Chapter 10
EEB Project System Integration and Technology Sperimentation Matrix

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ABSTRACT

Today an increasing number of cities are equipping themselves with three-dimensional urban modelling and simulation platforms for energy management to integrate both spatial and semantic data for enabling better decision-making. The work presented in this chapter is the result of the study carried out by Politecnico di Torino within the Energy Efficient Buildings (EEB) project. Collected data on urban and building scale are managed in specialized, independent, and heterogeneous domains such as GIS, BIM, and IoT devices for energy and electrical monitoring. Possible relationships among these datasets in the perspective of system integration have been carried out according to a rich matrix of experimentations. Specific tools, including innovative visualization technologies and web services, are put in place to allow final users to benefit from this data. The infrastructure is intended to establish a common interoperable ground among heterogeneous networks to achieve the goal of smart cities digital twins.

INTRODUCTION

The great challenges of this Millennium such as urbanization, resource efficiency, climate change, responsible consumption and production, globalization, circular economy, and connectivity frame cities as a reference point for future development. Tackling these priorities requires a systemic approach to innovation that aims for a system-wide transformation by affecting the economic, social and environmental dimensions as well as their interconnections. This implies a trans-disciplinary solutions-oriented perspective that integrates technology, advanced models, organization, governance and regulation and involves co-creation of knowledge and co-delivery of outcomes with economic, industrial and research actors, public authorities and civil society (European Commission, 2020). As is known, a Smart City provides "the effective integration of physical, digital and human systems in the built-up environment to

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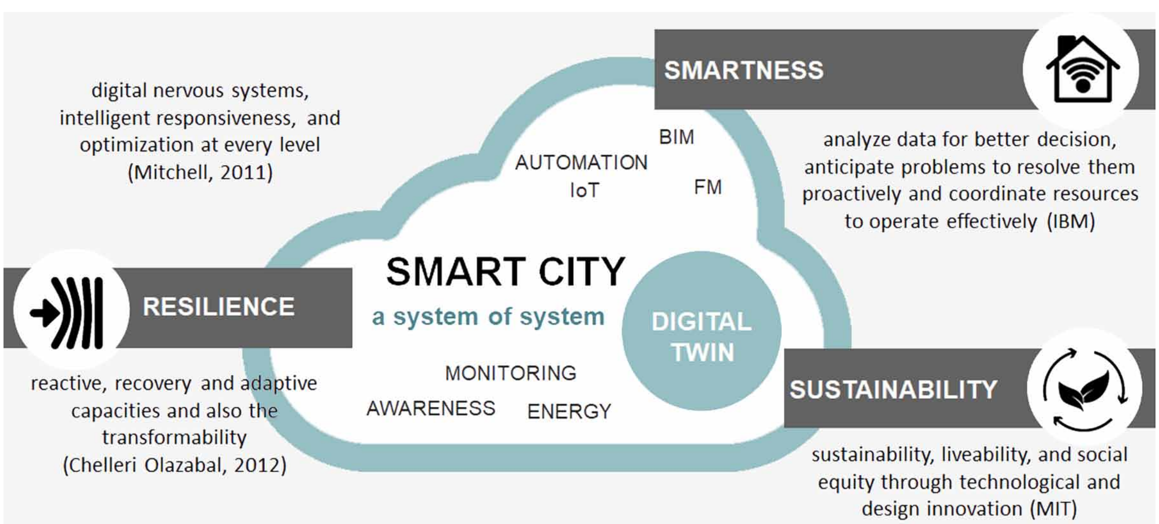
deliver a sustainable, prosperous and inclusive future for its citizens" (The British Standards Institution, 2014). In that framework, it is not a single system that defines an intelligent city, but an interconnected network of innovations, "a system of systems" (Mitchell, 2001), focusing on the interaction between network and network and between the city and final users to make sure that the city can be more suitable to the citizen's needs, and the citizen is increasingly active in the creation of new sustainable cities. Although often associated with energy efficiency and sustainability, smart cities are much more than that as outlined in Figure 1, concerning the efficiency of urban operation and services. Over the past years, Information and Communication Technology (ICT) allowed the correlation of data, processes and methods often very different from each other to make them available. At the same time, it links and strengthens networks of people, businesses, infrastructures, energy and spaces, besides providing intelligent organizational and governance tools (European Parliament, 2014). Cities and building managers need to have systems to analyze data for better decisions, anticipate problems to resolve them proactively and coordinate resources to operate effectively (IBM Corporation, 2012). Even more urgent today is to dwell on the concept of resilience exploring "the reactive, recovery and adaptive capacities and also the transformability of urban systems" (Chelleri & Olazabal, 2012). The resilient city is continuously facing an ever-widening range of pressures that focus on time in its various expressions: degradation, human neglect, natural hazard events, as well as transformation, innovation, and the constant evolution of human needs. To govern this evident complexity is imperative to refer to a knowledge system of the built heritage that from closed and static must become increasingly dynamic and updated with real-time information (Shah et al., 2019).

Figure 1. Smart City scenario



According to this vision, a more future-oriented definition of smart cities already comes from the Chinese National Smart City Standardization. It talks about "a new concept and a new model, which applies to the new generation of information technologies such as the internet of things, cloud computing, big data and space/geographical information integration, to facilitate the planning, construction, management and smart services of cities" (ISO/IEC JTC 1, 2014). Therefore, to works better, a smart city needs to be structured around a digital twin (Wright & Davidson, 2020; Riddhi et al., 2020) representative both of tridimensional representation with information relating to its operation and of how people interact with the built environment. Already successful in manufacturing with predictive and fault prevention functions, the potential of digital twins for buildings, infrastructure and entire cities is yet to be fully discovered. In this scenario, digital models can be seen as the foundation of this state-of-the-art knowledge and management systems. In fact, it is possible to trace a clear connection between Building Information Modelling (BIM), Geographic Information System (GIS) and the Smart City concept as they imported in the world of architectural and territorial design powerful tools able to give excellent data richness to the projects. As buildings have a significant impact on cities in terms of economic, efficiency and quality of life, the strengths of system integration are summarized below.

- The BIM environment is powerful for planning and simulations, enabling best design solutions with a reduction of errors, disputes, risks, cost, and time whether for new construction or renovation due to the computations and visualizations capability.
- Collaboration and data sharing enabled by the BIM methodology are the keywords for the entire construction value chain. Moreover, BIM data optimization during the building lifecycle promotes smarter facilities management services and improve the relationship between the building industry and the other sectors.
- BIM supports all levels of the communication process, exploiting new ways for data visualization and the presentation of projects. Thanks to the three-dimensionality of space and the interaction with new technologies, designers, public administrations as well as citizens can better understand design solutions and implement knowledge about the heritage.
- BIM and GIS can provide a broader perspective to analyze and manage the existing heritage, focusing on costs and energy saving, and, on the other to check the potential use of the assets and control new urban development. According to the possibility of integration with other datasets and the Internet of Things (IoT), the building manager can have a cross-scale dynamics vision and access real-time information about the service installed, making accurate assessments of the asset operating condition, enabling its better usage and utilization.

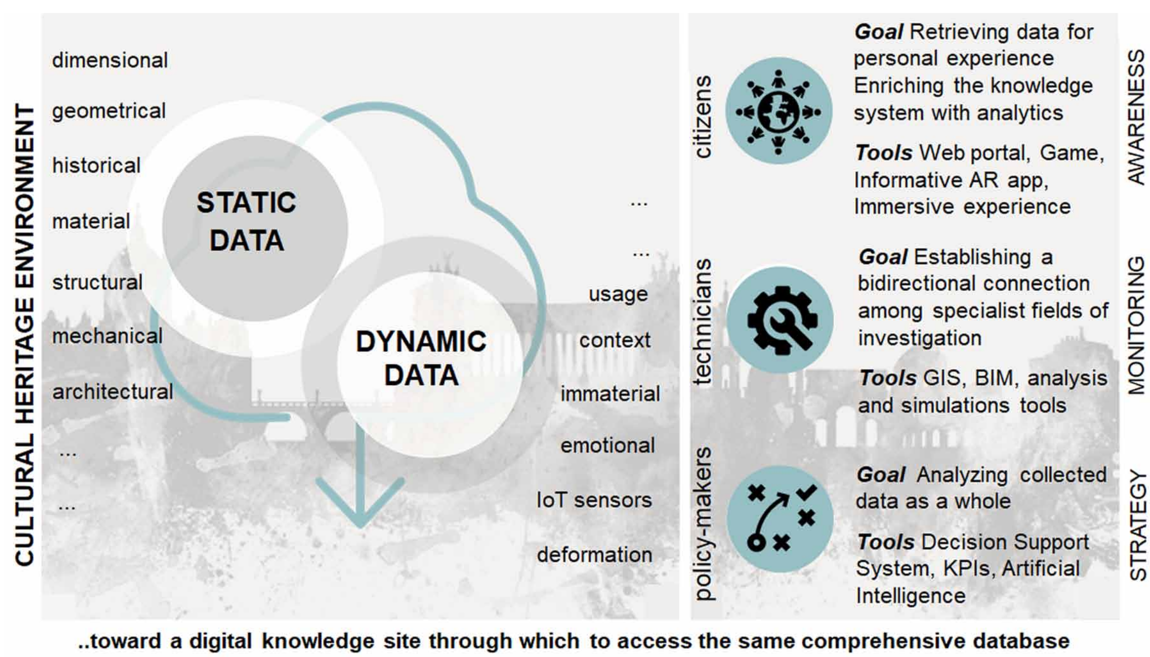
The construction industry can make a significant contribution to meet the long term objectives by adopting a multi-scale approach, from the building to the city scale, that includes (i) knowledge sharing among players and stakeholders, (ii) performance monitoring and management (iii) use of collaborative building management tools that integrate the whole lifecycle information from sourcing to building construction, facility management and refurbishing and end-of-life, (iv) a behavioural change of end-users and consumers regarding energy saving as well as conservation and maintenance. Hence, only an integrated approach that includes technology, collaborative tools, digital buildings, facility management and user awareness can have a tangible impact on the cities of tomorrow.

