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Building Information Modeling for a Smart and Sustainable Urban Space

Edited by

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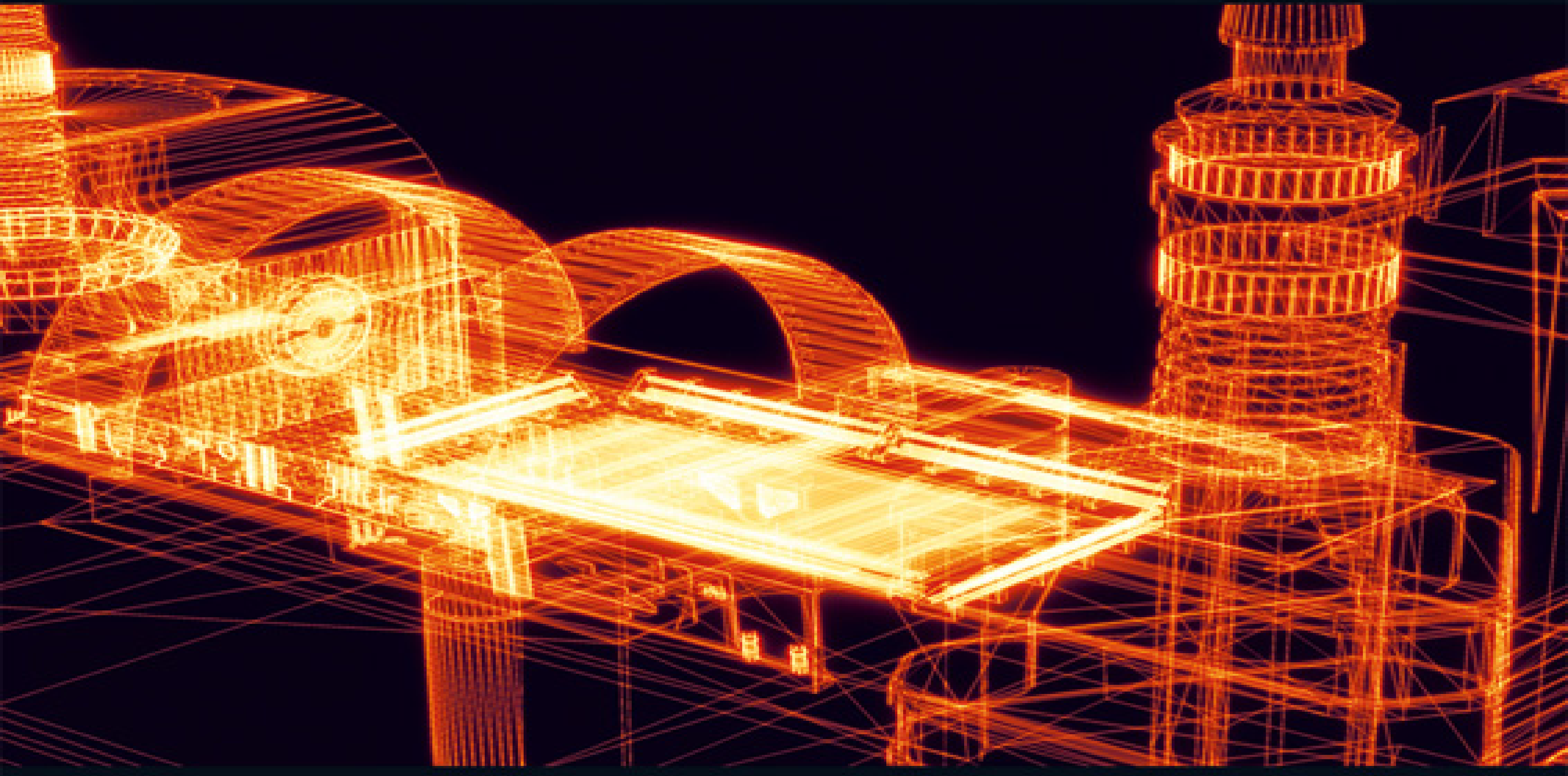

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Preface

Multi-scale Building Information Modeling (BIM) has the potential to become a powerful decision support tool for urban planning. It can be used to facilitate many applications in various fields such as wind simulations, energy studies, noise studies and various types of analyses that require placing a planned architectural design in its context and being able to follow its implementation and evolution in an urban context, and connecting it with other urban components such as networks, road infrastructures, etc. The 3D urban model has become an essential support for better communication with all stakeholders on urban issues.

