Integration of GIS data into 3D Space Partitioning to enhance architectural modeling

Sebastian Oswald[1] and Gresa Calliku[1]
[1]Fachgebiet für Bauinformatik, Technische Universität Berlin, Gustav-Meyer-Allee 25, 13355 Berlin, Germany
E-mail(s): s.oswald@tu-berlin.de, g.calliku@tu-berlin.de

Abstract: This paper explores the integration of Geographic Information System (GIS) data within a 3D unbounded space partitioning framework to enrich architectural modeling beyond conventional practices. By investigating how built environment data can be incorporated into a topologically connected 3D model, the study aims to understand its potential impacts on the design and construction phases of a project, as well as the role that integration of adjacent outer space might have, departing from the building scale to parcels, cadastral, and city development plans in the future. Space partitioning, which divides the Euclidean space into distinct nonoverlapping domains, is explored for its potential to improve modeling accuracy and efficiency. By laying the groundwork for the embedding of comprehensive spatial relationships into the modeling framework, the paper seeks to stimulate discourse on the dynamic requirements of construction projects and the transformation of iterative architectural planning practices. It outlines terrain integration as the initial phase of this exploratory and investigative approach to incorporate various scales in 3D modeling for advancement within the Architectural Engineering and Construction (AEC) industry.

Keywords: Space Partitioning, Topology, Architectural Design, Geometric Modeling, GIS

Erschienen in Tagungsband 35. Forum Bauinformatik 2024, Hamburg, Deutschland, DOI: 10.15480/882.13548

1 Introduction

Digitalization presents a significant challenge for the construction industry, necessitating improved coordination and data integration due to the participation of various disciplines in building projects. Building Information Modeling (BIM) was developed to meet these needs, facilitating transparent data integration among all stakeholders [1], [2]. Furthermore, Geographic Information Systems are crucial in construction projects in collecting, processing and visualizing geographic data, including parcel boundaries and terrain models [3]. Integrating GIS information early in the planning phase helps prevent errors and costly changes [4]. There is increasing interest in combining BIM and GIS systems to improve the execution of infrastructure projects, emphasizing the importance of accurate local terrain knowledge [5]. As these systems differ in several aspects, such as modeling paradigm and georeferencing, combining them poses a significant challenge [3]. This topic has been under investigation for some time, and different approaches have been developed (see [3], [4]).

Given the growing complexity and diversity of data in these areas, there is an urgent need for consistent modeling techniques. The aim of this paper is therefore to present an approach for building modeling in the context of its environment while adhering to a consistent modeling technique.

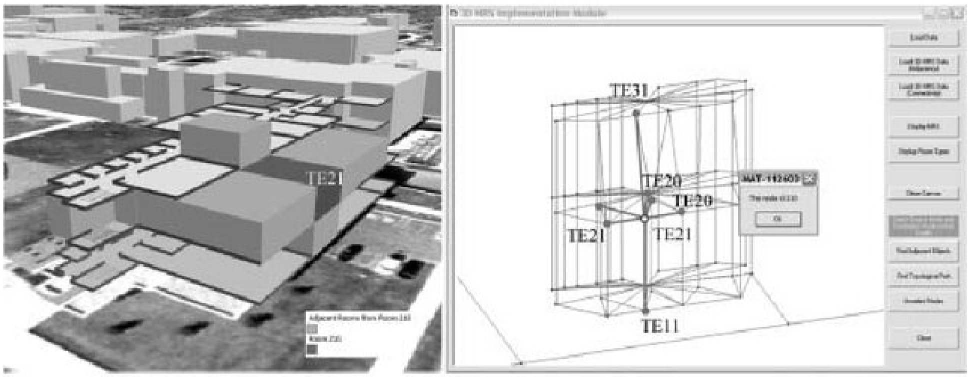
In this paper, this endeavor is referred to as the integration of GIS data into a 3D unbounded space partitioning framework. The term integration emphasizes the joint representation of GIS data and the schematic 3D architectural model to visualize and evaluate both.