The chapter illustrates the results of a preparatory study of the Politecnico di Torino in the digital twin perspective. From the digitalization of the built environment in the urban field, the possibilities of the interdisciplinary use of the deriving information between the different data domains are investigated. The background is the Zero energy buildings in smart urban districts project (Energy Efficient Buildings - EEB), which aims to pursue the objective of increasing energy efficiency of existing buildings and urban districts, through the pervasive use of non-invasive technologies for the real-time monitoring and control of environmental parameters and of the energy production/consumption using smart devices.

Methodology

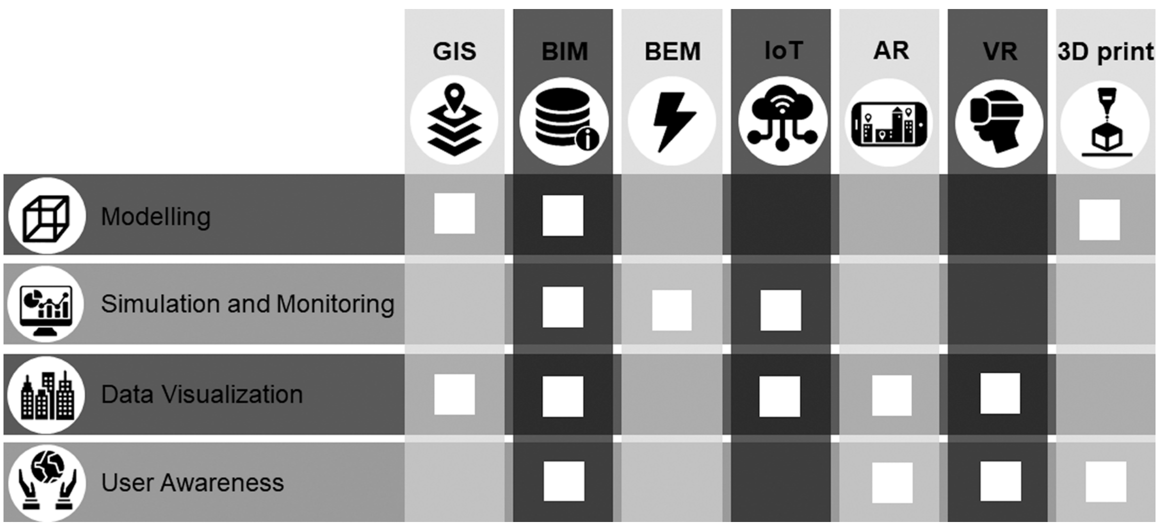
Over the years, a lot of time and resources are allocated to the "knowledge site" to survey, map, represent, and restore the memory and the current state of a building. For this purpose, technologies are considered fundamental in setting up an integrated knowledge framework from which it is possible to retrieve information for ordinary management conditions. In these terms, the research is directed towards innovative tools of data survey, collection, use and visualization to assess, maintain and prevent the built environment. An in-depth process of data acquisition and interconnection focused on the intrinsic features as well as the immaterial values of a place can raise awareness public administration, technical figures and citizens in terms of historical knowledge and identity. This approach can facilitate regeneration, urban resilience processes, participatory and sustainable planning. In this scenario, it is central to consider which information must be represented and in what way, so that they become descriptors as targets to be found in previously during on-site digital survey and in post-processing as information modelling strategies. Tools as GIS, BIM, IoT, Virtual (VR) and Augmented Reality (AR) can contribute to achieving the vision of digital twin of the built environment to manage the knowledge site more accurately in a digital way sharing and providing information from different perspectives.

Figure 2. Knowledge site methodological framework



As shown in Figure 2, the mission pursued is to establish a comprehensive database network to which different actors can access according to differentiated levels of information. Within this digital environment, Policy-makers are envisioned to be able to analyze the collected data as a whole, supported by Decision Support Systems (DSS), Key Performance Indicators (KPIs), and Artificial Intelligence (AI). Technicians could establish a bidirectional connection among specialist fields of investigation, taking full advantage of software interoperability for analysis and simulation. Finally, the citizens could use the data to enrich their personal experience, using virtual and augmented reality game-based informative applications, and provide feedback (White et al., 2021). Specifically, as stated in Figure 3, the proposed method seeks to integrate different systems, domains and technologies according to a rich matrix of experimentations to achieve the following goals: (i) modelling; (ii) simulation and monitoring; (iii) data visualization; (iv) user awareness.

Figure 3. System integration and technology experimentation matrix



The approach described below is generally valid; however, it is also illustrated by applying to a case study to provide a tangible example. Even if starting from a defined topic related to the energy field, the pilot shows how the most advanced technologies are used in a synergistic way to reach the mentioned objectives.

Case Study

Settimo Torinese, a medium-sized city of the Turin metropolitan area, was selected as a demonstrator of the EEB project to establish a cloud-based software architecture for monitoring and modelling buildings energy behaviour. With the aim of creating a system of interest to several users, both private and public buildings were considered to set information models useful for the realization of energy and management optimization assessments. The city consists of 300 census sections and approximately 3,600 residential buildings with 47,831 inhabitants. In this area, three representative public buildings, including a recently constructed public library and offices, a primary and a secondary school were mapped. The middleware is in charge of enabling the interoperability between the heterogeneous data-sources by three-layers. The bottom is the Data-sources integration layer that integrates heterogeneous hardware and software technologies by abstracting their features into Web Services. Specific IoT gateways were developed for different standards and protocols, such as ZigBee and Spirit. BIM, GIS and weather stations are software data-sources. The core of the middleware is the Services Layer that offers the components for developing generic applications and distributed services (Bottaccioli et al., 2017). Finally, the Application Layer provides a set of API and tools to develop a distributed application for building management and to post-process collected information. From this application context, the integration processes achieved are detailed in the following.

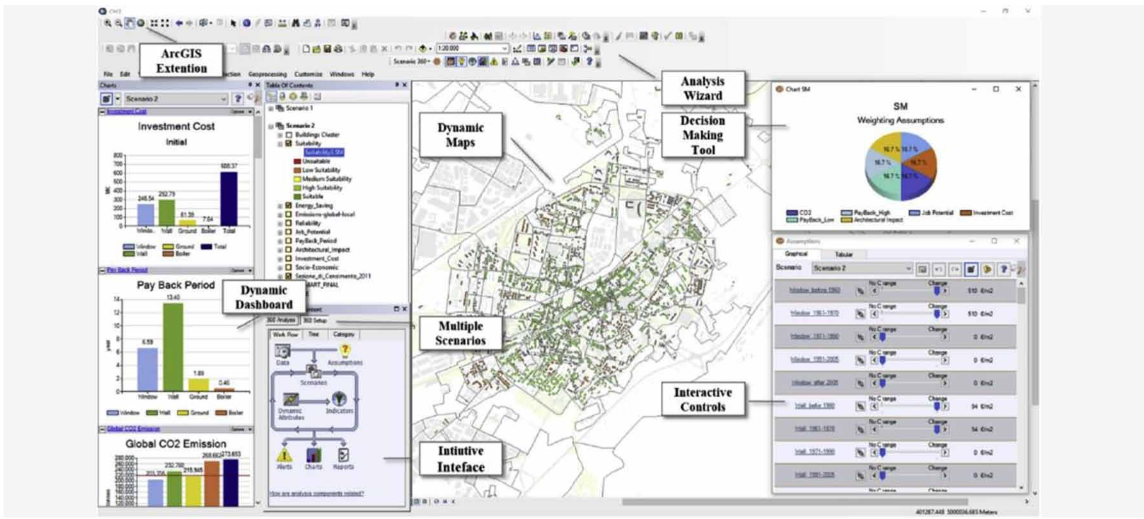
GIS-BIM Modelling

Since the city is the heart of the experiments on digital twins for the construction sector, there is immediately a definite problem in finding and managing information which goes from general to particular and vice versa. Through a GIS system, as anticipated, it is possible to obtain a general and transversal view of territory according to different perspectives and points of view. By superimposing the multiple information layers available, a large-scale representation can be managed, and cross-type queries can be performed. On the other hand, BIM environments provide a complete and detailed description of the characteristics of a single building or complex to promote better maintenance and retrofitting actions. The collection and visualization of data concerning an urban district are still considered a crucial point in the process and a challenging field of research.