This book presents the theoretical and practical basis for implementing a multi-scale BIM. It addresses the issues of data acquisition, modeling, integration and information sharing in an interoperable framework. The book analyzes and provides the basics of BIM and Geographic Information System (GIS) integration in the context of urban management, a preliminary step to achieve the intelligent and sustainable management of an urban space. This book also presents practical case studies illustrating some aspects of using the concept of multi-scale BIM to address certain urban issues, including the segmentation of Light Detection and Ranging (LiDAR) data for BIM modeling, the integration of BIM and 3D GIS for property value simulations and the contribution of BIM and 3D GIS to urban renewal.

Rafika HAJJI
Hassane JARAR OULIDI
September 2021

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I dedicate this work especially to my husband for his support and encouragement. I thank him for the sacrifices he has made for me. Thank you for the joy and happiness you bring to my life.

Rafika HAJJI
September 2021

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Hassane JARAR OULIDI
September 2021

List of Acronyms

ADE	Application Domain Extension
AEC	Architecture/Engineering/Construction
AIA	American Institute of Architects
AR	Augmented Reality
B-Rep	Boundary Representation
BDS	Building Description System
BIM	Building Information Modeling
BMLS	Backpack-Mounted Laser Scanners
bSI	buildingSMART International
CAD	Computer-Aided Design
CIM	City Information Modeling
CNN	Convolutional Neuron Network
CPM	Critical Path Method
CSG	Constructive Solid Geometry
DARCES	Data-Aligned Rigidity-Constrained Exhaustive Search
DBMS	DataBase Management System
DEM	Digital Elevation Model
DL	Deep Learning
DM	Dense Matching
DSM	Digital Surface Model
DTM	Digital Terrain Model
ETL	Extract, Transform, Load
FME	Feature Management Engine
FoV	Field of View

GIS	Geographic Information System
GLIDE	Graphical Language for Interactive DEsign
GLoD	Geometric Level of Detail
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HBIM	Historic Building Information Modeling
HMLS	Hand-held Mobile Laser Scanner
IAI	International Alliance for Interoperability
ICP	Iterative Closest Point
IDBE	Integrated Digital Built Environment
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFD	Information Framework for Dictionaries
IMU	Inertial Measurement Unit
ISO	International Organization for Standardization
ISPRS	International Society for Photogrammetry and Remote
	Sensing
KML	Keyhole Markup Language
LiDAR	Light Detection And Ranging
LoA	Level of Accuracy
LoB	Line of Balance
LoD	"Level of Detail"/"Level of Development"
LoGeoRef	Level of GeoReferencing
LoI	Level of Information
ML	Machine Learning
MMS	Mobile Mapping System
MNO	Modifiable Nested Octree

MVD	Model View Definition
MVS	Multiple View Stereovision
NIBS	National Institute of Building Science
NURBS	Non-Uniform Rational Basic Spline
OGC	Open Geospatial Consortium
RANSAC	RANdom SAmple Consensus
RDF	Resource Description Framework
RGB-D	Red–Green–Blue-Depth
SFM	Structure From Motion
SIFT	Scale-Invariant Feature Transform
SIRS	Spatially Referenced Information Systems
SLAM	Simultaneous Localization And Mapping
SLoD	Semantic Level of Detail
SPR	Spatial Partitioning Representation
SURF	Speeded-Up Robust Features
UBM	Unified Building Model
VLL	Vertical Locus Line
xBIM	eXtensible Building Information Modeling

Introduction

General context

BIM and 3D GIS for a multi-scale modeling of urban space

Urban space is both rich and complex. Its modeling must support the management of this urban complexity through the development of geometrically and semantically rich 3D models. Whatever the use, the availability of a 3D urban model is commonly accepted as a crucial need that requires organizations producing reference data to direct their developments towards the acquisition of 3D geographic reference systems.

