Geometry, Referencing, Representations, Standards and Semantic

Bridging the Gap between GIS and

GIS and Computer Aided Architectural Design (CAAD) follow distinct modelling paradigms for the generation and management of virtual 3D city models. New applications and the increasing demand for quality make it necessary to integrate models from both disciplines. Although in recent times the functionalities of 3D GIS and CAAD systems have been slowly converging, fundamental differences between the modelling approaches make it difficult to reach full interoperability. The authors treat in greater detail the differences between the 'worlds' of geometry representation, spatial referencing, multiple representations, international standards and semantic modelling. In addition, possibilities of bridging the gap are discussed.

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Virtual 3D city models have become increasingly important for urban planning, architectural design, disaster management and 3D cadastre. They have been established and used both in the GIS domain and in the domain of *Architecture, Engineering, Construction, and Facility Management* (AEC/FM). However, although GIS and *Computer Aided Architectural Design* (CAAD) are separate domains, each would profit from the integration of models from the other discipline:

- The GIS domain would get access to semantically-rich objects, gain access to the inside of buildings and generally become better platforms for planning
- CAAD would profit from the spatial context provided by the huge amount of geo-objects maintained in GIS

In the past, neither GIS nor CAAD systems provided full support for the representation, management and visualisation of large 3D city models. The current trend is for CAAD systems to incorporate GIS functionality, such as the support of geodetic coordinate reference systems and data-