Geographic Information System

A geospatial statistical model of the building stock can be developed in the GIS environment to provide a representative picture of the city's distribution of selected factors. As an example, the case of current energy consumption performance is given to critical areas on maps. In particular, a mixed approach methodology was adopted to joints Urban Energy Consumption Mapping (UECM), with Multi-Criteria Decision Analysis (MCDA) (operation research approach) and Stakeholders Mapping (SM) (social research approach) due to their complementarity in fulfilling different tasks in the urban energy planning process (Torabi Moghadam et al., 2017). The main phases developed regards the building stock data collection, geo-referencing territorial data, and the building stock characterization. The thermal energy consumption data for space heating was derived by the energy-use registered by the district heating system considering a period of 4 years. The geometrical features were defined from an *ArcGIS* map. A large building stock technical and performance characteristics were taken from the National Census database (ISTAT, 2011), while the EPC database (APE, 2015) was used for new building construction. The collected data were analyzed and elaborated to create a supporting dataset. Starting from this mapping, a Multicriteria Spatial Decision Support System (MC-SDSS) was built through the *CommunityViz* platform (Communityviz, 2020) and using Suitability Analysis and Interactive Impact Assessment models. The integrated platform allows the user to consider socio-economic, technical and environmental dimensions. *Scenario 360* Advanced Formula Editor was used to structure, edit, display and syncs all the components of the model by using dynamic attribute and indicators. As a result, the baseline and the possible future scenarios can be displayed by maps and charts in real-time (Torabi Moghdam & Lombardi, 2019) as shown in Figure 4. The tool is configured in a participatory and collaborative way to define and analyze the different energy saving-scenarios at urban scale considering various aspects of the problem.

Figure 4. CommunityViz interface (Torabi & Lombardi, 2019)
Source: (Torabi & Lombardi, 2019)

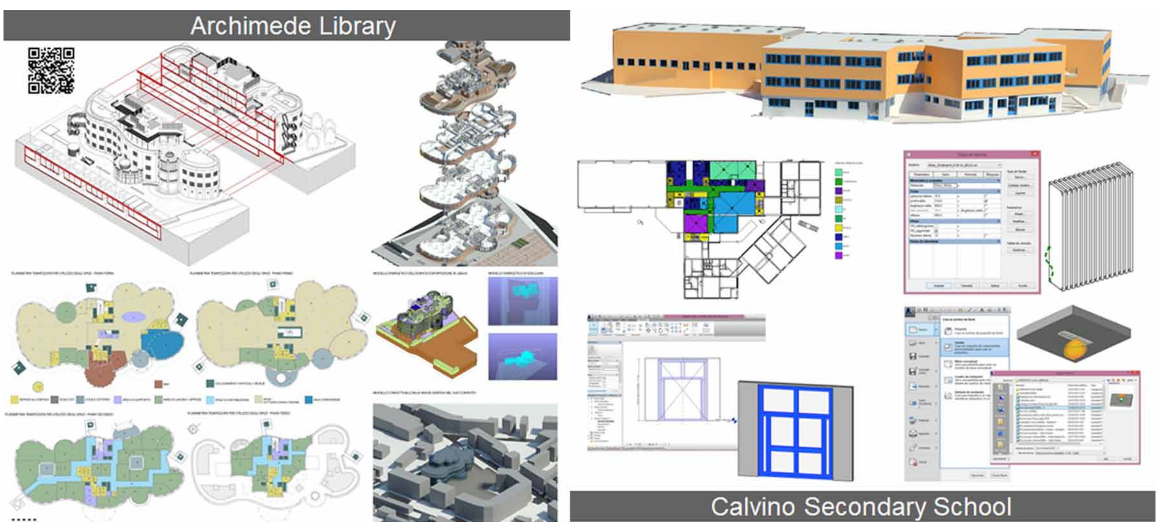


According to previous experience (Vinco et al., 2018), a simulator of solar radiation and photovoltaic production was realized on GIS basis to analyze the potential and the photovoltaic production within intelligent urban districts. Moreover, an innovative methodology for short-term (e.g. 15 minutes) forecasting of Global Horizontal Solar Irradiance (GHI) was tested. The neural network has been trained and validated with a four years solar radiation dataset collected by a real weather station. The GHI forecast output is used as input to the previously mentioned photovoltaic simulator to predict energy production in short-term time period (Aliberti et al., 2018).

Building Information Model

On the other side, single buildings can be analyzed more deeply by creating a BIM as-is model. Starting from the collection of technical documents, the current state of the public buildings selected as case studies was verified by an expeditious on-site survey focusing on possible optimization actions concerning space and energy management. In this sense, a qualitative rather than quantitative digitalization activity was considered. Realizing an effective BIM model does not just mean to implement all the objects and their properties, but it is necessary to organize information so that it can be functional in retrieving data for facility management activities (Teicholz, 2013). Considering the resources currently available for this type of activity, both in terms of data acquisition and updating, a conceptual and simplified representation was set up with a basic but consistent dataset. Accordingly, the models realized include the characterization of the building envelope, the inventory of spaces and intended use, and the mapping of system terminals. These objects are reliable in terms of number, size, and qualitative position in the room. To establish a link with IoT dataset, fictitious elements representative of the sensors installed in the field were introduced. The focus was on establishing a modelling methodology that could be valid and replicable to analyze the assets belonging to the same real estate portfolio. Although the parametric model is a database in itself, consulting it may not be immediate. For this reason, a unified template was created to obtain homogeneous and comparable outputs among buildings promoting immediate use of data by the Facility Manager/Department. The value of this study is traceable in the approach used aimed at making sense of BIM data to use it for lifecycle asset management effectively. Schedules and themed plan views were exploited for optimizing the architectural modelling phase and controlling the digital model in the perspective of interoperability and data integration. By appropriate use of shared parameters and equations within schedules, it is possible to make the most of their format for each different purpose, from analysis to managing or reporting. The accurate and structured inventory of the building elements allows relating information about spaces and relative intended use with the facilities costs and the energy consumption. In this way, it is possible to obtain several Key Performance Indicators (KPIs) for evaluating the utilization rate of the space and occupancy as well as maintenance costs chargeback (Ugliotti, 2017). The relationship between the model and facility management services can take place (i) through direct use of data and functionality setting in the modelling environment (e.g. building registry, space accessibility checks, fire-fighting requirements, minimum dimension for windows to guarantee the amount of sunlight), (ii) by exporting data to other formats through interoperability to perform simulations with specialized software (e.g. energy, computational fluid dynamics, structural, seismic) (iii) through the integration of data with other data sources (e.g. CAFM, CMMS, GIS, IoT).

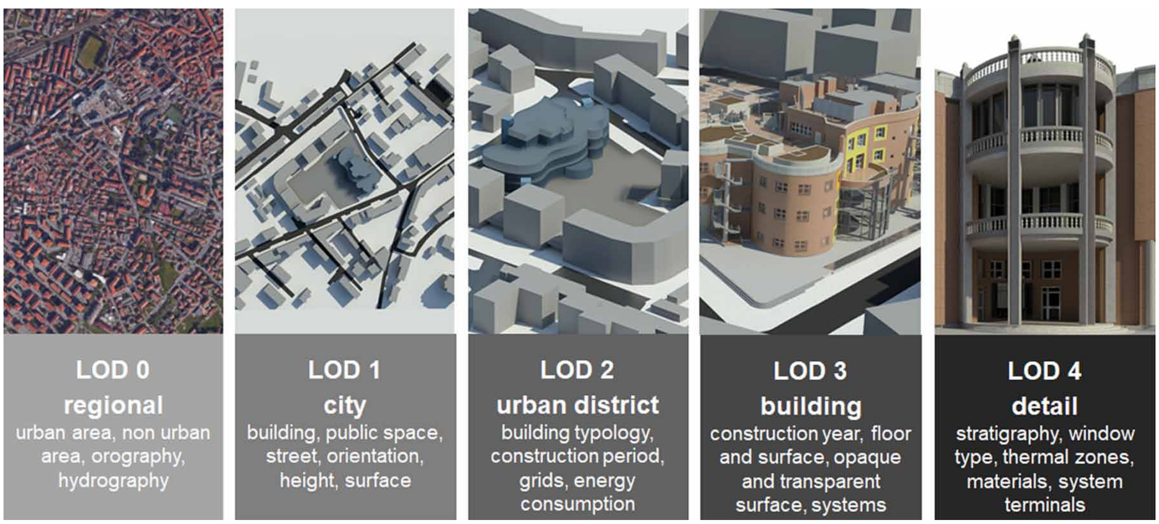
Figure 5. Public buildings BIM models



BIM-GIS Integration

In the scenario outlined, urban models as digital geometric twins can give value to the city services dealing with multiple aspects according to specific needs. As far as the district is concerned, a balanced mix of GIS and BIM data is required in order to improve decision-making and information processes. Within the energy assessment purpose, for example, general information such as location, orientation, size, use, energy consumption, as well as the characterization of building envelopes and installations, are some of the crucial subjects. As shown in Figure 6, five LODs (Torabi Moghadam et al., 2016) was identified to define a balance regarding the granularity of the information of the urban scale coming from the two different domains. From the regional level LOD0, more general and contextual, the LOD1 provide the three-dimensional view of the public cadastre, where it is possible to identify the building volumes that make up the city, combined with general data on location and use. Such information is mostly related to the GIS domain. LOD2 is the synergistic representation of the urban fabric, where the buildings are inserted in a network of services and distribution. This is the first stage of connection with BIM. LOD3 is focused on the building system, and LOD 4 introduces details specialist information on equipment and components.