The theme “Building” represents a reference component for spatial data infrastructures that shares relationships with other urban objects like infrastructures, city facilities, cadastral parcels, etc. In the Infrastructure for Spatial Information in the European Community (INSPIRE) directive, the theme “Building” is part of the reference data that is required in the European Data Infrastructure. According to the INSPIRE directive, the definition of a building is very broad:

> A building is an enclosed construction above and/or underground, used or intended for the shelter of humans, animals or things or for the production of economic goods. A building refers to any structure permanently constructed or erected on its site.

Within an urban diversity, the building is an object of reference that is at the center of several issues and is the subject of several studies. The building is, among other things, a space for living, working and human activities, which consumes resources and which defines and controls the dynamics of the urban space.

Faced with a wide range of applications and user needs that are both varied and evolving, the consistency of a general purpose 3D model is difficult to implement in terms of the types of objects to be represented as well as their geometric and semantic accuracy specifications, since the levels of detail and accuracy are strongly related to one's interest in the 3D objects to be represented in a specific application.

The process of digitizing a building leads to a complete, geometrically reliable and precise 3D representation, semantically annotated in the form of a building information system, commonly called BIM (Building Information Modeling). Through a collaborative process, BIM refocuses practices around a highly detailed digital model containing qualitative and quantitative information on a building, and allowing all stakeholders (project owners, architects, engineers, operators, owners, etc.) to coordinate their contributions throughout the lifecycle of the project. This process allows us to optimize the methods of the construction, management and operation of buildings and to become more efficient in terms of cost and time required for the development of a project.

BIM has its origins in 1962, where the basic premises were first established by Douglas C. Engelbart, who in his article "*Augmenting Human Intellect*" described the way in which the architect can perceive the evolution of their project with adjustments to information flows through an object-oriented design. In 1975, Eastman established the link between the architectural design of a building and the field of computer science, and then developed and implemented a Building Description System (BDS) that establishes the basis of object modeling through a model that encapsulates different information and their management within the BDS (Eastman 1975), in which the “element” is the basic unit to which information is added.

Today, BIM is one of the major technological innovations in the field of construction, providing a 3D information base for studies and simulations on an urban scale, including environmental studies, energy, noise, property value simulations, etc. BIM allows the characterization of the geometry of buildings, spatial relationships, quantities as well as properties of construction elements, cost, materials, etc. Beyond its contribution to the economy of construction through cost and time optimization, BIM responds to sustainable development through a model that integrates information on the elements of the model for intelligent and sustainable construction. Upon delivery of the building, an “as-built” version of the BIM represents the actual state of the building, which helps facility managers to undertake maintenance and intelligent building management operations.

At an urban scale, GIS (Geographic Information System) is proving to be a powerful system for managing spatial phenomena. It must therefore be aligned with the increased need for rich and well-structured three-dimensional data that can offer advanced functionalities in a 3D space. The problem is not reduced to a simple extension of 2D GIS solutions by adding a third dimension, but requires consistent modeling, representation, storage and 3D spatial analysis for an optimal management of 3D data.

Through the capture, modeling, storage, manipulation, analysis, sharing and representation of geographically referenced data, 3D GIS describes information about the environment as it is captured at different times in a 3D environment. However, it provides access to data that is less detailed than data from BIM, but more up-to-date and covers a wide spatial extent (Worboys and Duckham 2004), therefore giving BIM and 3D GIS two different scales of modeling and analysis.

Trivially, the development of a 3D GIS is motivated by the increased demand for 3D information, and also by the technological revolution in 3D data acquisition, 3D reconstruction and modeling, new 3D visualization techniques such as virtual, augmented or mixed reality, and 3D spatial analysis. The challenge today is to choose the most appropriate technique for modeling a given spatial problem, from a range of 3D acquisition solutions, which is continuously developing and increasingly accessible to (initially) non-expert users. The difficulty lies rather in the implementation of solutions for processing, optimized storage and knowledge extraction from a 3D dataset. Moreover, the quality and integrity of the acquired data are two important parameters to be taken into consideration in the development of 3D models.

BIM-3D GIS integration: A new paradigm for a smart and sustainable urban space

The planning and management of the built environment requires at least two levels of analysis and planning, either at the city or neighborhood scale (GIS) or at the building scale (BIM). An integration of both BIM and 3D GIS models will be beneficial to adapt urban territories to the digital age. The current research trend is towards the integration of approaches from the geographic information domain (3D GIS) and the architectural and engineering domain (BIM). The challenge is to make a multi-scale modeling of urban space.