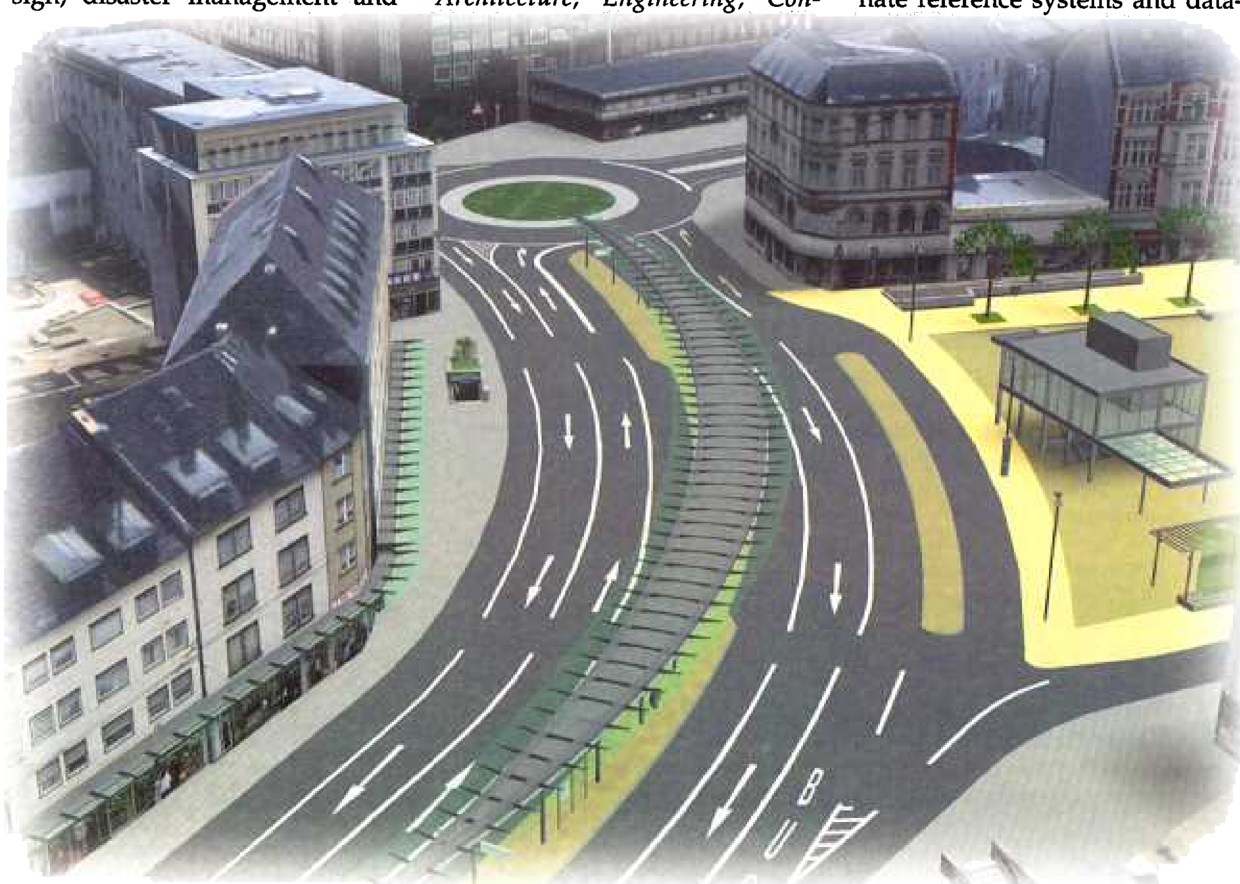


***Figure 1**, Integration of 3D CAAD and GIS models in an urban planning scenario. Whereas architecture models provide detailed information about the planned objects, GIS models set the environmental context. Image: City of Solingen, Stadtdienst 621/623. Planning version for the rebuilding of the Graf-Wilhelm-Platz. Design by Quick / Beckmann / Quick Architects, Berlin*

Modelling CAAD

base functionalities. On the GIS side, the main development concerns the integration of full support for 3D coordinates and 3D geometric primitives.

Two Worlds

Integration of 3D CAAD and GIS models is increasingly carried out for purposes such as urban planning (Figure 1). Although GIS and CAAD systems are thus getting closer, fundamental differences between the disciplines hinder the coherent integration of city models from these domains. The major difference originates in their distinct modelling paradigm. This is a result of the way in which 3D models are acquired. In the GIS domain 3D objects are acquired from aerial images, laser-scanner data or terrestrial measurements: that is, observations. Therefore an accumulative modelling principle is applied which allows easy description of the observed features. In contrast, the CAAD domain follows a generative modelling approach. CAAD models are the result of a construction process and focus on manmade artefacts rather than on representation of topography.

Geometry Representation

Of all the different modelling principles for 3D geometry, the *Boundary Representation* (B-Rep) and the *Constructive Solid Geometry* (CSG) are most important for 3D city models (Figure 2). The B-Rep model is defined as the accumulation of all surfaces enclosing the volume of an object. Because surfaces are explicit, textures can be draped directly onto them. 3D polygons can efficiently be rendered using hardware acceleration from 3D graphic cards. The B-Rep modelling approach is especially suited to representation of measured 3D object geometries, since it can describe even complex polyhedra by just one geometric object.

In CSG models, the object geometry is composed of volumetric and parametric primitives that are combined using the set theoretical operations union, intersection and difference. Following the generative modelling paradigm, CSG is well suited to model construction as applied in architectural design. A look on the system side reveals that most CAAD systems realise a hybrid modeller supporting both CSG and B-Rep. Problems arise since these systems:

- Are not designed to handle the large number of objects in a city model
- Offer as yet only limited GIS functionality

However, 3D GIS is currently limited by the fact that it realises only B-Rep. This makes it difficult to incorporate AEC/FM models in a way that would allow their subsequent editing using generative modelling tools.

Spatial Reference

When dealing with geo-information, the exact spatial reference is of the utmost importance. Geo-information systems traditionally offer strong support for the various *geodetic Coordinate Reference Systems* (CRS). Besides geographic and projected coordinates, some GIS models also allow different CRS for planimetry and height. Embedded procedures for coordinate transformations in GIS make it possible to combine geo-objects with different CRS.

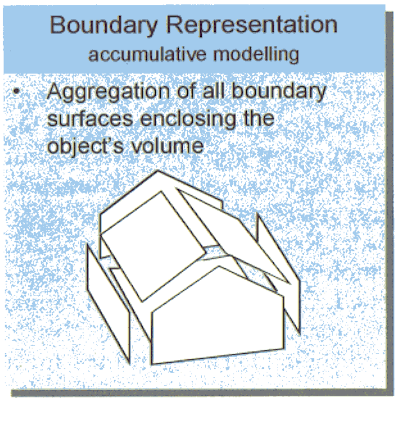
Geo-referencing has played only a minor role in CAAD systems so far. Architectural models are typically restricted to Cartesian coordinate systems. During construction, 3D objects are often modelled using local model coordinates without referring to a CRS. Geo-referencing is done (often manually) by the explicit application of an affine transformation which translates, scales and rotates all objects in a project to their world coordinates. Whereas the explicit representation of absolute coordinates in GIS models enables efficient indexing and immediate processing, it inhibits the use of prototype objects. Prototypes are defined using local coordinates and can be instantiated at different locations in a 3D-city model by a simple transformation. Therefore, classical GIS data models make it necessary to explicitly represent every streetlight, traffic light, tree and other vegetation object.