Figure 6. Calibration of the information level according to the different scales of representation (Torabi Moghadam et al., 2016)
Source: (Torabi Moghadam et al., 2016)

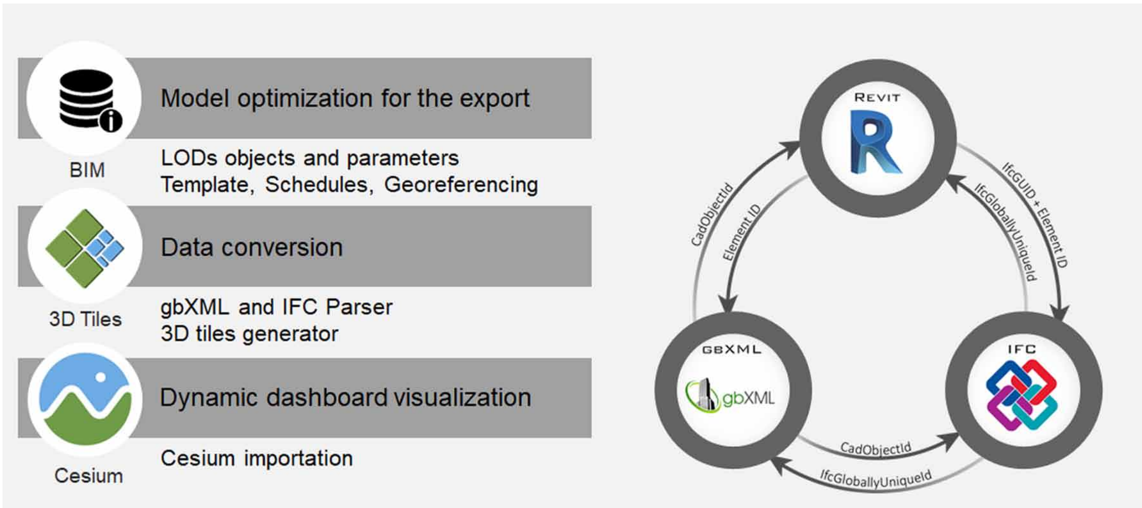


In addition to the different scales of investigation and levels of contents, the primary issue in integrating BIM and GIS systems reflects their diversity concerning modelling environments and reference systems, two-dimensional and georeferenced and three-dimensional objects in local coordinates respectively. Several integration methods were tested to export and convert both geometries and information into BIM-GIS-compatible formats. A preliminary attempt to display the BIM model and the shapefile together refers to the use of the proprietary software, such as *Autodesk Infraworks*, as a common platform for Industry Foundation Classes (IFC) (buildingSMART International, 2020) and CityGML (OGC, 2020) formats, which are considered the two critical standard exchange in the building industry. A further opportunity is to implement the information part of the two systems, for example exporting the *Revit* ODBC database. However, to achieve full integration, there is a need to provide interoperability at the semantic level (Karan et al., 2015) through a web-service interface, which preserves both geometric and alphanumeric information. This approach enables the connection of heterogeneous data sources, enriching the data visualization modes and the query possibilities for a more detailed overview of the built heritage. In these terms, it is possible to investigate buildings/districts/cities according to several knowledge purposes, calibrating the information of interest from time to time.

To pursue this objective, an interoperability methodology (Provera, 2017) aimed at creating a platform for the free interactive visualization of parametric models on an urban scale was tested by using virtual globes and exploiting the 3D Tiles technology (OGC, 2020). The digital globes are scale-bound structured models of celestial bodies in virtual space. They enable distortion-free visualization of earth imagery and digital images on a three-dimensional structure at any scale and from any angle (Aurambout et al., 2008). As presently used extensively in areas such as education, research/collaboration, and disaster response, these systems are revolutionizing display and integration of earth observation data in terms of both to the access and content contribution democratization. For the technical users, virtual globes have vastly reduced the overhead associated with accessing global archives of satellite imagery by eliminating purchase costs and effort required to stage and manage extensive image holdings. Regarding the modern virtual globes, the most outstanding examples in open source domain are *NASA Web World Wind* and *Cesium* as they leverage the latest technologies for Web: JavaScript, WebGL and HTML5. According to this, non-experts users can make links to their earth observation data through Application Programming Interface mapping (API) web services. The globes can be conveniently customized with specific content and diverse sources to meet the needs of case increasing productivity for individual projects and studies. One application is the realistic 3D building models implementation by exploiting different modelling and photogrammetry systems. In this context, 3D Tiles are an open specification for streaming and rendering massive heterogeneous 3D geospatial datasets such as Photogrammetry, 3D Buildings, BIM, Instanced Features, and Point Clouds. The foundation of 3D Tiles is a spatial data structure that enables Hierarchical Level of Detail (HLOD) so only visible tiles are streamed and only those that are most important for a given 3D view (Cozzi, 2015). The BIM-GIS integration project developed pursues the aim to bring to the same platform data and geometries from the two different IT environments. On the BIM side, the main obstacle is the non-capability of direct use of the native format file, such as .RVT for *Autodesk Revit* software, as an exchange code language. Previous researches have studied the interpretation of the gbXML format (Massara, 2016; CSI Piemonte, 2019). In this study, the IFC features capabilities were also interpreted and compared. The interoperability process involves a sequence of conversion and transferring procedures intended to maintain and display information and scenes from sectoral and non-communicating BIM and GIS software. The overall procedure involves three main steps summarized in Figure 7: (i) BIM model optimization for open formats exportation; (ii) 3D tiles generation; (iii) dynamic visualization dashboard. As general considerations, the gbXML standard is characterized by energy-specific data export capability. At the same time, IFC adopts a comprehensive and generic approach to represent the entire building project, covering domains from building construction to building operation.

Moreover, the IFC uses a "top-down" and relational approach, which yields in a highly organized and complex data representation schema. Ideally, it can maintain semantic integrity automatically as it can trace back all the changes when a value of the element in the schema changed. The "bottom-up" gbXML schema is flexible, simpler and easier to understand, facilitating the quicker implementation of extension for different design purposes (Dong et at. 2007). Another fundamental difference concerns the way geometry is generated. gbXML only exports basic rectangular plane surfaces, while the IFC classes correspond entirely to an object including different 2D/3D representation, from simple extrusion to detailed volumes. Another critical remark involves the possibility to fully control the transfer mode by the IFC in terms of objects filtering as well as mapping file customization and additional information. Based on these arguments, a model optimization mode was experimented to obtain a standardized export procedure.

Figure 7. Sequence of conversion and transferring procedures for BIM-GIS district model



Step 1: BIM Model Optimization

Primarily, it is indispensable to define the objects and the information which have an essential role in the final user experience. The LOD definition represents the capability of the 3D model to increase or decrease the complexity of its geometries and the amount of information to display, increasing the subsequent rendering efficiency on the virtual globes. LOD2, LOD3, LOD4 previously mentioned were considered. Given this, the first step to accomplish in the preliminary modelling phase is the creation of a customized project template. This strategy is intended to limit the proliferation of random data and elements which can cause misunderstandings and redundancy errors. Especially in the IFC exports, the pre-defined environment includes coding and naming systems, object styles and libraries, additional parameters as well as 3D view settings and specific schedules. The latter are used to extract and manage only the elements of interest contained in a specific 3D view and to select the attributes for each level of detail by setting dedicated schedules for each object category. Besides, the model must be positioned correctly in terms of georeferencing and north orientation. The quality of the export must be verified before taking the next steps. As mentioned before, in the case of gbXML format, it is necessary to check the correct export of surfaces from a geometrical point of view to avoid voids, room overlaps, and air-surface generation. Modelling guidelines in this area are widely investigated as they are used for energy simulations, as illustrated in the next section. The *Revit gbXML 3D viewer* is used to manage the energy setting, visualize the level of the rooms by level and the analytical surface examining warnings one by one. In the case of IFC, the customization of the IFC class name parameter through IFC Mapping file and of the IFC project template allows us to make the given setting replicable on different models and projects. The IFC standard selected is the IFC 2x3 coordination View 2.0. "Export only elements in view", "Export schedules as property sets", "Export only schedules containing IFC, PSet or Common in the title" are some of the property sets to include. The results of the IFC exportation is checked using *BIMVision*, a freeware IFC model viewer. To establish a connection between the Revit model entities and its exportations in the different exchange formats, it was essential to trace the encoding system for the identification of the elements. In the gbXLM tree structure, every surface is identified by the CADObjectId, which contains a text string reporting the name of the object type and a sequence of eight decimal characters representing the Revit ID. The IFC specification uses a Globally Unique Identifier (GUID) resulting in 22 character length string. Figure 7 shows a summary of the different identifiers to track single building elements and data along the interoperability process. In this project, only two exchange models were analyzed for communication between models, but this method gives the researcher the possibility to relate them in order to find the more satisfying combination of geometries and data visualization.

