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EXPLORING THE NEEDS AND APPLICABILITY OF A 3D URBAN LAND REGISTER INFORMATION SYSTEM

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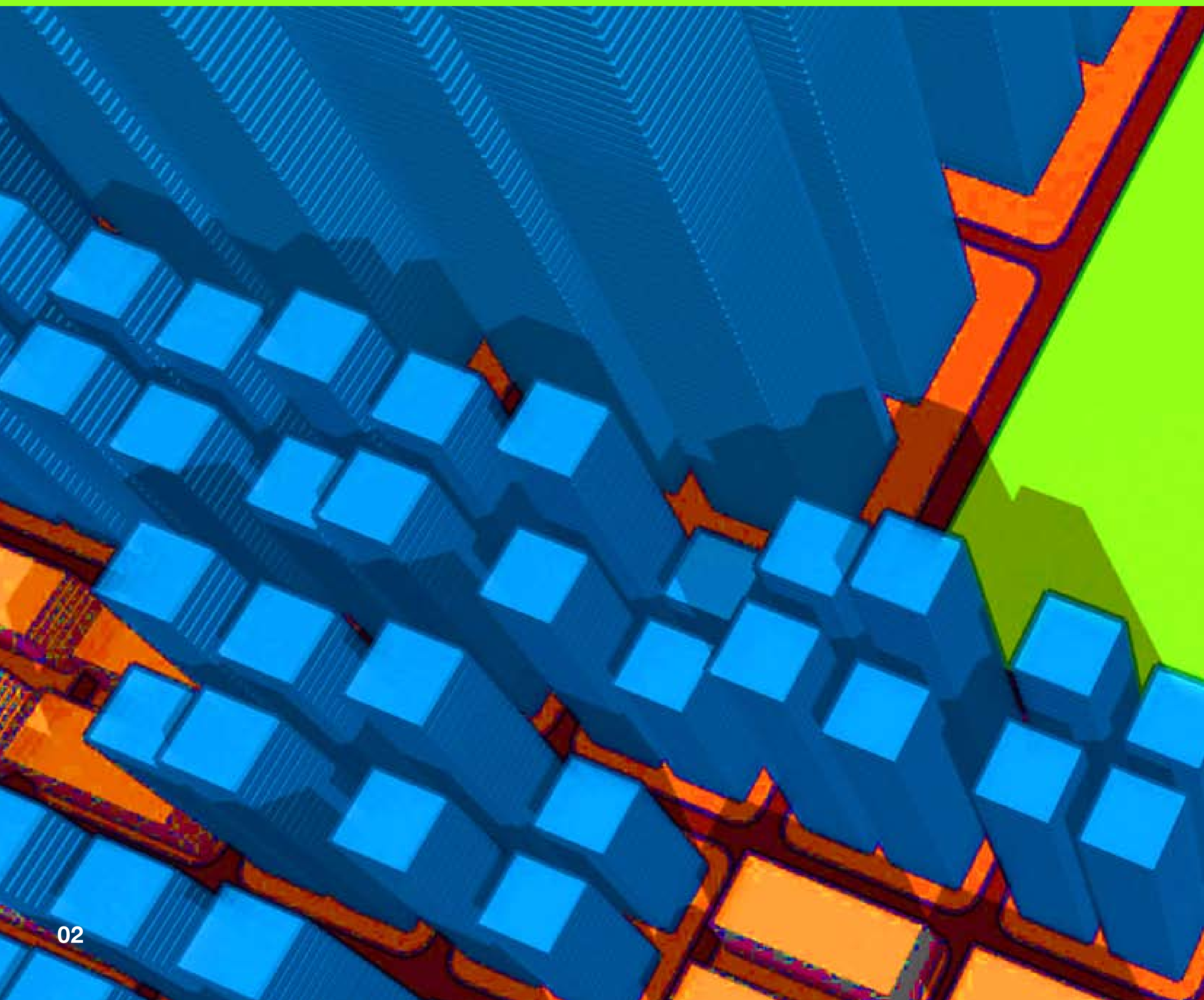
Introduction

Nowadays, everything is labelled "3D". 3D movies, ever more realistic 3D videogames, 3D virtual worlds… GPS navigation system may even display your route information as a 3D view. People talk about 3D technology even for toothbrushes and razorblades. So, it might be thought that visualising cities in 3D might be quite reasonable for the lay person, as a result of the growth of tools such as 3D urban databases, 3D land information systems. Of course, geomatics surveyors, used to working with photogrammetry and land surveying, are quite familiar with 3D approaches, and have started to develop 3D urban models, in collaboration with computer scientists, urban planners and architects.

With funding from the RICS Education Trust, Roland Billen and colleagues of the University of Liege explored what was needed in order to encourage the implementation of 3D land information systems. However, they soon discovered that their aims needed to be revised. "Our initial thought was that it was obvious to everyone that all types of urban information was going to be defined and stored in 3D or even 4D. We were wrong". The inevitability of an evolution to 3D virtual cities and 3D urban GIS was not shared by everybody. Furthermore, the applicability issue is not limited simply to land registers but to whole concept of 3D urban information. This meant that the researchers had to take a step back, to explore attitudes towards 3D urban models.



Their work addressed four key questions:

Where do we stand on the development of 3D urban models? What are current achievements? What are the future technical and research issues? Do we fully use the potentiality of 3D urban models?

What does it mean to move to a 3D frame of reference? How do we change our mind-set from a 2D way of thinking to a 3D one? Do we have a too limited vision of 3D objects? In particular, the researchers discussed some of their previous ideas concerning the types of objects that should be taken into account when developing 3D urban models.

Do people know their 3D needs? How do people react to the idea of moving to a new 3D frame of reference? Do users, developers, scientists have the same feelings about this? At the end, what do we need? This section summarizes enquiries we have made over the last 3 years. We have been reassured about the need to develop real 3D spatial data infrastructures (SDI)

What is the basis of a "good" 3D SDI? Could we learn from past experiences (when people had to move from 2D paper maps to 2D information systems)? We strongly believe that the development of any kind of information system start with a strong and comprehensive conceptual stage. We will show how concepts such as conceptual models and ontologies can be used to build the foundation of strong and reliable 3D SDI.

