



GISBIM

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Lectures and notes for a digital integrated design



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BIM-GIS integration towards Digital Twin: shaping smart for rethinking cities

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Cities are complex systems connected to demographic, economic and ecological conditions and evolution. The progressive transformation of the *modus vivendi* and related needs of the population requires accurate analysis to understand the ever-increasing complexity of urban contexts.

Cities are the main sources of environmental pollutants on a global level and the places where vulnerability to climate risks and related upheavals can be tackled, as well as the major socio-economic and human health challenges. Therefore, they are the most appropriate places to start the transition towards sustainability, linking the sustainable development agenda with the ICT of pervasive digital research and development.

Trying to build a scientific and technological system allowing to analyze and predict future scenarios and events that may have a significant impact on communities is strategically important in order to develop and direct risk prevention interventions as well as sustainable management of buildings and urban agglomerations.

In fact, a deep understanding about relevant connections between the integration of urban planning with different enabling Information Communication Technologies - ICT¹ (such as modelling and simulations, Internet of Things, Artificial Intelligence for learning and reasoning) is becoming more and more related to a new paradigm based on approaching predictive scenarios in urban sustainability for the configuration of long-term policies. In fact, the development of Urban Intelligence² (UI) paradigms set out ecosystems of technologies aimed at improving quality of life and wellbeing, defining a new urban environment made up of Smart City systems.

The introduction of ICT-based dynamic strategies in urban development needs a deep focus on a user-approach including the interactions between people and infrastructures through the definition of a City Digital Twin, which is namely a cyber-physical counterpart of all the city systems and subsystems, combining advanced real-time multidisciplinary city modelling, simulation and learning tools with numerical optimization techniques.

Thus, Urban Intelligence environments are able to provide alternative strategies and scenarios supporting policy makers and stakeholders in designing sustainable and customized solutions. Then the main characteristics of a Urban Intelligence architecture are:

- fully multidisciplinary integration of city layers;
- real-time connection and evolution with the city;
- integration of participative strategies to include “human oriented” information;
- modularity of application.

A City Digital Twin³ based on a Urban Intelligence paradigm leverages crossovers between mobile networking (IoT - Internet of Things), process modelling, and Artificial Intelligence (AI), with the aim of learning, reasoning, and targeting a city (Smart City) where infrastructures and city assets are coordinated and integrated using digital technologies [1, 2].

The result is a digital eco-system of infrastructures and services that allows the creation of a Digital Twin (DT) of complex real/physical systems such as cities, including their systems and subsystems (e.g., transportation, energy distribution, water usage, population, education, health, cultural heritage, etc. [3]).

The result is a digital eco-system of infrastructures and services that allows the creation of a Digital Twin (DT) of complex real/physical systems such as cities, including their systems and subsystems (e.g., transportation, energy distribution, water usage, population, education, health, cultural heritage, etc. [3]).

Some experiences of DT models have been implemented in India, Southeast Asia, and Europe [4, 5] always trying to solve very specific problems without a full common/global approach for UI providing effective generalizations [6].

This is why the evolution of Smart City approaches opens up new directions towards integrated and intelligent systems for the government of cities, using multiple integrated data sources (from sensors to data platforms for Citizen involvement) using a holistic approach. The objective is a real-time integration of heterogeneous data controlled by multidisciplinary optimization approaches in a flexible and adaptive digital model that learns from and evolves with the real city, being capable of anticipating future scenarios.

From this perspective, the integration between Building Information Models (BIM) and Geographic Information Systems (GIS)⁴ becomes a crucial strategy aimed at increasing efficiency in information processes between building systems and subsystems analysis, urban planning applications, disaster management, cadastre and homeland security and so on.

Smart City applications need mass data, both static and dynamic, current and historical, geometrical and semantic, microscopic and macroscopic to integrate ICT and IoT solutions in a secure way to manage city assets etc. Therefore, BIM and GIS can be used to collect, manage and create lifecycle data of vertical facilities, as well as data describing the urban environment, which is horizontally distributed. Hence, integrated application of BIM and GIS is becoming essential in Smart City management applications where data of both facilities and urban environment are required.

The idea of Digital Smart City shapes such the creation, analysis and use of information about the urban environment in all its dimensions, managing to ensure the desired quality of life for its inhabitants, while achieving sustainable results in economic, social and environmental terms. In other words, a Digital Twin of a urban system can also be a key tool for the storage, visualization, analysis and creation of data useful for managing the urban lifecycle.