It is important to note that this paper sets the foundations for this approach. These foundations include clarifying the usefulness and relevance in the field of architectural modeling. Chapter 2 describes the approach to project implementation from the early service phases and explains the benefits of integrating GIS data. The chapter ends with a description of a case study that will be used in subsequent research to visualize the progress of this investigation based on real-world scenarios. Chapter 3 deals with the aspects of GIS and BIM that need to be considered in order to realize geometric integration. This includes in particular the implementation of georeferencing and the investigation of existing and usable data formats of Digital Terrain Models (DTM). Chapter 4 discusses the 3D unbounded space partitioning framework and explains how it improves consistency and supports architectural design. Finally, an outlook is given for the upcoming steps of holistic integration and the use of publicly available city models and GIS data.

2 GIS Data in Architectural Modeling

2.1 Preliminary Design Phases

The preliminary phases of an architectural project are, though of a preparatory nature, those to define the scope of the project. Depending on the tools and methods that planners use, a structure emerges with certain formal and contextual features. This structure may or may not meet or exceed its forseen design aspirations. Embarking on this journey with integrated geoinformational data [6], rather than proposing a secluded 3D model of a building, allows designers to quickly project and iterate within existing premises [7]–[10]. This approach can significantly improve project flow for planners and enable efficient project management for the contractor. An illustration of a tool that allows this integration is given in Figure 1.



(a) (b)

Figure 1: GIS, 3D Model and Spatial Configuration with relevant adjacencies [11]

During the Feasibility Design (FD) phase, planners conduct a comprehensive field study, which they later need for the Conceptual Design (CD) phase and the subsequent stages of the project. Site analysis provides them with vital insight into what should be designed and how to best accommodate the project demands while it guides them in making informed and effective design decisions. However, during the CD, a lot of this information is concurrently important, complex, and interrelated. Relaying solely on the planner can risk losing a significant amount of relevant data that may go flattened, as various factors often take precedence over others. Therefore, it is essential to ensure that all relevant data accumulated in the initial phases of the project is meticulously collected, documented, consistently followed, and readily accessible as needed. Data models that enable design in a consistent, connected geometric model are mentioned in Chapter 4.

2.2 Spatial Modeling: A Case Study

Integrating various geometric and geospatial data, each with unique scale, formats, and features, poses a challenge in creating an integrated model suited to different building typologies. Two distinct approaches to overcoming this challenge are standardization and contextualization. Standardization involves streamlining general spatial generation patterns, while contextualization would demand a tailor-made approach to each building typology. Patterns for the conceptual design of a chosen typology, in the given case an education and research facility, while assisted from space partition, are to be identified. Figure 2 illustrates how GIS data and partition modeling can be integrated into the existing data flow. When incorporating these elements into the Preliminary design phases (FD, CD), it is advisable to redefine the data intake and output processes to enhance the overall design efficiency. Case-specific guidelines determine the necessary space allocations based on the demands of academic and learning commons as well as the overall capacity. The geospatial constraints are investigated from the beginning and incorporated to generate spatial configurations that are best suited to accommodate these demands. By leveraging geometric modeling requirements such as non-convex, compact, and connected content (bounded, inner space) and context (unbounded, outer space) configurations can be designed. Through graph-based data analysis, the spatial combinations satisfying a set of requirements are iteratively to be determined.