A 3D city model can be viewed as a digital mock-up representing the structure, in three dimensions, of a city. Many 3D city models have recently been created or are in the process of creation, in relation to the development of geographic information systems (GIS) as they are usually associated to GIS databases. These 3D city models are constructed from laser data (LIDAR), photos (terrestrial, satellite or aerial one like orthophotos), maps (cadastral, city, soil) and databases containing location-based information, etc. These data are becoming more readily available, as are real-time visualization possibilities, with the advent of free and three-dimensional viewers such as Google Earth. So, there is a growing demand of 3D city models and many cities have been or are being modelled: in Europe (mainly in Western Europe) and all around the world. However the generation and the maintenance of 3D city models is costly. That is why there is currently much work in progress (EuroSDR, etc.) exploring ways of automatically generating 3D city models from multiple data sources.

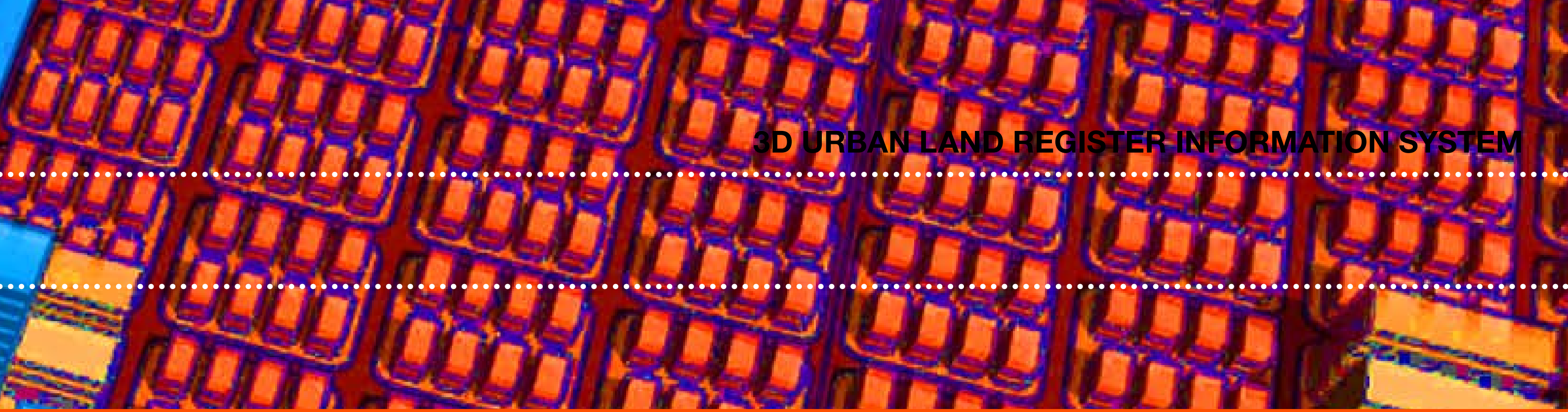
Cadastre refers to a data set containing information related to land ownership and rights. This usually takes the form of maps and descriptions of uniquely identifiable land parcels. For each parcel, legal information such as ownership, easements and mortgages are recorded.

CityGML is a new information model for the representation of 3D urban objects. It defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantic and appearance properties.

A Spatial Data Infrastructure or SDI is a platform-neutral and implementation neutral technological infrastructure for geospatial data and services, based upon non-proprietary standards and specifications (The European Committee for Standardization -CEN)

Where do we stand with 3D urban models?

While 3D modelling has traditionally focused on the graphical representation of a city, there is a now a trend towards more semantic representation of cities, to include non-physical aspects of cities. There is also a trend towards a standardization of 3D city models, using CityGML. CityGML is an XML-based format open data model, which is intended to become an open standard for 3D city models. It has been defined by the members of the Special Interest Group 3D (SIG 3D) of the Initiative Geodata Infrastructure North-Rhine Westphalia (GDI NRW) (Gröger et al. 2007, Kolbe et al. 2005, Kolbe and Gröger 2003). Recently, CityGML has been adopted as a standard by the Open Geospatial Consortium (OGC). CityGML aims to reach a common definition of the basic entities, attributes and relations of virtual 3D city models that can be shared over different application fields.