Step 2: 3D Tiles Generation

The second step involves the conversion and standardization of data giving the Batched 3D Models (B3DM) tileset as output. For the 3DTiles generation, a custom open-source converter software developed in the beta version was used as Middleware (Massara et al., 2019). This includes IFC and gbXML Parser, which converts the model in a 3D mesh surfaces with associate attributes, and the 3DTiles generator, which creates a tileset.json file and a B3DM asset for each model. These parts are implemented with Oracle Java Platform, Enterprise Edition 8 technology (Oracle, 2020). The software is implemented with a decoding tool that through specific query s able to detect and analyze the IfcPropertySet contained in the model and recognize in which visualization level the attributes contained must be shown. The software can suddenly parse the IfcPropertySingleValue extrapolating the “Name” and “Value” of the parameters. In this way, the same object of the model can show different attributes according to the LoD represented on *Cesium*. Each category and type of object requires a dedicated parsing procedure for the extraction of geometry and attributes. It is a long time-consuming road for mapping the full IFC with API.

Step 3: Dynamic Visualization Dashboard

This 3DTiles asset can now be loaded through the glTF format the on the *CesiumJs 1.60* framework, thanks to a HTML calls which load all the files to a specific web server. In addition to the BIM models, the shapefile of the surrounding urban context was imported through the same tile format. In *Cesium*, the server-side sends the B3DM data with attributes based on which the styling can be accomplished in client-side without further data requests from the server, which improves the user experience and reduces the computation load in the server. Figure 8 shows the dashboard interface. In the top-right corner, it is possible to see the view’s navigation tools. Pointing the mouse over an object, this will be highlighted and a cloud panel showing the properties attached to the object will appear. The zoom of the view controls the level of detail. A first notable difference in the use of the two formats is that gbXML is not able to handle the original object modelled in Revit, but only the portions with which adjacent rooms come into contact. For example, for LOD 2, which refers to a conceptual representation of the building, the geometry from the district shapefile must be used. Conversely, different entities depending on the LOD can be used from an IFC export. Besides, the colours used for the rendering derive from IfcColor class of the Revit model as RGB coordinates. As in the gbXML case, some geometries can be displayed as transparent surfaces in specific points of view. This issue is probably due to the manageability of the normal attribute object of the glTF model of the building. With the IFC model, the problem is accentuated by the fact that the objects are more complex and composed of a lot of planar surfaces. Concerning the way geometries are generated, discontinuities among analytical surfaces may be resulting in a disconnected representation. Based of its light and ease geometrical structure, gbXML is an interesting way to represent BIM models on a GIS platform. However, its structure based on planar surfaces is inadequate for the visualization and interrogation of detailed building element, and it is limited to a low detail display. In the case of IFC, some difficulties or errors are given by the return of complex objects. Taking windows as an example, the dashboard is currently unable to represent this kind of object, since they are composed by several elements such as glass, frame, handle, each with a particular representation and its reference system. Nevertheless, the higher potential is recognized in the use of IFC for the quality of geometries and attributes managed.

Figure 8. Cesium Dashboard interface

BIM-IoT Energy Simulation and Monitoring

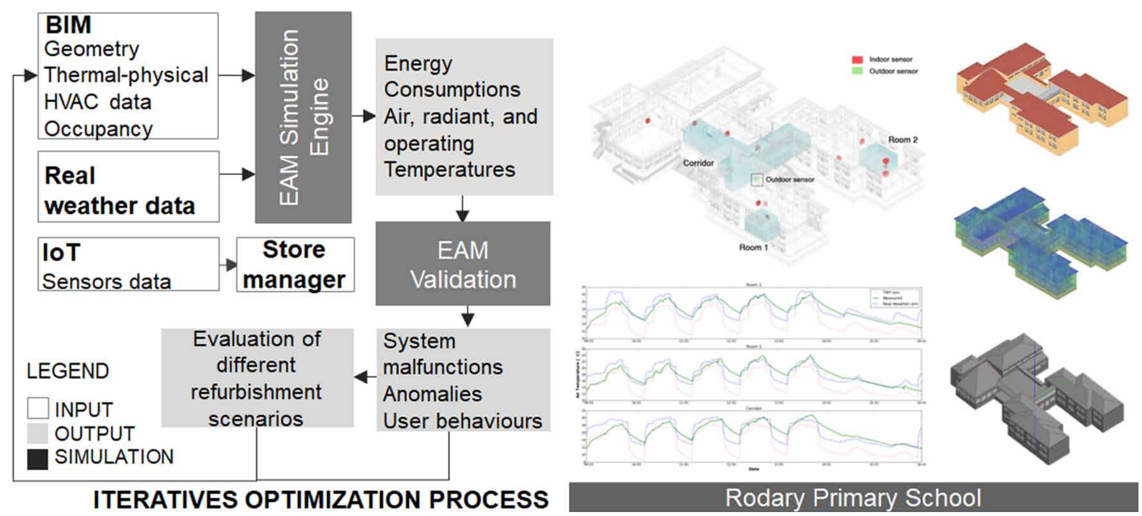
As the existing heritage is one of the focal points of this study, BIM was also exploited to perform energy simulations and certifications in order to promote retrofit actions. As they represent a significant repository of graphical and alphanumeric information, parametric models can include useful data for energy analysis such as: (i) accurate building envelope characterizations in terms of correct stratigraphy, thermal and physical properties; (ii) space typology and occupation profile; (iii) materials; (iv) system schemes and terminal typology; (v) attached documentation relating to interventions and operation. Traditionally the energy modelling activity is carried out according to a traditional approach by manually imputing all the needed information to describe a building and by redesigning its geometry for every plant view. This procedure implies a considerable amount of time, mainly when applied to an extensive heritage and increase the probability of making errors. These difficulties can be overcome thanks to the BIM methodology, optimizing the process and making it integrated. In the ideal case, the geometry and envelope characteristics of the building can be extracted directly from the architectural model to evaluate the energy performance and execute thermal calculations, minimizing misinterpretations and incorrect approximations encountered in practice. Several interoperability tests towards energy-dedicated software have been carried out with the main aim of evaluating the quality of the data exchange. *Edilclima* and

DesignBuilder were selected in order to consider two different types of simulation engines within the stationary and dynamic model calculations method, respectively. It is necessary to admit that a total exchange can not be reached with the current level of software development. For this reason, a range of solutions was developed to optimize the exportation and to speed up the data input phase. That includes modelling guidelines to simplify the architectural model concerning non-energy significant elements and to represent spaces, joints between elements, and complex geometries. Most of the interoperability problems affect any building model, while some specific ones are related to historical or modern buildings due to their particular construction typology. For instance, thermal simulations are based on one-dimensional heat transfers, so they cannot consider curved surfaces – like walls, slabs or ceilings –, which must be approximated with a finite number of flat surfaces (Ugliotti et al., 2016). Since many information contained in the model are not transferred, such as transparent component or shading elements, shared parameters and customized families (Barone, 2017) are used to make the data explicit and more easily accessible to support the filling in the energy software. As mentioned above, the gbXML export must be carefully checked to avoid the analytical surface. The level of adoption of the BIM in the energy field is conditioned by many variables, including the complexity of the building, the analysis to be carried out and the software used, the level of experience of the modeller, if the process is moving towards progressive automation.

Moreover, the building energy modelling and monitoring approach is one of the most challenging as it combines the knowledge of the buildings established by BIM with real data from the field, collected by the IoT devices. This aspect represents the core of the EEB project that pursues building management mainly devoted to energy-managers providing near-real-time and historical information on environmental parameters of buildings and spaces. This integration enables to validate the Building Energy Model (BEM) with real data from monitoring activities beside energy consumption bills. An iterative energy optimization process (Bottaccioli et al., 2017) has studied to manage the refurbishment scenarios starting from the correlation of the *EnergyPlus* simulation engine output and the indoor air temperature and humidity collected and sent in the Store Manager every 15 minutes. As a strong point of these simulations, third-party weather data source from the nearest weather station (i.e. solar radiation, outdoor air temperature and humidity) was used instead of the default Typical Meteorological Year (TMY), which is not representative of the real weather conditions. According to this approach, validation is much more reliable, given the ongoing climate change. Comparing the air temperature charts, measured data and simulation results with real-weather conditions have the most similar trend compared to the TMY simulation. Analyzing the temperature and consumption trends, factors that may affect the energy model can be identified, such as user behaviours, malfunctions and anomalies in the system. By comparing measured and simulated data, it is possible for example, to discover non-regular trends of real indoor temperatures due to faults in on/off schedules of the heating system or efficiency losses of the building-system.