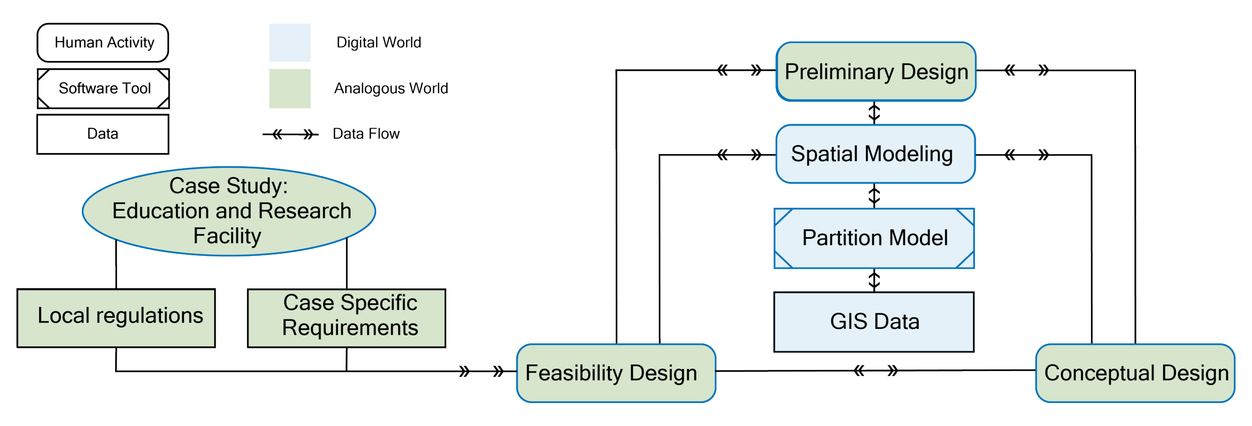


Figure 2: Spatial Design Realm

It is essential to develop an integral spatial concept before designing any building models. A widely recommended approach in research involves creating a spatial and a topological function connection, as illustrated in Figure 1b [11]. This process graphically arranges the individual units according to their functionality and interrelationships, providing an initial basis for the overall layout.

At this point, the question arises as to whether and how this concept can be implemented on the intended site. It is therefore pivotal to thoroughly evaluate the plot of land intended for development, along with its guidelines and limitations, including these considerations into the planning process. The way in which this should be done is explained in the following chapters.

3 GIS Models and GeoBIM

3.1 Georeferencing of Spatial Data

To facilitate structured planning, as discussed in chapter 2.2, construction should be modeled within its environmental context. This method, known as GeoBIM, and its implementation challenges have been explored in [12], [13].

The integration of BIM and GIS is challenging due to differences in georeferencing spatial data. Geodetic Coordinate Reference Systems (CRS) represent objects in relation to the entire Earth, whereas local Project Coordinate Systems (PCS) only describe specific buildings without considering other surroundings [3], [4].

A CRS uses a projection with known discrepancies to the real world. The Universal Transverse Mercator (UTM) projection, based on the ETRS89 reference system, is used in the European Union for the CRS representation. ETRS is a three-dimensional geodetic reference system (x, y, z) [4], [14]. The UTM projection maps the curved ellipsoidal surface of the Earth to a horizontal Cartesian plane (X, Y), which inherently involves geometric distortions, as shown in Figures 3 and 4. These figures illustrate that real lengths in the model are shortened because of these distortions.

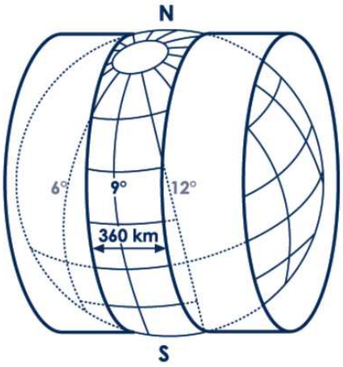


Figure 3: Universal Transverse Mercator Projektion [4]

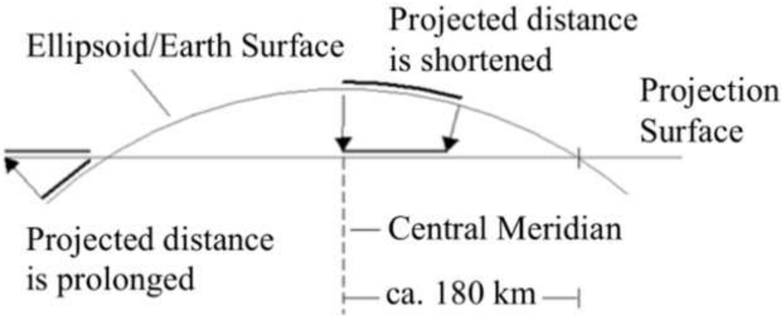


Figure 4: The distortions induced by the UTM projection [4]

To minimize distance and area distortions, strips of the ellipsoid are projected onto a cylinder with an elliptical cross section. This method is depicted in Figure 3. The approach in this paper involves modeling within a CRS. Since a CRS mapped to a UTM uses a three-dimensional Cartesian coordinate system (x, y, z), construction planning and modeling can be executed in this system. This approach, previously described in [4], is one of three methods and is considered advantageous. For practical use, the model must be transformed back using a scale function due to distortions in the CRS dimensions. The latest version of Autodesk Revit 2025 enables the import of terrain data as point clouds in DWG, DXF, DGN and CSV formats. Georeferencing in BIM represents the current state of the art [15], [16].