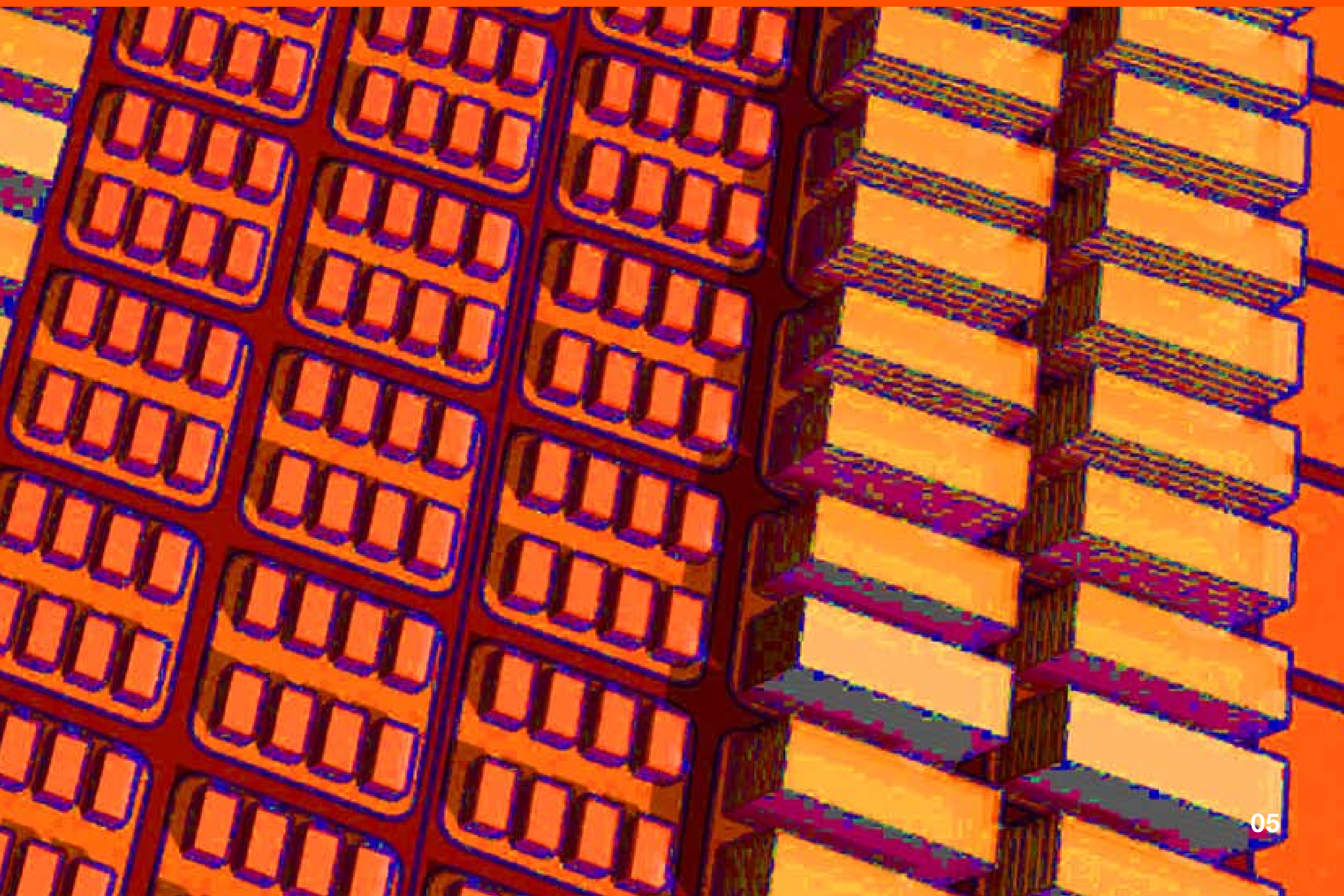


The people that these 3D city models are aimed at is wide, including urban planners, designers, engineers, technicians, policy makers, city authorities, decision-makers, inhabitants, investors and the media. The intended uses are also wide, covering urban planning and design, telecommunication planning, traffic regulation, disaster modelling, architecture, heritage preservation, infrastructure and facility services, promotion of economic development, security and tourism.

Indeed, by using 3D city models, it is possible to visualize what a city will look like after a proposed change, or predict and visualize which parts of a city will be affected by a flood, as well as predicting how severe the impact on the buildings will be. Moreover, such models can help show the location of existing hidden structures (e.g. underground pipes), or underline heritage-rich areas.

As these applications do not all need the same accuracy, different levels of detail (LoD), ranging from simple digital terrain models to more detailed indoor models, have been defined geometrically (geometry of roof changes with LoD) and semantically (openings appear at a given LoD).

To increase its scope, CityGML has been recently provided with an extension mechanism to augment the urban data with features from specific domain areas, such as noise mitigation. Although useful, this extension mechanism is limited and cannot support accurate models related to urban issues such as transportation, building energy consumption or pollutant propagation. Furthermore, although urban planning is currently one of the most important fields of application for 3D city models, the usability of these models for urban decision-making has not really been assessed or quantified.



Moving to a 3D frame of reference, what does that mean?

Traditionally, three groups of objects have been used to describe cities in 3D - buildings, vegetation and communications networks. While these do describe the physical aspects of a city, it is a very narrow definition. There is a whole range of other 'objects' that should be included to get a true virtual city. This relates particularly to the operational data needed for urban planning and especially cadastre, which goes far beyond the real objects described above. For example, cadastral offices maintain details of juridical boundaries and of the legal status of real estate. According to a classification proposed by Sisi Zlatanova (Zlatanova 2000; Billen and Zlatanova 2003) objects such as people, companies, taxes, etc. should be included in the scope of objects organised in a GIS.

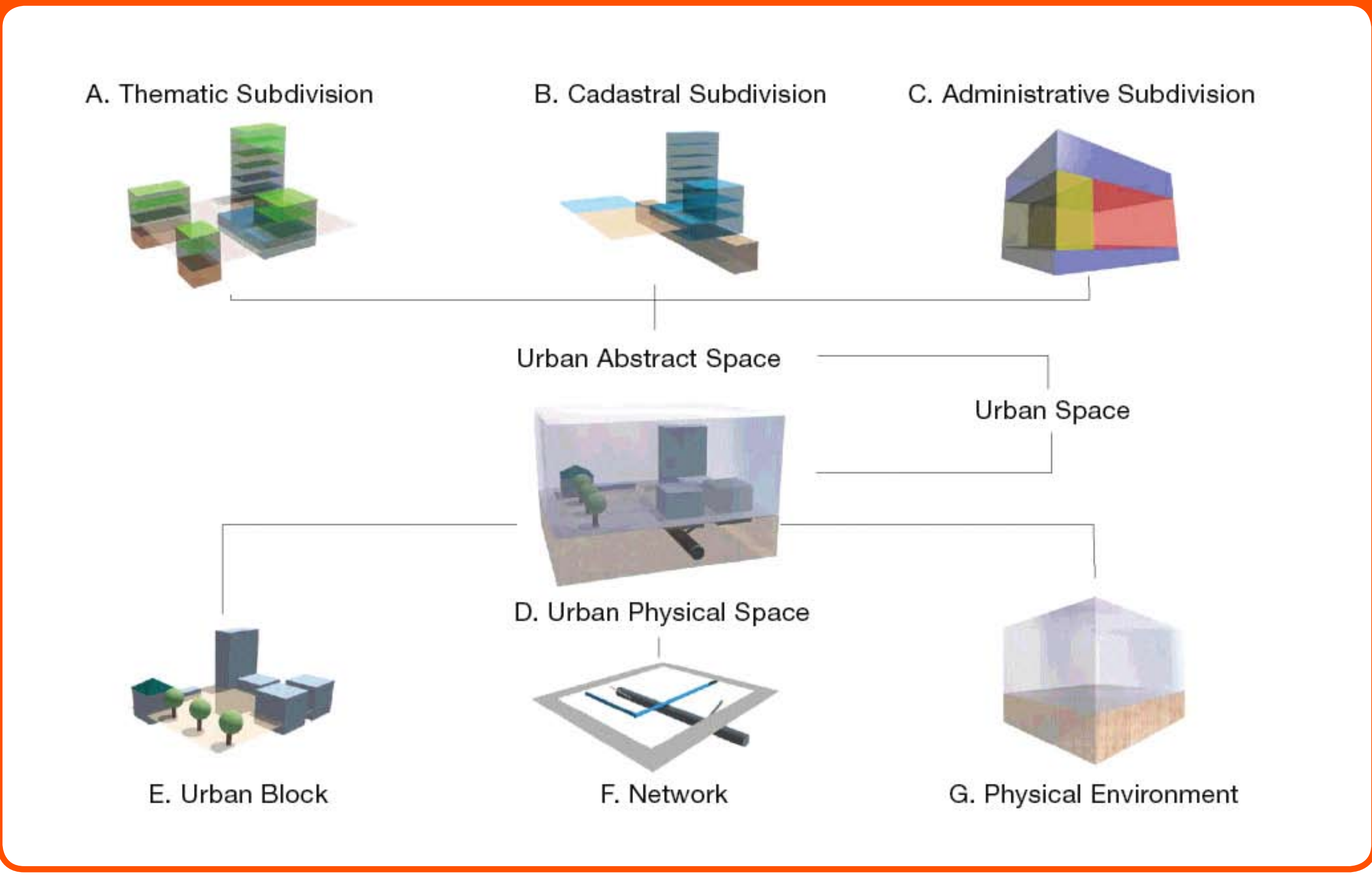
Consequently, four basic 'groups' of objects have been defined, as follows: juridical objects (e.g. individuals, institutions, companies), physical objects (e.g. buildings, streets, utilities), fictional objects (e.g. administrative boundaries) and abstract objects (e.g. taxes, deeds, incomes). Since all these objects have semantic characteristics (in other words they can be defined or described in some textual form) the key differentiation between these types of object is whether or not they have geometric characteristics. In other words, there are objects with either:

1. non-complete geometric characteristics (i.e. only location) – the juridical objects;
2. complete geometric characteristics and existence in the real world – the physical objects;
3. complete geometric characteristics and fictive existence – the fictional objects; and
4. without geometric characteristics – the abstract objects.

Therefore, moving to a 3D frame of reference is not only about expressing objects with 3D coordinates and shapes, but is more concerned with defining objects representing various aspects of a city in 3D even if they are not normally regarded as 3D objects.

The need for 3D fictional objects is not as straightforward as the need for 3D physical objects. While it seems relatively straightforward to move from a 2D representation of a building to a 3D representation, given the unambiguous physical nature of a building, it is not so obvious in the case of fictional objects (administrative units, etc.). However, taking such objects into consideration is indeed one of the keys of 3D urban GIS development. They dramatically influence the types of applications and treatments that can be performed with such systems. Figure 1 lays out the multiplicity of objects (in this case, only physical and fictional objects) which can constitute a reference base for virtual cities.

Figure 1: Some physical and fictional objects composing the urban space



Do people know their 3D needs?

How do other researchers react to these new ideas? What do potential users think about this? Are developers ready to move towards this direction? To start answering these questions, the researchers discussed these ideas with a number of key users and researchers.

Researchers' feedback

The initial idea for 3D cities came from people working on SDI and cadastre. Therefore, the first set of people that the researchers decided to contact were other researchers working in related domains, such as urban planning (potential users) and 3D data acquisition and modelling (potential data providers).

What they found was that urban planners are looking for concepts and tools that can be used to support the integration of these different objects. Virtual cities are popular, but some experts have reservations about the 3D frame of reference; for some specialists, 2D geo-reference data remains the general rule, and extending this to 3D is linked to specific applications. For some experts, defining objects in 3D is their specific expertise with a very narrow field of application, and moves to develop a "common" 3D frame of reference might be seen by them as losing part of their domain expertise. This "protective" behaviour is not unusual, especially when doing Information System re-engineering (involving organisational re-structuring). These findings came in particular from various discussions with urban planners during the COST action "Towntology".

The work of researchers who are familiar with 3D data acquisition (surveying, photogrammetry, laserometry, etc.) has focussed mainly on techniques for reconstructing physical objects. Over the last 10-15 years, much research has been dedicated to the automatic or semi-automatic 3D feature extraction and object reconstruction. Obviously, this approach was only concerned with physical objects and the resultant 3D urban models contained mainly above-ground structures. More recently, new trends have appeared, such as modelling of underground structures and physical environment and the development of data format exchange standards (CityGML) to ensure interoperability. All of these support the development of 3D SDIs. Consequently, this research community has started to think more deeply about the modelling of 3D physical objects by considering 3D semantic information; there is a clear move towards enriching 3D models. As Roland Billen noted, "This is something that I have been arguing for over the course of the last ten years." More can be found by looking to new COST action TU 0801, "Semantic enrichment of 3D urban models" (http://www.semcity.eu/).

Towntology?

Towntology is a project that is being implemented as part of a COST Action programme, (COST - European Cooperation in Science and Technology - is one of the longest-running European instruments supporting cooperation among scientists and researchers across Europe) to develop a taxonomy of ontologies in the urban civil engineering field.

More details can be found at:
http://liris.cnrs.fr/~townto/

SDI-Mapping agencies' feedback

Having explored the opinions of researchers, the next step was to undertake a 'deep needs analysis' inside an SDI agency. The researchers were able to take advantage of another research contract that they were engaged on, with a government organisation based in Brussels, the *"Centre Informatique de la Région Bruxelles – Capitale"* (CIRB), who are in charge of the production and management of large-scale geographical reference database (called UrbIS 2) for Brussels. The researchers conducted several meetings with SDI developers and managers and with users to identify 3D needs in a city like Brussels. What did they find?

For SDI developers and managers, moving to a 3D SDI seems reasonable, especially when thinking about 3D physical objects which seem to cover most of the users' needs. However, what the researchers found was that the technical staff within SDIs who are responsible for collecting data were more reluctant to include 3D fictional objects or 3D semantics, as well as 3D physical objects. The feeling seemed to be that they had doubts about how to maintain a coherent system using such different kinds of data. The researchers noticed that this group of people seemed to be driven by short term objectives, and placed great emphasis on the system producing good animation without thinking about any extra added value.