Given the absolute centrality of data in the configuration of full-digital processes, a significant development is the integrated use of GIS and BIM for information management and processing. Although they share the essential concept of describing the real world through the combination of representation and information, they are conceived and developed as belonging to different domains.

While BIM focuses on buildings and on the representation of construction details, i.e. micro-level data, often unrelated to context, GIS specializes in geospatial information defining the environmental level, and it is used to generate information at the macro-level, such as topographical data.

Their main differences can be summarized in different users, application focuses, development phases, spatial scales, coordinate systems, semantic and geometric representations, levels of granularity and methods of storing and accessing information. The need for a global vision of the city, both in width (house, neighbourhood, city) and in depth (architecture, structures, installations), is growing a general interest to deepen the overlapping nature of BIM and GIS. The integrated use of these technologies can bring benefits in both fields of action. Infact, information from a GIS can facilitate BIM applications such as site selection and on-site material placement, while BIM models can help generate detailed models in a GIS and lead to greater effectiveness in project management. While BIM systems focus on developing objects with the maximum level of detail in geometry, GIS is applied to analyse objects, which already exist in the physical environment, in the most abstract way.

That is why achieving interoperability between both domains will offer substantial benefits, as each domain brings information and services the other lacks.

⁴ A BIM-GIS model requires a complex semantic framework. However semantic models are needed for different engineering and planning applications that require complex queries and analysis.

For example, considering the information management of new construction projects, the integration of BIM and GIS can support applications such as supply chain management, getting a detailed takeoff in the early procurement phase, using GIS to perform geospatial analysis of the logistics delivery in a visualized construction supply chain management system, developed for tracking materials and providing warning for delivery accidents. This visualized method of digital monitoring and control reduces time and cost for logistics delivery. Even for building retrofit projects, the integration of BIM and GIS supports decision-making. Putting as-is geometric BIM data and other necessary data into GIS, it becomes possible to create a pre-retrofit simulation model to perform building data, mapping issues to be renovated and corresponding solutions for building renovations.

This development leads to an important design and process innovation for territorial information systems playing a fundamental role in addressing the development of built environment, providing both the congruity information management in GIS environment and the information produced through BIM processes. GIS systems are able to provide the context and the cartographic basis of any intervention and, at the same time, it extends the value of BIM design data through their visualization and geographical analysis that can be performed.

It can be observed even how the theme of overlapping models and their ability to interact without loss of information, (i.e. interoperability), represents the main aspect for the effective possibility of grouping models.

From a methodological development point of view, it is clear that the import and incorporation in a GIS of the geometries and data useful to computerize the entity in a timely manner, involves, on the one hand, a greater exploitation of the potential of BIM on different scales of representation, on the other hand, thanks to this context, the GIS technology can be consolidated to provide essential information to the organizations for managing the building heritage.

This capability becomes possible through the creation of geodatabases, identifying entities spatially related one to each other. In this regard, one of the most important drivers is sharing the information that must be entered only once into the database, giving the possibility to optimize information management, increasing accuracy through the addition of new information, not by iterative entry of the same data already entered.

However, researchers use different integration patterns and platforms still lacking enough practice and validation in different fields for the whole lifecycle. Therefore, for future research, it is suggested a focus on issues including using a unified model, better based on standard data format of Industry Foundation Classes (IFC)⁵ and City Geography Markup Language (CityGML)⁶ for Smart City applications on multiple purposes across the whole lifecycle, developing a corresponding data platform.

In addition, achieving a coherent collaboration between both domains will enable the creation of a continuity of information on a multi-scale level that connects buildings and the urban environment.

It seems necessary to introduce different levels and approaches on interoperability, that is defined as the “capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units”⁷.

Furthermore, existing standards identify three main levels of interoperability:

⁵ IFC is defined as an object-based file format oriented specification for exchanging, sharing and re-using information throughout the building industry's life cycle. It is an open file format developed and maintained by International Alliance for Interoperability since 1995. El-Mekawy, M.; Östman, A.; Hijazi, I. *An Evaluation of IFC-CityGML Unidirectional conversion*. Int. J. Adv. Comput. Sci. Appl. 2012,3, 159–171

⁶ CityGML, is a common information model and XML-based encoding for the representation, storage, and exchange of virtual 3D city and landscape models. It is realized as an opened data model and implemented as an application schema (Schema is the organization or structure of a database. The term is often used in relational databases and object-oriented databases) for the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange issued by Open Geospatial Consortium (OGC) and ISO/TC211 Geographic information/Geomatics. It provides a standard model and mechanism for describing 3D objects in relation to their geometry, topology, semantics and appearance generalization of hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. Gröger, G.; Plümer, L. *CityGML Interoperable semantic 3D city models*. ISPRS J. Photogramm. Remote Sens. 2012,71, 12–33.