In this context, BIM models can be used to evaluate different refurbishment scenarios (e.g. external/internal coat application, fixtures replacement and power peaks regulation), becoming a new input immediately available for the simulation. This process is iterative and can help building and energy-managers in evaluating the best solution for both energy performances and Return of Investment. As Information and Communication Technologies and Machine Learning techniques look as crucial players in the development of new control policies based on systematic knowledge and prediction of energy behaviour, such as Demand/Response and Demand Side Management applications, an indoor air temperature forecasting method has been studied exploiting a non-linear autoregressive neural network

Figure 9. Proposed energy modeling optimization process (Bottaccioli et al., 2017)
Source: (Bottaccioli et al., 2017)



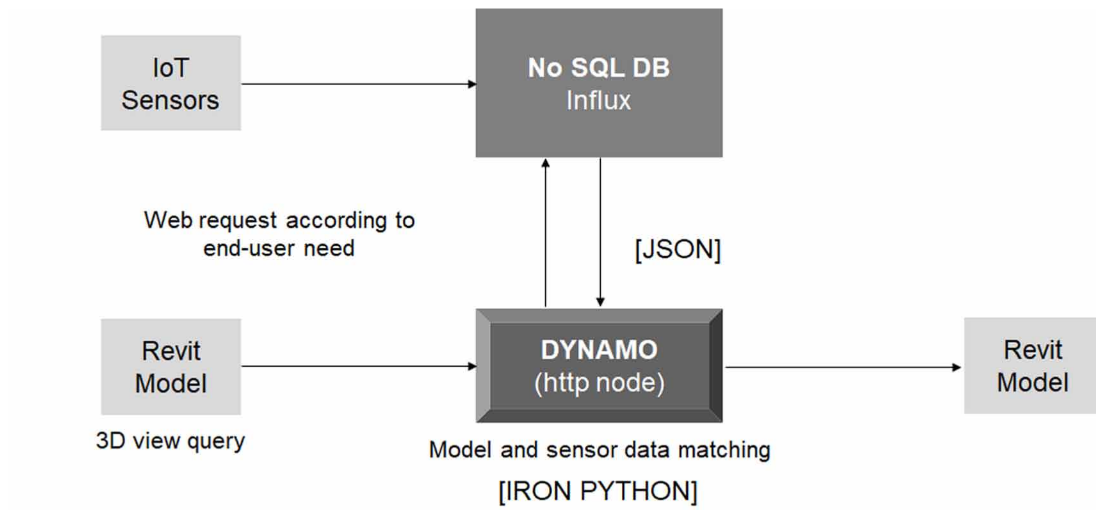
(NAR). It bases its predictions on past values of the series and current and past values of the exogenous driving series, producing the error of prediction. The neural network has been trained and validated with a dataset consisting of six years (four training-set and two validation-set) of indoor air-temperature values (real and synthetic, one sample every 15 minutes) of a building demonstrator (Aliberti et al., 2018). As the monitoring period foreseen by the project was too short for this type of activity, the BIM model and *EnergyPlus* were used again this time to generate a consistent artificial database. The goal is to predict the values of indoor air-temperature (that corresponds to the ahead k-step prediction of the system) in the most extended period with the best accuracy compared to the original output. The same environments considered for the validation of the energy model mentioned above were studied. The analysis of performance indicators highlighted an overall good performance in predicting temperature values up to two hours with 13 regressors. This kind of approach allows energy profiles prediction, for example, to exploit the flexibility of electro-thermal devices or to reshape thermal energy to reduce the peaks in district heating.

BIM-IoT Energy Data Visualization

As a further opportunity to interconnect data from different databases, a functionality to recall and query data from IoT sensors within the BIM environment was implemented. In particular, *Dynamo* software in plug-in mode from *Autodesk Revit* was used to bring dynamic data recorded in *InfluxBD* into dialogue with static data from the digital model. *Dynamo* allows users to operate through Visual Programming processes through which it is possible to link elements to define relationships and sequences of actions that make up custom algorithms. *Dynamo* hosts a rich ecosystem for development and allows the user to create web requests for data access to other servers/clouds. The aim is to retrieve the temperature and humidity data from the installed sensors of the different case study and map them as parameters within the BIM models.

Using this mode, the values measured in the field can be interrogated from a graphical database. To achieve this, first of all, the sensors have been modelled in a simplified way and placed in virtual environments, in the same position as the real ones. Each sensor object is identified within the model by a unique *Revit* identifier and a code that identifies it with respect to *InfluxDB*. The integration methodology, as illustrated in Figure 10, foresees the following procedural steps: (i) connection to the external resource and web request, (ii) correlation of data from an external resource and BIM data, (iii) populating data in the BIM model from external resource; (iv) historical and real-time Temperature and Humidity data query.

Figure 10. BIM and IoT data correlation methodological scheme



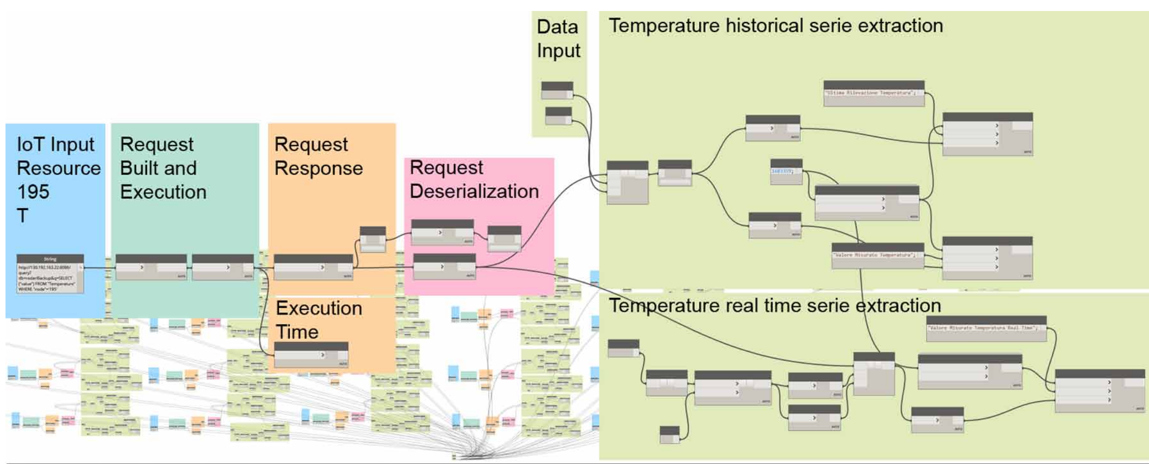
Dynamo, thanks to its ability to interface directly with the modeling software used, makes it possible to manipulate the BIM database in an integrated way, extending its potential. The connection to new external resources, instead, is managed through REST communication interface. The script implemented, reproduced in Figure 11, performs the following actions through the use of nodes and functions.

- Connection and authentication to the *InfluxBD* non-relational database.
- Creation and execution of an HTTP information request to the Web Server.
- Control of the HTTP response of the query and the execution time of the request.
- Extraction and deserialization of the response content through JSON files.
- Selection of the values of interest (Temperature, Humidity and Timestamp) according to real time and by manual query with date and time for the historical series.
- Population of the corresponding attributes associated to the sensor objects with the extracted values.

In the specific case, each web request recalls the measured value range of an individual sensor. Therefore, two http requests have been set for each sensor, one for Temperature values and the other for Humidity. In the case of Rodari Primary School, the data corresponding to the 15 sensors installed were extracted. The values are updated every time the script is executed. As far as the historical series values are concerned, it is possible to specify the date and time by means of classic input from script or *Dynamo Player* interface from *Revit* model. Once the data is mapped inside the BIM model, it can be displayed in different modes. In addition to being visible among the properties of the sensor objects and present of the schedules, it is possible to visualize them graphically through labels of the sensor objects. Through an additional *Dynamo* script the Temperature and Humidity data mapped on the sensor objects have been transferred to the rooms where they are contained. In this way, it has been possible to create thematic maps, as visible in Figure 12, with the measured values at a given time and to obtain an overall view.