The researchers met with a panel of users (some of whom are currently using the large-scale database UrbIS 2) and from this they identified two user profiles; those with well identified 3D needs, and those without.

Users with well identified 3D needs have usually already started to develop applications in 3D. They add 3D information to the 2D reference data and they run specific models (such as environmental simulation) or use specific software (rendering, CAD/AEE). They had some reservations about using 3D reference data, as they have already developed their own solutions. However, commented Roland Billen, "They usually admit that data updating is going to be a real issue for them". It is worth mentioning that the needs that they had identified related exclusively to physical objects, and these users were initially rather sceptical about including other kinds of 3D information.

Users without well identified 3D needs are usually stuck in a traditional 2D way of thinking which prevents them from envisaging their work in a "real-life" 3D environment. Similarly, beyond the huge conceptual effort required to work in 3D, they also mentioned technical limitations as being a major drawback.

In conclusion, what they found was that moving to a full 3D description of the environment is a big change in people's mind and people's technical habits. The key seems to be to provide "common" 3D objects of reference or, in other words 3D master maps, which could be used for a wide variety of applications. Developing real 3D SDI, with standards, concepts, objects and tools will provide a strong framework that will allow people to store and query 3D data, and to produce 3D information. By providing them with open, documented and interoperable data infrastructures, it should be possible to overcome most of the technical concerns. Taking into account non-physical objects is crucial, even if it is currently underestimated; otherwise, the representation of the 3D virtual city would only be partial, with limited application and value.

What is the basis of “good” 3D SDI?

With the advent of CityGML, the geographic information domain is making up for lost time in catching up with the standards developed in 3D computer graphics and in AEC (Architecture, Engineering and Construction). However, integration between these standards to develop efficient integrated models is a challenge that must be taken up by these disciplines. This integration will be probably done within database management systems (DBMS) (Zlatanova and Prosperi 2005). Such integrated systems are beginning to emerge, (Döllner, Baumann et al. 2006) but many problems remain to be solved, in addition to simply the technical aspects (such as acquisition, storage, processing, visualization, etc.). The first key issue to resolve is the definition of generic urban 3D information models. As many of the current models have been developed separately by different research teams – often without giving any real thought to the three-dimensional nature of the urban space – what is now needed is to try to develop 3D reference objects at the urban scale which can be shared by the majority of users and which can be enriched with semantic information.

What is the current thinking on the development of integrated systems to manage 3D spatial information at the urban scale? This is the conceptual and philosophical basis that the researchers believe to be essential for the effective development of these systems. This approach follows the current trend of the geographic information science, which focuses on defining fundamental concepts definition and spatial ontologies. The researchers employ the concept of meta-design, and their approach is first to perceive spatiality and then use that to develop their ontology. This ontology is compared to the CityGML in the framework of the “building” object design.

A model is always based on a perception or a particular representation of the real world. This perception corresponds to the conceptual step of GIS development. This step aims to develop feature catalogues for the conceptual data models. These feature catalogues can be thought of as a group of formalized documents which clearly define the concepts and objects which depict the designer’s perception of the real world. During this stage of conceptualisation, ontologies are expressly or implicitly used.

Ontology as a philosophical discipline was rediscovered for the development of artificial intelligence (AI). Efficient models of the real world requires that there is a clear and formal definition of related concepts and of their interrelations. The definition of the ontology for the (geo-) spatial domain has been one of the key topics of research in GI sciences (Frank 1997; Smith and Mark 1998; Fonseca, Egenhofer and al. 2000; Vangenot 2004). The ultimate goal is to get a set of exchangeable universal definitions (notably for the purpose of interoperability), and there has been significant research into the definition of objects, processes and of relations, at different scale levels and granularity levels, which constitute (geo-)spatial domain (with or without a time element).

Thus, it is crucial to be able to express as clearly as possible the ontology which underlies any model from its very beginning. In this work, Roland Billen describes the ontology that they have been developing, which has been inspired by their experience in the field of data acquisition. At first, they consider the world as static, without any temporal (or time) element and they do not consider granularity level (in which there is no consideration of scale at this level of abstraction).

What is an ontology ?

An ontology is a common vocabulary for describing the concepts that exist in an area of knowledge and the relationships that exist between them. An ontology allows for a more detailed specification of the relationships in a domain than is the case with a thesaurus or taxonomy.

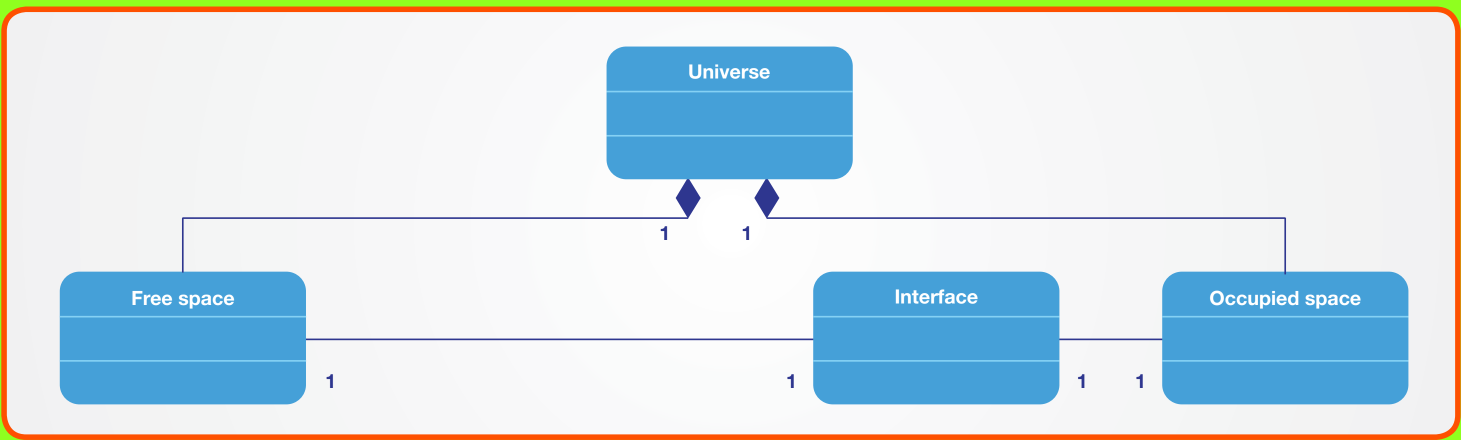
What is the basis of “good” 3D SDI?