3.2 Sources and Tools

The previous chapter determined that the modeling should be based on a CRS, requiring a DTM based on ETRS89 within Europe. These DTMs are created, quality assured, and digitally processed by surveying companies for planning and construction purposes [17]. The format of the DTM is crucial. In [17] the IfcTerrain tool was presented to convert existing DTMs into the IFC format. It seemed necessary to implement such a tool, as there are a considerable number of different formats, which are shown in Figure 5.

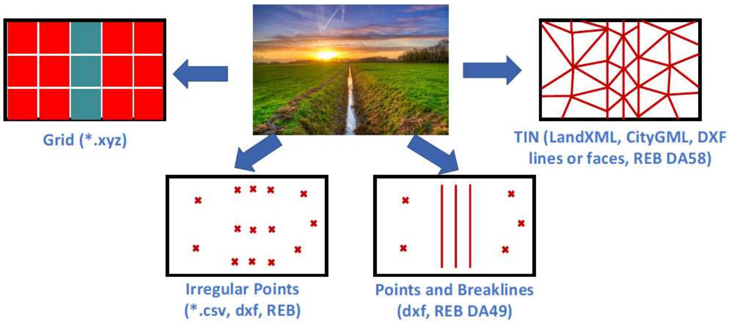


Figure 5: Different formats representing digital terrain models (DTM) [17]

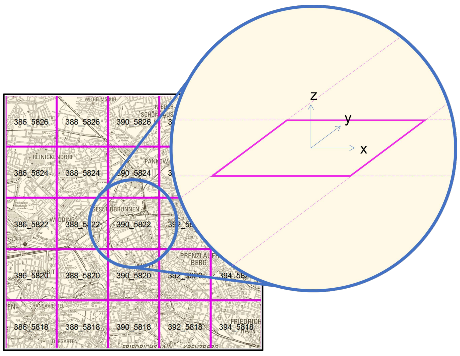


Figure 6: Visualization of an imported section. Edited image of [18]

Own investigations have shown that in Germany, DTMs are primarily available in XYZ format and geoTIFF, covering various regions or the entire country. These DTMs come in different grid sizes, from 1x1m to 1000x1000m (e.g., see [18]). Coarser grids result in less accurate elevation data as a result of linear interpolation between data points. To manage data size, the grids are divided into equally sized numbered sections (e.g. 2km x 2km). Figure 6 schematically illustrates the import of a 2 km x 2 km section of Berlin Gesundbrunnen, with the coordinate origin in the center. The dashed lines represent the unbounded planes within the three-dimensional model.

A prototype was developed to integrate DTMs into a 3D unbounded space partitioning framework [19] using point data from XYZ and geoTIFF formats to perform Delaunay triangulation, creating a Triangulated Irregular Network TIN. TINs are vector-based geographic data formed by triangulating multiple vertices into a mesh of triangles [20], [21]. Chapter 4.2 details how DTMs are imported, visualized, and modeled within the 3D framework based on a 1m grid width in a 2km x 2km section.

4 Space Partitioning and Data Integration

4.1 Partition Concept

The Partition Concept represents a paradigm shift in digital geometric modeling for applications in architecture, civil engineering, and geospatial science [22]. At its core, this concept involves dividing the unbounded Euclidean space into discrete, clearly defined point sets, referred to as domains [19]. Unlike traditional boundary representation (BRep) methods, which often struggle with geometric errors, the Partition Concept offers a robust approach to spatial modeling [23], which organizes space into consistent and connected bounded and unbounded domains, ensuring that neighboring elements share boundaries within designated contact zones.

The concept emphasizes both topological relationships and geometric requirements, such as watertightness, non-convex and manifoldness. Topologically, it builds on constructs such as CW complexes and half-edge-based data structures to effectively manage spatial relationships. Geometrically, it ensures in every work step that the models are watertight (free from gaps or overlaps) and manifold (continuous and non-self-intersecting) [23]. A unique feature of this approach is the introduction of imaginary domains to represent unbounded spaces. By comprehensively addressing these aspects, the goal is to create consistent and interconnected geometric models by integrating GIS data and building models. It overcomes traditional modeling limitations, highlighting complex spatial relationships, and is particularly valuable for design in fields such as navigation and energy modeling, where relationships and robustness are crucial.