BIM-AR-3D Printing Energy User Awareness

Figure 11. Dynamo script for populating temperature and humidity data on sensor objects

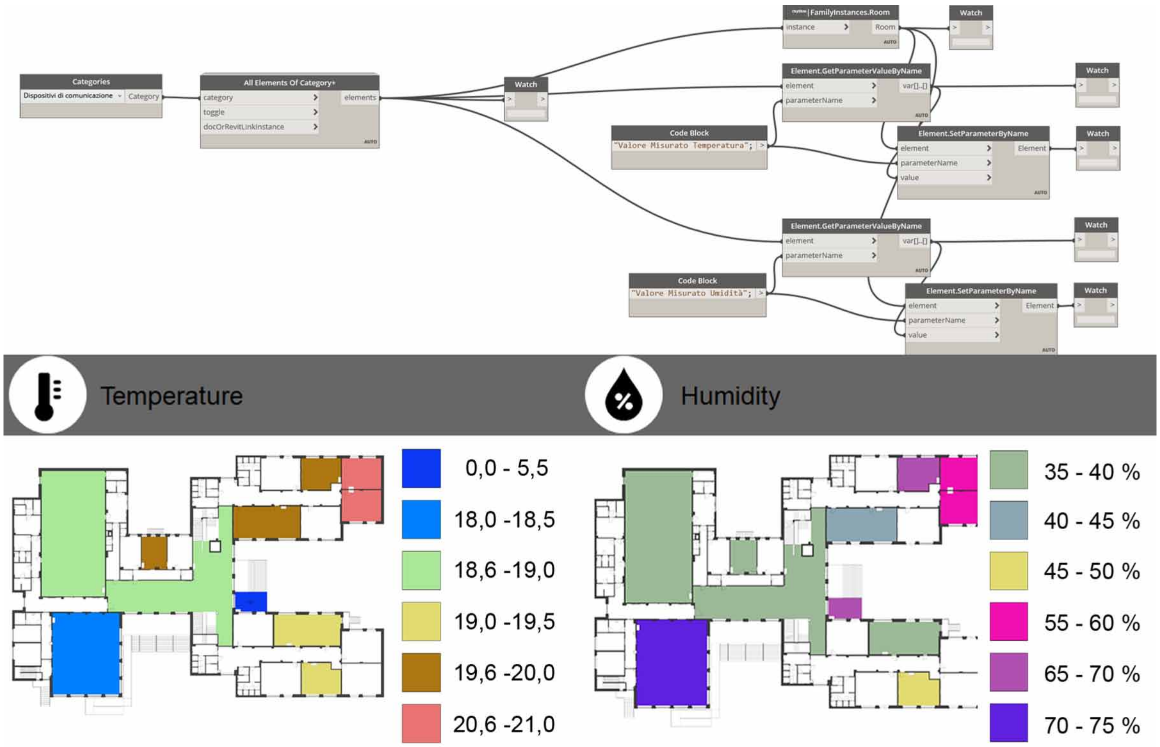


<IoT Sensor Schedule>

A	B	C	D	E	F	G	H	I	J	K	L	M
Object	ID	Level	Room ID	Room name	Room Area	Room Volume	Real Time Temperature	Time Temperature Measurement	Temperature Measured Value	Real Time Humidity	Time Humidity Measurement	Humidity Measured Value
IoT Sensor	195	XPTE	19	Canteen	197.27 m²	690.43 m³	18.6	09/01/2017 17:04:15	18.45	70.21	09/01/2017 17:04:15	70.32
IoT Sensor	42	XPTE	18	Gym	288.11 m²	2117.64 m³	19	09/01/2017 17:04:12	19.22	36.9	09/01/2017 17:04:12	37.53
IoT Sensor	207	XPTE	48	Secretariat	29.66 m²	103.82 m³	20.02	09/01/2017 17:04:12	20.38	36.81	09/01/2017 17:04:12	36.69
IoT Sensor	106	XPTE	25	Psychomotricity Laboratory	76.65 m²	245.28 m³	19.84	09/01/2017 17:04:14	20.1	42.22	09/01/2017 17:04:14	42.17
IoT Sensor	19	XPTE	21	Classroom 1D	42.72 m²	136.70 m³	20.34	09/01/2017 17:04:15	20.03	65.66	09/01/2017 17:04:15	65.92
IoT Sensor	142	XPTE	22	Classroom 1C	44.08 m²	154.29 m³	20.74	09/01/2017 17:04:16	20.75	59.07	09/01/2017 17:04:16	59.63
IoT Sensor	241	XPTE	23	Classroom 1B	44.83 m²	156.91 m³	20.68	09/01/2017 17:04:25	20.87	55.79	09/01/2017 17:04:25	55.83
IoT Sensor	79	XPTE	39	Theatre Laboratory	74.18 m²	259.65 m³	19.4	09/01/2017 17:04:13	19.59	37.9	09/01/2017 17:04:13	37.4
IoT Sensor	48	XPTE	41	Classroom 2A	42.43 m²	135.78 m³	19.46	09/01/2017 17:04:15	19.63	49.01	09/01/2017 17:04:15	49.12
IoT Sensor	208	XPTE	33	Main entrance	229.69 m²	860.18 m³	19.64	09/01/2017 17:04:12	19.22	37.4	09/01/2017 17:04:12	37.53
IoT Sensor	112	XPTE	302	External area	23.00 m²	178.60 m³	5.02	09/01/2017 17:04:13	4.98	68.83	09/01/2017 17:04:13	68.38
IoT Sensor	60	XP01	79	Classroom 4B	44.92 m²	157.24 m³	20.3	09/01/2017 17:04:13	20.01	55.97	09/01/2017 17:04:13	56.05
IoT Sensor	248	XP01	81	Classroom 4A	44.08 m²	154.29 m³	20.01	09/01/2017 17:04:14	19.83	59.8	09/01/2017 17:04:14	59.7
IoT Sensor	75	XP01	82	Classroom 4C	44.91 m²	157.18 m³	19.99	09/01/2017 17:04:13	19.79	58.69	09/01/2017 17:04:13	58.79
IoT Sensor	45	XP01	96	Classroom 3D	42.43 m²	148.49 m³	20.14	09/01/2017 17:04:15	20.08	64.8	09/01/2017 17:04:15	64.09

The engagement of ordinary users towards energy-oriented behaviours is one of the objectives of the dissemination activities of research projects (De Luca et.al, 2017). Since young generation will be the society of the future and one of the case studies is a school, the gamification approach was considered to stimulate children to take an active role in sustainability issues. Specifically, an interactive BIM-based map was created to activate a guided learning path on smart cities strategies exploiting AR and 3D printing. In the first task children can experience VR through the use of customized cardboard to visualize the three dimensional models of the EEB case studies and their surroundings, compare them with 3D printed version. By framing the correspondent QR Code and putting the smartphone in the viewer, their immersive vision is enabled through a stereoscopic rendered view generated by Autodesk

Figure 12. Thematic map of measured temperatures



360 cloud platform. As output, players learn to observe the urban context, understanding that there are several fields of application besides buildings, considering for example green areas, squares and streets, up to consider the entire city. In the second task, smart city strategies are investigated through a quiz. Questions are displayed in AR on tablet or smartphone with the use of Aurasma application by framing the training points on the map. Clicking on the device screen at the correct answer, the solution and a brief suggestion for sustainability are displayed. Finally, the last task allows children to experience Augmented Reality by recomposing a jig saw puzzle of the school district. The model was exported through .FBX in Autodesk 3DS Max to allow the AR visualization through the AR-media plug-in. This activity encourage people to work and cooperate together to create something new for a more efficient city and making the system the positive experiences. From an educational point of view, the map helps children both to emphasize the importance and effectiveness of the strategies traditionally used and to encourage the application of new technologies to achieve the targets of a smart city.

FUTURE RESEARCH DIRECTIONS

As many aspects of smart environments are already in use through internet-controlled building management systems (e.g. lighting and temperature regulation within buildings, traffic management systems, real-time information about means of transport), managing the building/city physical assets represent a critical field of technological application to enable better decisions about maintenance and usage what-if

Figure 13 EEB 3D BIM Map (De Luca et.al, 2017)
Source: (De Luca et.al, 2017)

scenarios. Thanks to the experiences gained in other sectors, there is a growing shift from a sustainable static vision of a city towards a resilient dynamic, in which the possibility of human-digital model interaction becomes central. In the same way that the IoT is rapidly spreading through the setting up of increasingly innovative services, experiences such as those illustrated in this research should be encouraged to enable increasingly smart city digital twin-oriented framework. The spatial geometric correlation of dynamic sensor data can enrich not only energy analyses but also structural and seismic evaluations. In this context, in addition to ordinary aspects, a new vision opens up for the emergency management such as earthquake, damages in conflict area, pandemics like Covid-19, which can be monitored before and better managed afterwards. The extension of the controlled parameters and their relationships will increase the resilience of the city.