Proposed ontology – first level of abstraction

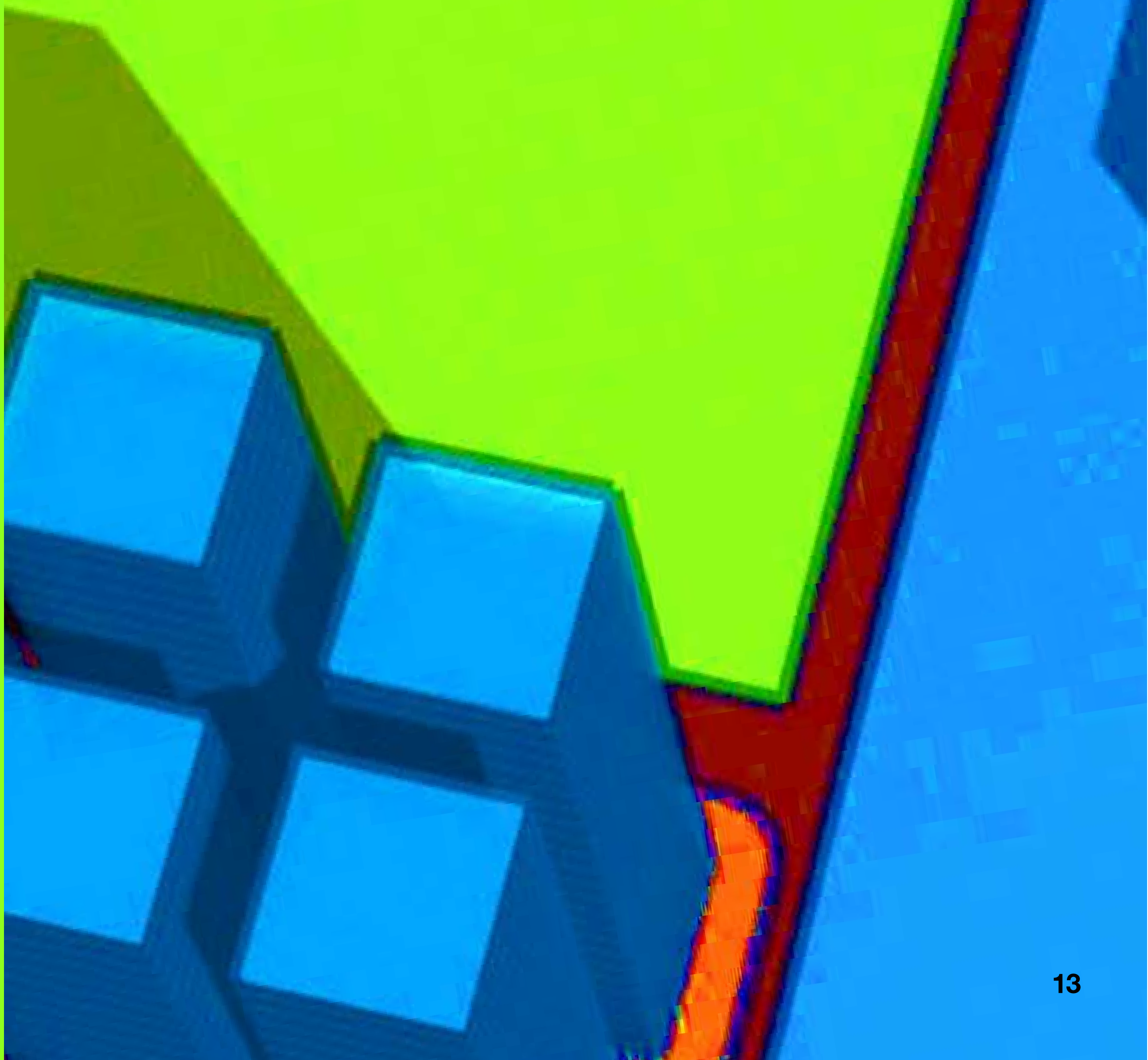
1. The physical universe is composed of free space and occupied space.
2. The free space is that portion of universe in which it is possible to move physically.
3. The occupied space is that portion of universe in which it is not possible to move physically.
4. Moving from one space to another free space is made through an interface without thickness.
5. Only the interface can be perceived (measured) from the free space.

As human beings, we exist in the free space, and we are aware of the existence of the occupied space through our perception of the interface. We perceive its form, position, texture, radiometry (colour), etc. Similar to human perception, data acquisition modes that cannot penetrate the occupied space are only able to detect the attributes of the interface, but not beyond. We are not therefore aware of potential free space parts that may be completely enclosed within the occupied space.

Figure 2: First level of abstraction of the proposed ontology



At this stage, it is already possible to conclude that a model based on this ontology would be concerned solely with the surface geometry of space, as only the interface is measurable and it is without thickness. Furthermore, as the occupied space is inaccessible, it is not possible to model it other than in its relationship to free space. It is a different vision that goes beyond that of construction or architectural models (for example IFC standards - Industry Foundation Classes) which consider elementary building blocks (solids); the two approaches are complementary (one considering solid elements constituting objects, and the other one considering interfaces between free space and objects).



