twin, supporting its application as a processing system, to run simulation, study performances and suggest possible improvements to be applied back to the real object or space.

Digital Urban Image: Though Lynch's urban image theory has not been applied to the design of a virtual city, its efficiency forenhancing wayfinding has been proved in many studies. The underlying assumption is that the city image, which is obtained from sketch maps or interviews, provides information on the imageability of the city elements. Lynch defined image-ability as a "quality in a physical object which gives it a high probability of evoking a strong image in any given observer". The integration of digital tools for the collection, analysis and visualisation of data enables the simulation of possible transformation scenarios giving to urban image a dynamic and previsional value for the present and for future transformations.

Knowledge-Based Intelligence Systems: Computer programs that use a centralised repository of data known as a knowledge base to provide a method for problem-solving. Knowledge-based systems are a form of artificial intelligence (AI) designed to capture the knowledge of human experts to support decision-making. An expert system is an example of a knowledge-based system because it relies on human expertise. The inference engine processes and locates data based on requests, similar to a search engine. A reasoning system is used to draw conclusions from data provided and make decisions based on if-then rules, logic programming or constraint handling rules. Users interact with the system through a user interface.

Mental and Conceptual Maps: Forms of graphical representation of human thought. The mental map is theorised by British cognitivist Tony Buzan, starting with some thoughts on note-taking techniques. The purpose is to implement visual memory and thus memorization of concepts and information in recall. The conceptual map represents the network of relationships between several concepts, starting with an initial one. This learning methodology was theorised by Joseph Novak in the 1970s. Novak's theories are strongly related to those of David Ausubel. Conceptual maps are often related to Buzan mind maps. From the latter, concept maps differ in their distinctly cognitive orientation, which makes them particularly useful in contexts such as knowledge management, training, and problem solving. In contrast, mind maps, which are more creatively oriented, are used in an evocative and emotional key. The use of software for the digital creation of maps has enabled their use in the operational sphere as well. In this sense, interesting applications are those where has been solved the integration between the evocative baggage and hierarchical-associative structure of mind maps, the expressiveness of conceptual maps and the computer tools typical of office automation. The concept of *solution maps* has been introduced in the literature in this regard.

Territorial Education: Territory becomes a space of experience, that enlarged educational space; it is co-responsible in redefining the school curriculum Territorial education is a new model of education that cares about the learning of the subjects more fragile and accompany the growth of each and everyone, to face the future challenges for a sustainable, cultural and social development, prosperity and welfare. The topic on territorial education in a digital learning perspective assumes a founding reflection on interdisciplinary technologies to support the implementation of urban skills centred around elements of territorial permanence. The idea of addressing pedagogic practices on territorial education through the theme of Information Systems for the city (exploring also the interaction between AI learning systems and urban models) supports the educational function of the city. It means to offer interpretative pedagogical tools of the city and adaptive solutions to meet the needs of users from the co-creation of innovative educational and training tools related to experience-based learning, situated learning, the use of service-learning approaches, citizen science, participatory action research, and conflict mediation.

Urban Learning Analytics: Empowered by AI, are meant as a learning workflow which continuously assesses the potential of innovative solutions in the visual interpretation and correspondence of urban assets to educational and social impacts on the citizens. It is an horizon in line with the principles and recommendations of the OECD, AI Policy Observatory (https://oecd.ai/en/ai-principles), which pushes the different learners, structures, institutions and territorial organisations to combine their skills with those of the others, to confront each other and to emerge from self-referentiality.

Virtual Learning Territories: Cities and landscapes in digital form with significant challenges in applying the principles of transformative learning in online, higher education contexts. Integrating theory with practice and simultaneously ensuring the authenticity of that practice creates a rich and complex virtual territory for research and opportunities for building upon theory. The principles of transformative learning provide vital navigation tools to learners, educators and researchers alike for exploring and inhabiting the online territory. In this way, it becomes important to acquire specific skills that help young citizens to think and live as citizens, advocating for a more democratic society and an ‘urban citizenship’ in which they believe, preparing them from the primary education level to play a vital role in becoming agents of change rather than mere observers of change. In order to build a stable, peaceful and inclusive democracy within sustainable spaces, environments and cities, today’s rapidly changing conditions require the use of relevant and increasingly technologies to strengthen the individual’s awareness of urban space, enable closer collaboration between groups, communities and institutions, and changing the way people learn to experience the city and learn from it. Indeed, it is in urban spaces, as democratic spaces, that ‘acts of citizenship’ take place and that links between various ‘civic spaces’ are built.