CONCLUSION

This chapter presents some of the most significant results achieved by the EEB project. The study, while considering strictly energy-related aspects, launches a methodology for the collection, digitalization and integration of information in a framework queryable by different levels of users depending on the tools and services used. The most exciting aspect goes beyond the vertical management of specific domains, but rather lie in the possibility to relate them to each other, constituting an enlarged knowledge environment. The main areas covered involve GIS for the representation at territorial level, BIM for the building scale, IoT sensors for energy and electrical monitoring and the use of innovative visualization technologies such as Augmented and Virtual Reality. The focus is still on the sensorization of 3D models, but the experimental matrix is starting to exploit the capabilities of the Internet of Things and Artificial Intelligence. The most complex aspect to address is certainly to establish an environment that makes data sources accessible that are not homogeneous in terms of assets, scale, and content. Owners, managers, technicians, citizen: everyone is looking for data. It all starts with content selection and storage. For cost and processing time savings, standardization of digital models built in BIM and GIS environments should be aimed at making the data immediately accessible and comparable. In this way, building data become descriptors useful to establish a multidisciplinary picture of an asset. Moving towards a cyber-city allows to democratize the access to information extending the area management capabilities. The combination of tools tested creates a structure able to collect under the same batch different versions of the same model, overcoming the static representation of the scene in favour of a customizable smart 3D streaming where significant advantages in terms of rendering speed and fruition can be experienced. This solution thanks to its web-based nature enable maximum effect in communications and cognitive awareness. In this direction, software must also work in order to be more and more open and interoperable in order to save optimize the analysis phases of alternative scenarios more and more performing, keeping all the necessary parameters under control. The context that comes to outline provides an improvement of shared knowledge within profiles awareness.

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REFERENCES

Aliberti, A., Bottaccioli, L., Cirrincione, G., Macii, E., Acquaviva, A., & Patti, E. (2018). Forecasting short-term solar radiation for photovoltaic energy predictions. *Proceedings of the 7th International Conference on Smart Cities and Green ICT Systems*, Volume 1: SMARTGREENS, 44-53. 10.5220/0006683600440053

Aliberti, A., Ugliotti, F. M., Bottaccioli, L., Osello, A., Macii, E., Patti, E., & Acquaviva, A. (2018). Indoor air-temperature forecast for energy-efficient management in Smart Buildings. *IEEE Proceedings*, 272-277.

APE. (2015). https://www.certificato-energetico.it/

Aurambout, J., Pettit, C. J., & Lewis, H. (2008). *Virtual Globes: the Next GIS?* Landscape Analysis and Visualisation.

Barone, L. (2017). Interoperabilità BIM per l'analisi energetica. In BIM: verso Il catasto del futuro. Conoscere, digitalizzare, condividere. Il caso studio della Città di Torino, (pp. 105-110). Gangemi Editore spa.

Bottaccioli, L., Aliberti, A., Ugliotti, F. M., Patti, E., Osello, A., Macii, E., & Acquaviva, A. (2017). Building energy modelling and monitoring by integration of IoT devices and Building Information Models. *Building Digital Autonomy forna Sustainable World (COMPSAC),* 914-922.

buildingSMART International. (2020). https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/

Chelleri, L., & Olazabal, M. (2012). *Multidisciplinary perspectives on urban resilience. Workshop Report.* Bilbao, Spain: BC3, Basque Centre for Climate Change.

Communityviz, (2020). https://communityviz.city-explained.com/

Cozzi, P. (2015). *Introducing 3D Tiles*. https://cesium.com/blog/2015/08/10/introducing-3d-tiles/

De Luca, D., Del Giudice, M., Dellosta, M., Fonsati, A., Osello, A., & Ugliotti, F. M. (2017). Augmented and virtual reality for smart cities users' awareness. In *INTED 2017, 11th International Technology, Education and Development Conference*, 4333-4342. IATED Academy.

Dong, B., Lam, K. P., Huang, Y. C., & Dobbs, G. M. (2007). A comparative study of the IFC and gbXML informational infrastructures for data exchange in computational design support environments. *Proceedings: Building Simulation*, *2007*, 1530–1537.

European Commission. (2020). *Horizon 2020 Work Programme 2018 – 2020* (European Commission Decision C(2020) 1862 of 25 March 2020). https://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-fet_en.pdf

European Parliament. (2014). *Mapping Smart City in the EU*. https://www.smartcities.at/assets/Publikationen/Weitere-Publikationenzum-Thema/mappingsmartcities.pdf

IBM Corporation, . (2012). *IBM Smarter Cities. Creating opportunities through leadership and innovation.* Author.

ISO/IEC JTC 1. (2014). *Smart cities. Preliminary Report 2014.*

ISTAT. (2011). https://www.istat.it/it/archivio/104317

Karan, E. P., Irizarry, J., & Haymaker, J. (2015). BIM and GIS Integration and Interoperability Based on Semantic Web Technology. *Journal of Computing in Civil Engineering*, *30*(3), 04015043. doi:10.1061/(ASCE)CP.1943-5487.0000519

Massara, F. (2016). Trying to visualize GIS & BIM information on the web: a solution using Leaflet and Cesium. *FOSS4G Bonn 2016*.

Massara, F., Provera, F., & Ramassotto, A. (2019) Streaming and rendering the Turin 3D geospatial content through GIS and BIM integration. *FOSS4G Bucharest 2019.*

Mitchell, W. J. (2001). *Smart Cities*. https://smartcities.media.mit.edu/

OGC. (2020). https://www.ogc.org/standards/3DTiles

Oracle. (2020). https://www.oracle.com/technetwork/java/javaee/tech/index.html

PiemonteC. S. I. (2019). https://github.com/csipiemonte/ogc-citygml-utils

Provera, F. (2017). *Implementation of BIM methodology for district data visualization.* Master Thesis in Building Engineering, Politecnico di Torino.

Riddhi, D., Siddhi, D., & Hemal, T. (2020). Digital Twins: Current problems in Smart City and Recommendations for future technology. *International Research Journal of Engineering and Technology, 7*(5).

Shah, S. A., Seker, D. Z., Rathore, M. M., Hameed, S., Ben Yahia, S., & Draheim, D. (2019). Towards Disaster Resilient Smart Cities: Can Internet of Things and Big Data Analytics Be the Game Changers? *IEEE Access: Practical Innovations, Open Solutions*, *7*, 91885–91903. doi:10.1109/ACCESS.2019.2928233

Teicholz, P. (2013). *BIM for Facility Managers*. John Wiley & Sons. doi:10.1002/9781119572633

The British Standards Institution. (2014). Smart cities – Vocabulary. *PAS*, *180*, 2014.

Torabi Moghadam, S., & Lombardi, P. (2019). An interactive multi-criteria spatial decision support system for energy retrofitting of building stocks using CommuntiyVIZ to support urban energy planning. *Building and Environment*, *163*, 106233. doi:10.1016/j.buildenv.2019.106233

Torabi Moghadam, S., Lombardi, P., & Mutani, G. (2017). A mixed methodology for defining a new spatial decision analysis towards low carbon cities. *Procedia Engineering*, *198*, 375–385. doi:10.1016/j.proeng.2017.07.093

Torabi Moghdam, S., Lombardi, P., Ugliotti, F. M., Osello, A., & Mutani, G. (2016). BIM-GIS Modelling for Sustainable Urban Development. *NEWDIST*, *2016*(Special Issue), 339–350.

Ugliotti, F. M. (2017). Utilizzi del modello BIM per il FM. In BIM: verso Il catasto del futuro. Conoscere, digitalizzare, condividere. Il caso studio della Città di Torino, (pp. 56-73). Gangemi Editore spa.

Ugliotti, F. M., Dellosta, M., & Osello, A. (2016). A BIM-based energy analysis using Edilclima EC770 plug-in. Case study: Archimede Library, EEB Project. *Procedia Engineering*. *WMCAUS*, *6*(161), 3–8. doi:10.1016/j.proeng.2016.08.489

Vinco, S., Bottaccioli, L., Patti, E., Acquaviva, A., Macii, E., & Poncino, M. (2018). *GIS-Based Optimal Photovoltaic Panel Floorplanning for Residential Installations.* Paper presented at 2018 Design, Automation & Test in Europe (DATE). 10.23919/DATE.2018.8342049

White, G., Zink, A., Codecá, L., & Clarke, S. (2021, March). A digital twin smart city for citizen feedback. *Cities (London, England)*, *110*, 103064. doi:10.1016/j.cities.2020.103064

Wright, L., & Davidson, S. (2020). How to tell the difference between a model and a digital twin. *Advanced Modeling and Simulation in Engineering Sciences*, *7*(1), 13. doi:10.118640323-020-00147-4

KEY TERMS AND DEFINITIONS

3D Tile: Technology used to streaming and rendering massive heterogeneous 3D geospatial datasets such as Photogrammetry, 3D Buildings, BIM models, Instanced Features, and Point Clouds according to different Hierarchical Level of Detail.

Digital Knowledge Site: A constantly evolving process of retrieval, organization, preservation and updating of the building knowledge in a digital environment considering both material and immaterial aspects.

Dynamic Data: Data from monitoring systems or information that does not remain unchanged over time, including emotional and intangible aspects.

Energy Model: A virtual or computerized simulation of a building realized with specialized software, focusing on energy performance calculation or assessment.

Smart City Digital Twin: Digital three-dimensional replica of the physical assets that make up the urban environment (buildings, urban infrastructure, utilities, movement of people and vehicles) integrated with real-time information which is structured as full-fledged system of interconnected things capable of interacting with humans not only to monitor but to prototyping and predict.

Urban Model: Computer-based digital environment used for visualizing the distribution of indicators on graphical maps and testing planning policies on the future form of cities.

Visual Programming: Computer language that allows programming activities even for non-expert users through the graphic manipulation of the elements and not through written syntax.