List of Abbreviations

AEC/FM	Architecture, Engineering, Construction, and Facility Management
B-Rep	Boundary Representation
CAAD	Computer Aided Architectural Design
CRS	Coordinate Reference System
CSG	Constructive Solid Geometry
GML	Geography Markup Language
IAI	International Alliance for Interoperability
IFC	Industry Foundation Class
ISO	International Organisation for Standardisation
LoD	Level of Detail
OGC	Open GIS Consortium
XML	Extensible Markup Language

Multiple Representations

3D-city models are often classified with respect to their resolution and generalisation level (Figure 3). In many existing models three discrete *Levels of Detail*



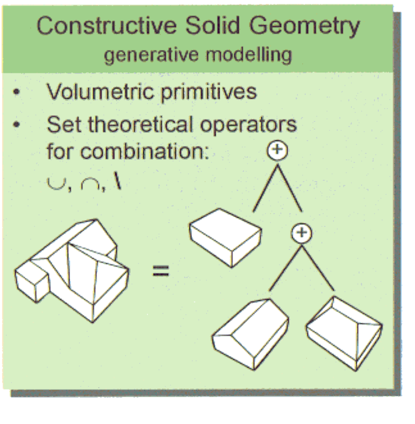


Figure 2, 3D GIS and the AEC/FM domain prefer different geometry representations. Whereas architecture models are typically constructed from volumetric primitives, GIS models are composed of the observable object surfaces

(LoD) are distinguished:

- LoD 1 comprises simple buildings with flat roofs
- LoD 2 comprises building models with roof structures and textured facades
- LoD 3 comprises highly detailed models also containing smaller features like chimneys, stairs and balconies

Since often the data for each LoD is obtained by specific acquisition methods, single objects may have multiple representations that are simultaneously valid. The continuation process of city models implies a second representation dimension. Geo-objects change over time and therefore have different representations at different points in time (in any LoD!). This aspect is especially important for the development of 3D cadastres, where the complete history of spatial objects has to be maintained. In contrast to the LoD case above, at any time exactly one representation of an object is valid. Furthermore, in a planning scenario some objects may exist in different concurrent versions. Since these alternative representations may exist in different LoDs and at any point in time, versions add another dimension to the problem of multiple representations. Currently, neither GIS nor CAAD systems provide mechanisms for the realisation of all three different representation dimensions.

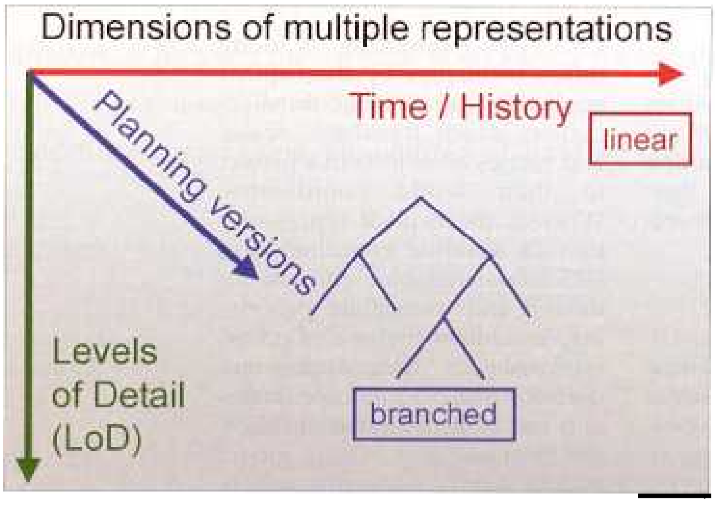


Figure 3, In 3D city models each object can have multiple representations according to the respective point in time, different planning versions and specific level of detail

International Standards

The good news concerning the interoperability of 3D-city models is that there exist comprehensive international standards up to ISO level. The bad news is that these standards have been developed within separate contexts by distinct organisations that have then submitted their work to different ISO technical committees (Figure 4). In the AEC/FM domain the *International Alliance for Interoperability* (IAI) has developed the *Industry Foundation Classes* (IFC, ISO/PAS 16739). IFC defines a product model in the sense that it covers both the geometry and the semantic properties of buildings and their components. For example, IFC contains definitions for buildings, storeys, walls, roofs, rooms, stairs and so on. With the *Geography Markup Language* 3 (GML3), the *Open GIS Consortium* (OGC) has released an XML-based standard for the representation of 0-4D geo-objects. GML3 is based on different 191xx ISO standards. It is a 'meta format', which means that it can be tailored to different application domains.