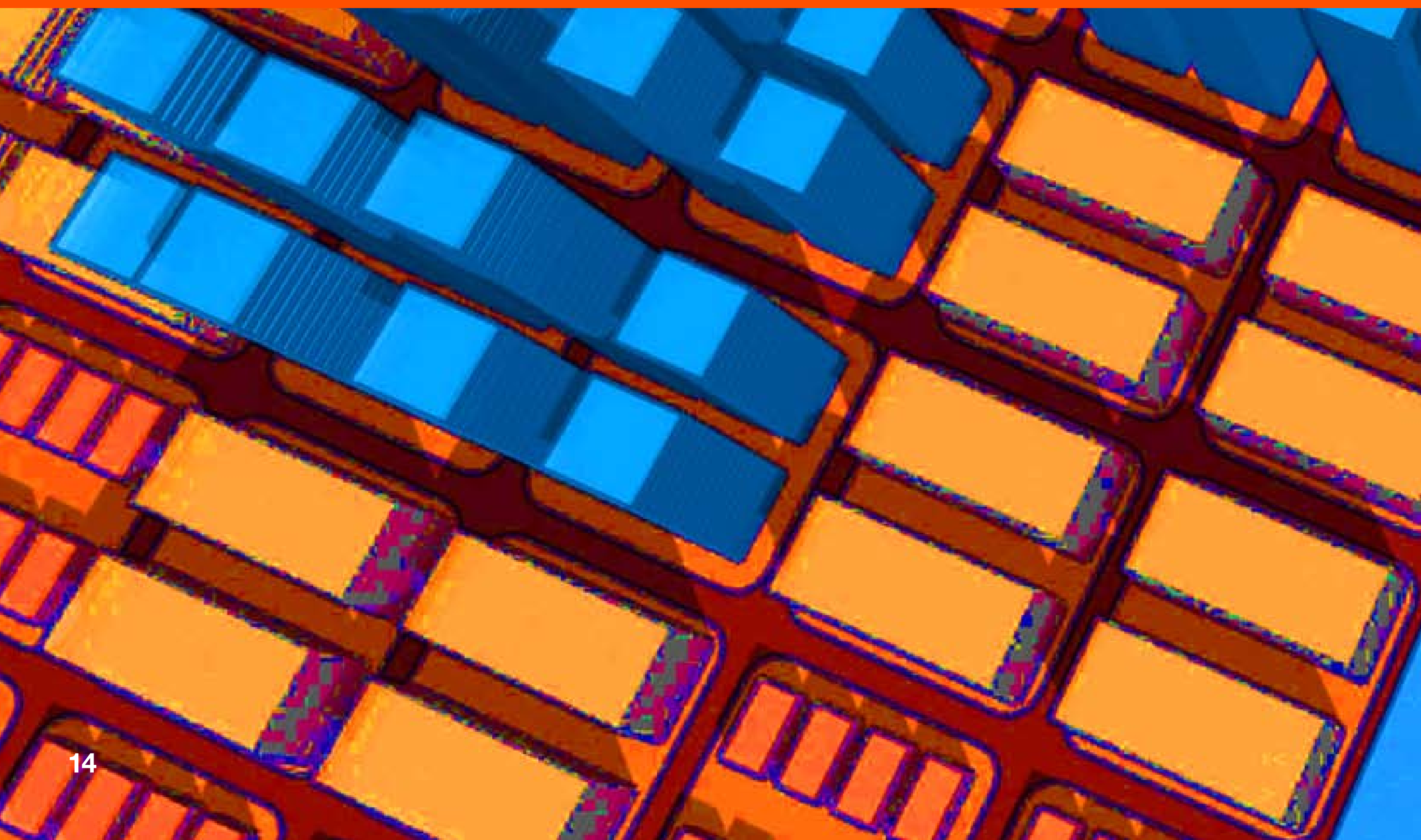
What is the basis of “good” 3D SDI?

Proposed ontology – second level of abstraction

6. The interface can be segmented into portions of interface according to semantic, morphological, radiometric, or other criteria.
7. The free space can be segmented into free sub-spaces.
8. The occupied space can be segmented into occupied sub-spaces.
9. A physical object is composed of one or more occupied sub-spaces and potentially of one or more free sub-spaces.
10. In the latter case, the free sub-space to be considered is a specialisation called internal free sub-space.
11. A physical object is linked to one or more portions of the interface, which will be called portions of internal envelope if they border another internal free sub-space composing a physical object, or portions of external envelope if they border an external free sub-space.
12. An opening is a contact area between two internal free sub-spaces or between an internal free sub-space and an external free sub-space.

These rules call for some comments. Firstly, it allows us to work out the geometry of an object (for example a building) by measuring the associated portions of interface.

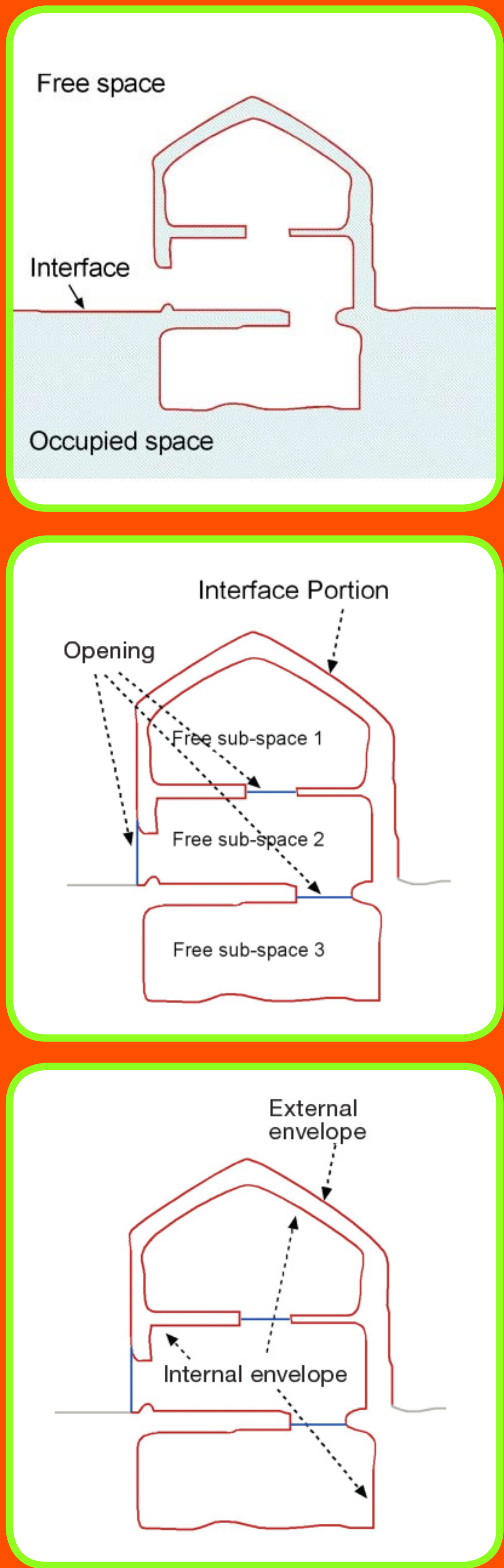
Internal free sub-spaces which are linked to the object allow us on the one hand to differentiate the portions of internal envelope from the portions of external envelope, and on the other hand, to envisage through openings the connectivity both within the object and between the inside and the outside of the object. Consequently, the way that the internal free sub-spaces composing a fixed object are modelled determines the maximum level of detail with which the inside of the object can be considered. On the other hand, it is conceptually possible to envisage a lower level of detail by envisaging a generalisation of the internal free sub-spaces (and of the portions of the internal envelopes that border them). For example, if the internal free sub-space represents a “room”, it is possible to envisage a generalisation through a concept of “floor”.