⁷ ISO/IEC 2382-1:1993 Information Technology — Vocabulary — Part 1: Fundamental terms.

- Data interoperability concerns the creation, meaning, computation, usage, transfer and exchange of data (ISO/IEC 20944-1, 2013)⁸;
- Syntactic Interoperability concerns information formats and the ability of two or more systems to exchange structured information (ISO 16678, 2014)⁹;
- Semantic Interoperability concerns the ability of two or more systems or services to automatically interpret and use information that has been exchanged accurately (ISO 16678, 2014).

These information layers are connected and built upon each other, where the lower levels provide elements required by upper level functionalities and without all levels of interoperability, metadata cannot be shared effortlessly efficiently and profitably. Therefore, without data interoperability information would not be sent correctly from one device to another. Furthermore, without syntactic interoperability, data is not handled properly, which means it will not respect the formats, encoding, properties, values and data types. And finally, without Semantic interoperability, the meaning of the language, terminology and metadata values used cannot be exchanged or properly assumed. Hence, in regards to BIM and GIS interoperability levels, only the semantic level has not been yet solved. Therefore, ISO 11354 (ISO 11354-1, 2011¹⁰) proposes to achieve semantic interoperability between multiple systems through three semantic approaches: unification, integration and federation.

The final ambition is to configure a digital approach to UI basing on interoperability between BIM and GIS integration towards DT models of the city organized into layers that cooperate and reconfigure themselves to solve assigned problems. High level decisions can be provided through a coordinated multidisciplinary approach, leveraging fully multidisciplinary integration of city layers, connection and evolution with the city, and integration of participative strategies to include “human-oriented” information, as well as modularity of application. The proposed methodologies for a new digital urban planning could lead to some significant results at a strategic level (planning and intervention on city infrastructures, mobility systems, energy distribution, etc.) as well as at an operational level (urban planning in connection with services management, local mobility planning, building design and performance, site and settlement planning) and also on emergency levels (integrating resiliency and sustainability into emergency preparedness).

⁸ ISO/IEC 20944-1:2013 *Information Technology — Metadata Registries Interoperability and Bindings* (MDR-IB) — Part 1: Framework, common vocabulary, and common provisions for conformance. The ISO/IEC 20944 series of International Standards provides the bindings and their interoperability for metadata registries, such as those specified in the ISO/IEC 11179 series of International Standards. ISO/IEC 20944-1:2013 contains an overview, framework, common vocabulary, and common provisions for conformance for the ISO/IEC 20944 series of International Standards.

⁹ ISO 16678:2014 *Guidelines for interoperable object identification and related authentication systems to deter counterfeiting and illicit trade*, establishes a framework and outlines functional units used to achieve trustworthiness and interoperability of such systems. It does not specify any specific technical solutions, but instead describes processes, functions, and functional units using a generic model to illustrate what solutions have in common. Object identification systems can incorporate other functions and features such as supply chain traceability, quality traceability, marketing activities, and others, but these aspects are out of scope of ISO 16678:2014.

¹⁰ The purpose of ISO 11354-1:2011 is to specify a Framework for Enterprise Interoperability (FEI) that establishes dimensions and viewpoints to address interoperability barriers, their potential solutions, and the relationships between them. ISO 11354 applies to manufacturing enterprises, but can also apply to other kinds of enterprises. It is intended for use by stakeholders who are concerned with developing and deploying solutions based on information and communication technology for manufacturing enterprise process interoperability. It focuses on, but is not restricted to, enterprise (manufacturing or service) interoperability.

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Concluding remarks

A university is a community of scholars and students. Its mission is to meet the socio-educational needs of a human capital committed to facing the complexities of the challenges in contemporary society.

In this moment of great suffering and strict restrictions, all the figures in this community are called on to contribute.

Knowledge, new training horizons and international cooperation are the pillars upon which the entire organizing committee built the International Summer School GIS-BIM for digital integrated design.

We also wanted to summarize the didactic and human activity in the contents collected in this book. The goal is to render the 10-day ISS learning experience available in order to build new ones in the future.

The organization committee is already at work on the next editions of the Winter and Summer Schools on the issues of integration not only in terms of practical and innovative methods but also through cooperation and growth with academic and professional realities of the world.

For information and contacts on the activities related to the integration development of GIS-BIM solutions please visit the website: www.gis-bim.eu.



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