In February 2003 the OGC and the IAI announced their official co-operation. An ongoing project is investigating the conversion of models between the formats. However, such conversions will be problematic because IFC supports both CSG and B-Rep geometry, whereas GML3 is restricted to B-Rep. Furthermore, IFC currently offers only little CRS support.

Semantic Modelling

The modelling aspect, which has progressed best in recent years, concerns the explicit representation of object semantics. With IFC and GML3, both the AEC/FM and GIS domain nowadays provide data models and exchange formats which are not only able to represent object geometries but also their type, structure, function and relations to other objects. In order to create a semantic model, ontology has first to be developed. Ontology defines all terms, the meaning of different objects and their interrelationships for a specific application domain. Whereas such ontology has been developed for the AEC/FM domain by the IAI, no common ontology has yet been defined for 3D-city models in the context of GIS.

In an initiative designated the Geodata Infrastructure North-Rhine Westphalia (GDI NRW) we are currently working on the definition of a unified 3D-city model for GIS. About fifty parties in German industry, academia, administration, municipalities and cadastre are participating in the development. The model comprises differentiated concepts for the different types of real world objects in cities, like buildings, streets, waters bodies, vegetation, terrain etc. The model is based on ISO standards from the ISO 191xx family. In an forthcoming testbed a GML3 application schema will be derived.

Bridging the Gap

3D-city models from the GIS and AEC/FM domains differ substantially in many aspects. Thus it cannot be expected that either GIS or CAAD systems will solve all above problems in the mid-term. Instead, semantic modelling is the key to the integration of (geo-)objects from both domains. Such objects will be presented both in terms of the GIS and the CAAD model. The mapping of the two different ontologies then allows interpretation of objects from one domain in the context of the other. It is a question of future research how to ensure consistency between coexisting models. The long-term goal should be definition of a common ontology for 3D-city models with specific profiles for GIS applications and the AEC/FM domain. A first step would be the broader discussion between GIS and CAAD communities on the one hand and the users of 3D-city models on the other.

Further Reading

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- Adachi, Y., Forester, J., Hyvari-

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Websites

www.ikg.uni-bonn.de/sig3d/ (homepage of the SIG 3D of the initiative Geodata Infrastructure North-Rhine Westphalia GDI NRW)◆

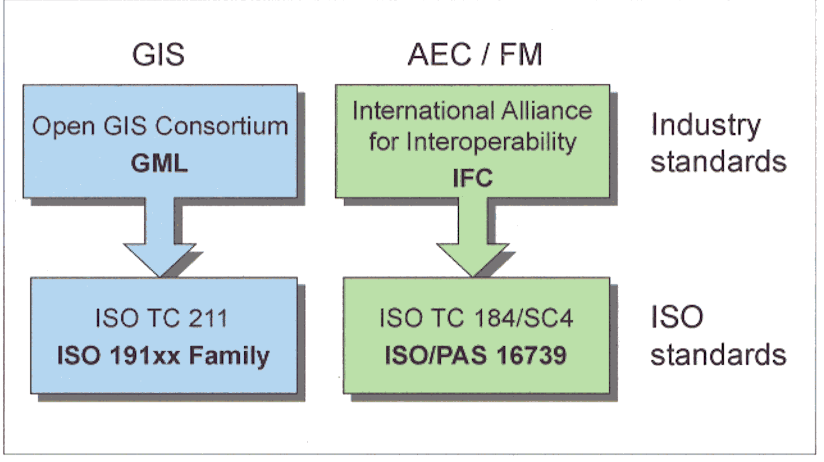

***Figure 4**, GIS and the AEC/FM domain have their own industry standardisation organisations that submit proposals to different technical committees of the ISO. Since 2003 OGC and IAI have co-operated with the long-term goal of seamless integration of architecture and GIS models*

Biography of the Authors

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