The result of this integration is GeoBIM, a hybrid process that combines information from the BIM micro-scale (building) and the GIS macro-scale (neighborhood, city, region, etc.). Thanks to its very detailed and precise information on the elements of a building, the BIM feeds the information represented by the GIS; the latter contains more general information and extends to a wider spatial context.

One example of the potential of 3D GIS is its ability to provide a platform for the simulation of urban issues related to the concept of a “Smart City”. If the major issue for politicians today is sustainable construction and the implementation of green strategies for new cities, the upgrading of existing buildings to meet the axes of sustainable development is not to be overlooked. 3D GIS plays a major role in this context. On the other hand, BIM provides very detailed and well-structured information about the building which allows its design, construction, management and operation to proceed in a sustainable and intelligent way.

Faced with a sustained urban dynamic and taking into account economic, social and environmental changes as well as the reforms undertaken, the territories of tomorrow are called upon to develop a capacity for resilience and sustainability capable of meeting the major challenges they face. Thus, the implementation of a new model of development and urban planning that responds to the many challenges of competitiveness, social cohesion, preservation of resources and sustainable development and innovation requires the development of concepts and new approaches to planning and a better integration of opportunities offered by new 3D technologies. The integration of 3D GIS and BIM allows the study of the dynamic relationship between physical and environmental conditions, urban geometry and the properties of each building. Such integration will help achieve smart, resilient and sustainable urban spaces (Niu *et al*. 2015). Having multi-scale urban models not only helps to meet the current requirements for urban space analysis and management, but also helps meet the future and prospective needs of tomorrow's cities.

However, there are several conceptual and technical complexities that arise from BIM-3D GIS integration. This is mainly due to dissimilarities between the two domains in terms of spatial scale, level of granularity and detail (LoD), geometry representation methods, storage and access, and semantic dissimilarities. There are three main levels of 3D BIM-GIS integration: data-level integration, application-level integration and model-level integration. This last level is more flexible until one of the two models (BIM or 3D GIS) is extended through its standard to integrate the data and elements of the other model. Another more advanced level of extension is the development of a meta-model that mediates between the two models at a higher conceptual level. In the literature, the contributions in the integration of BIM and 3D GIS are notable, but are far from being able to solve all the technical problems inherent to this integration (Biljecki and Tauscher 2019). This is a niche area of research that is still active.

Interoperability: a major challenge for multi-scale BIM

In the general context of "Data Sciences", the exchange and sharing of data is unavoidable. Given the heterogeneity of systems, tools and formats, interoperability is recognized as a major challenge in the integration of multi-source data. Interoperability is the ability to ensure that data generated by one user can be correctly interpreted by all other users (Shen *et al*. 2010). Data interoperability enables reliable and efficient information exchange: it is a prerequisite for effective system integration in a collaborative context. The goal is to eliminate or reduce time-consuming and error-prone manual interventions inherent in the operation or exchange of data between software and users.

Interoperability in 3D urban modeling is the fundamental objective behind the development of the CityGML standard. CityGML is an open data model for the storage and exchange of 3D city models. The objective of the development of CityGML is to achieve a common definition of the basic entities, attributes and relationships of a 3D city model. CityGML is based on a very rich geometric, topological and semantic data model. It also provides a multi-scale representation through a number of defined levels of detail for urban objects (Gröger *et al*. 2012). The most commonly used level of detail is that of buildings.

In the field of construction engineering, IFC (Industry Foundation Classes) has been proposed as a standard based on an open object-oriented model. IFC is designed to model the objects of a BIM in terms of geometric information, semantics and relationships between elements to facilitate the interdisciplinary coordination of BIMs, the sharing and exchange of data between IFC-compliant applications, and the transfer and reuse of data in different contexts.

Over the last few years, a number of studies have been conducted to examine the potential for the integration of GIS and BIM (GeoBIM) through the standardization of exchanges between IFC and CityGML. However, the technical issues inherent to the management of interoperability between the two schemas are far from being mastered and still mobilize several research groups such as the EuroSDR GeoBIM working group (Noardo *et al*. 2020).