4.2 Partition Platform

The Partition Platform is an implementation of the Partition Concept, providing a practical framework for consistent spatial modeling [19]. It employs a two-fold modeling approach: a simplified user model for space divisions and a detailed core model with advanced features that include orientation, twin domains, and dihedral cycles, following GIS standards such as ISO 19107. The platform's cornerstone is its use of only two elementary work steps, split and merge, to modify adjacent domains while maintaining topological consistency. These operations are executed with strict adherence to topological rules, with work steps sorted by dimension to ensure consistency [23], offering a robust framework for consistent spatial modeling with a two-fold approach: a simplified user model for space divisions and a detailed core model with features including orientation, twin domains, and dihedral cycles.

The integration of DTMs is demonstrated as part of the modeling process. DTMs, imported using formats like `XYZ` and `geoTIFF`, are processed through Delaunay triangulation to form a TIN, providing precise elevation data for planning and construction. Georeferencing spatial data using CRS such as ETRS89 ensures that models align with real-world coordinates. The TIN splits the space model within the partition into an unbounded ground and an unbounded air cell, as well as unbounded partial neighboring surfaces. Overall, it provides a first step to a more comprehensive solution for geometric and topological integrity, which is essential for modern spatial modeling needs in the built environment.

5 Summary and Outlook

As described in the introduction, this paper is intended to form the foundation for the approach of modeling a building in the context of its environment while adhering to a consistent modeling technique. This paper especially focused on the architectural design iteration and the integration of DTM into a 3D unbounded space partitioning framework.

The next step is to integrate 3D city models into the framework presented. This extension makes it possible to plan and construct buildings in relation not only to the natural environment but also to existing buildings and infrastructure. Taking into account the boundaries of the property and the existing buildings allows for more precise and comprehensive planning. This offers considerable advantages, as potential conflicts can be identified at an early stage and costly planning errors can be avoided. In addition, urban planning specifications and guidelines can be better adhered to, leading to more efficient and sustainable construction methods.

The integration of city models into the existing system represents a further significant step towards fully digitized and networked construction planning. This development opens up new opportunities for integrated and transparent collaboration between all parties involved and contributes significantly to the optimization of construction processes. Therefore, further research will be done and published to document the progress of this investigation. The case study presented in chapter 2 will continue in the following steps and will illustrate the findings and progress made.

References

[1] J. Blankenbach, C. Clemen, and R. Becker, “Grundlagen und Informationsmanagement der BIM-Methode”, *Leitfaden Geodäsie und BIM (Version 3.2)*, 2023.

[2] R. M. Aziz, T. I. Nasreldin, and O. M. Hashem, “The role of BIM as a lean tool in design phase”, *Journal of Engineering and Applied Science*, 2024. DOI: 10.1186/s44147-023-00340-3.

[3] M. Jarosch, “BIM & GIS”, in Springer Fachmedien Wiesbaden, 2023. DOI: 10.1007/978-3-8348-2118-8_14.

[4] Š. Jaud, A. Donaubauer, O. Heunecke, and A. Borrmann, “Georeferencing in the context of building information modelling”, *Automation in Construction*, 2020. DOI: 10.1016/j.autcon.2020.103211.

[5] A. Bradley, H. Li, R. Lark, and S. Dunn, “BIM for infrastructure: An overall review and constructor perspective”, *Automation in Construction*, 2016. DOI: 10.1016/j.autcon.2016.08.019.

[6] J. Stoter and S. Zlatanova, “3D GIS, where are we standing?”, *ISPRS Joint Workshop on ’Spatial, Temporal and multi-dimensional data modelling and analysis’, Québec, October, 2003*, Jan. 2009.

[7] R. Billen and S. Zlatanova, “3D spatial relationships model: A useful concept for 3D cadastre?”, *Computers, Environment and Urban Systems*, 2003. DOI: 10.1016/S0198-9715(02)00040-6.

[8] F. Döner, R. Thompson, J. Stoter, *et al.*, “4D cadastres: First analysis of legal, organizational, and technical impact—With a case study on utility networks”, *Land Use Policy*, 2010. DOI: 10.1016/j.landusepol.2010.02.003.

[9] M. El-Mekawy, A. Östman, and I. Hijazi, “A Unified Building Model for 3D Urban GIS”, *ISPRS International Journal of Geo-Information*, 2012. DOI: 10.3390/ijgi1020120.

[10] C. A. Carrasco, I. Lombillo, and J. Sánchez-Espeso, “Methodology for the generation of 3D city models and integration of HBIM models in GIS: Case studies”, *VITRUVIO - International Journal of Architectural Technology and Sustainability*, 2022. DOI: 10.4995/vitruvio-ijats.2022.18808.

[11] J. Lee and M.-P. Kwan, “A combinatorial data model for representing topological relations among 3D geographical features in micro-spatial environments”, *International Journal of Geographical Information Science*, 2005. DOI: 10.1080/13658810500399043.

[12] F. Noardo, T. Krijnen, K. Arroyo Ohori, *et al.*, “Reference study of IFC software support: The GeoBIM benchmark 2019—Part I”, *Transactions in GIS*, 2021. DOI: 10.1111/tgis.12709.

[13] R. De Laat and L. Van Berlo, “Integration of BIM and GIS: The Development of the CityGML GeoBIM Extension”, in T. H. Kolbe, G. König, and C. Nagel, editors, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011. DOI: 10.1007/978-3-642-12670-3_13.

[14] J. P. Snyder, *Map Projections: A Working Manual*. Books Express Publishing, 2012.

[15] “Autodesk revit 2025 - import von geländedaten”. (2025), [Online]. Available: https://help.autodesk.com/view/RVT/2025/ENU/?guid=GUID-A1E1DE84-29AE-4B99-B377-091C0AC45249.

[16] *DIN ISO/TR 23262:2021 – GIS (Geospatial) / BIM-Interoperabilität*, Deutsches Institut für Normung e.V. (DIN), Jan. 2022.

[17] C. Clemen, M. Schröder, T. Kaiser, and E. Romanschek, “IFCTerrain – A Free and Open Source Tool to Convert Digital Terrain Models (DTM) to OpenBIM Industry Foundation Classes (IFC)”, *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2021. DOI: 10.5194/isprs-annals-VIII-4-W2-2021-145-2021.

[18] Senatsverwaltung für Stadtentwicklung und Wohnen Berlin, *Geoportal Berlin - Metadaten: DGM1, Berlin (2016)*, 2016. [Online]. Available: https://gdi.berlin.de/geonetwork/srv/ger/catalog.search#/metadata/fa02f9e1-a0df-3be1-b0aa-bc624c0c7ff5.

[19] W. Huhnt, M. Sternal, and P. J. Pahl, “Modeling bounded and unbounded space with polyhedra: Topology and operators for manifold cell complexes”, en, *Advanced Engineering Informatics*, 2022. DOI: 10.1016/j.aei.2022.101790.

[20] R. Fellegara, F. Iuricich, Y. Song, and L. D. Floriani, “Terrain trees: A framework for representing, analyzing and visualizing triangulated terrains”, *GeoInformatica*, 2023. DOI: 10.1007/s10707-022-00472-3.

[21] Lund University, J. Lim, P. Pilesjö, and Lund University, “Triangular Irregular Network (TIN) Models”, *Geographic Information Science & Technology Body of Knowledge*, 2022. DOI: 10.22224/gistbok/2022.2.7.

[22] W. Huhnt, J. Z. Vetter, and M. Sternal, “Space Partitioning as a Holistic Alternative to Traditional Geometric Modeling Workflows in the AEC Industry”, in *Advances in Information Technology in Civil and Building Engineering*, 2023, pp. 415–426. DOI: 10.1007/978-3-031-32515-1_29.

[23] M. Sternal and W. Huhnt, “Robust Modeling of Polyhedral Space Partitions”, in *Advances in Information Technology in Civil and Building Engineering*, 2023, pp. 427–442. DOI: 10.1007/978-3-031-32515-1_30.