Note that an object which is constituted only by occupied sub-spaces is only observable through a portion of the external envelope (“plain” object or object with inaccessible inside). Similarly, it is possible to envisage objects only observable through their portion of internal envelope (for example an underground pipe).

The defined CityGML semantic classes are composed of buildings and other man-made objects, vegetation, hydrographical objects and utilities networks.
As discussed above, CityGML offers a pragmatic solution for modelling urban areas. As is often the case in the world of geographical information, the ontology that CityGML designers use is implicit and therefore never clearly formalised. It appeared to the researchers that this implicit ontology should not fundamentally differ from the one who underlies our development.

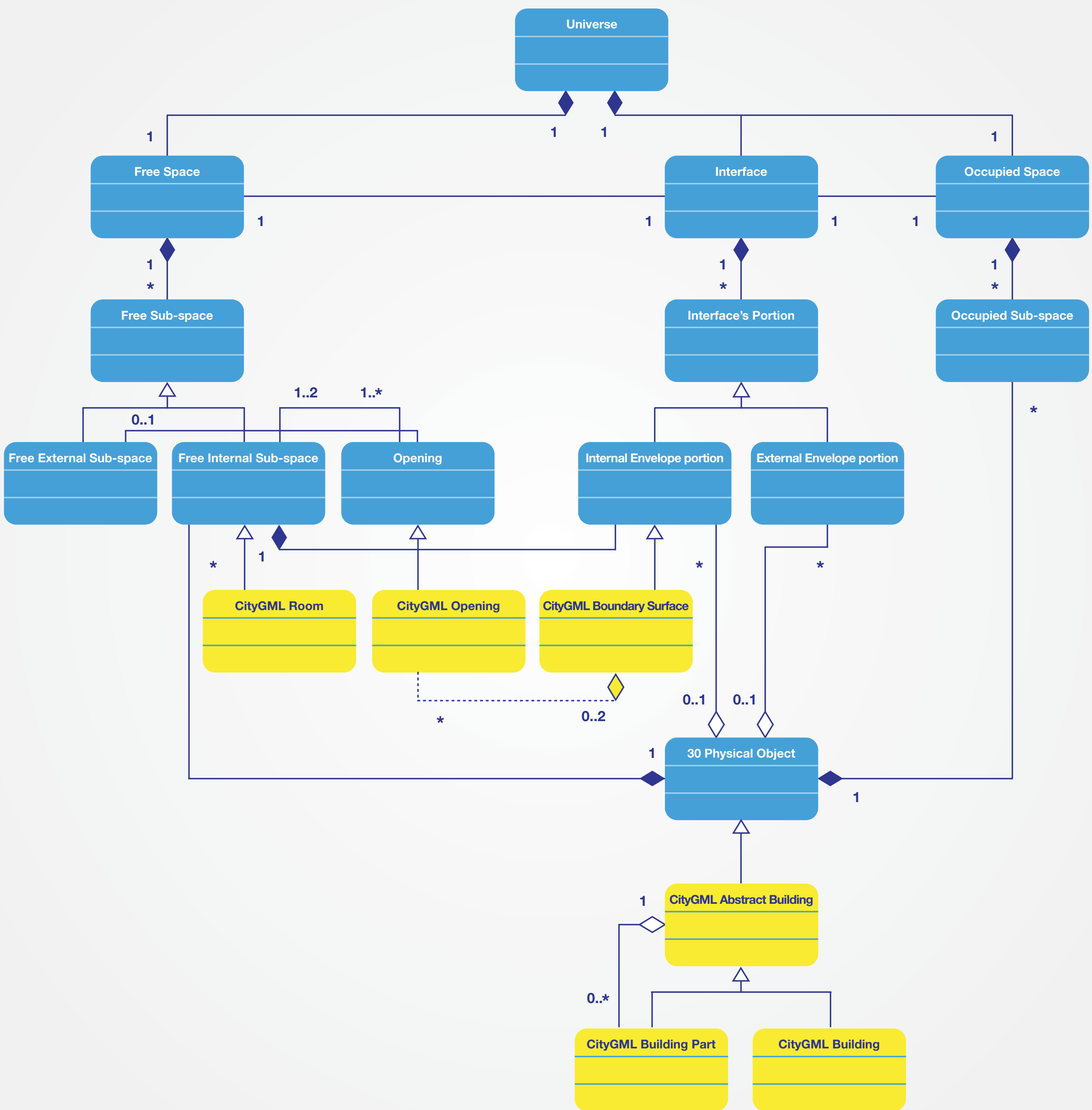
Figure 3: Some abstraction levels of the proposed ontology (traverse cut into a building)



What is the basis of "good" 3D SDI?

The following diagram (figure 4) offers a reformulation according to our meta-model of a number of buildings-related objects of CityGML. The aim of the researchers has been to study the correspondence between CityGML and their proposed ontology and hopefully to enrich CityGML by strengthening its ontological base.

Figure 4: Integration of CityGML objects in the proposed ontology

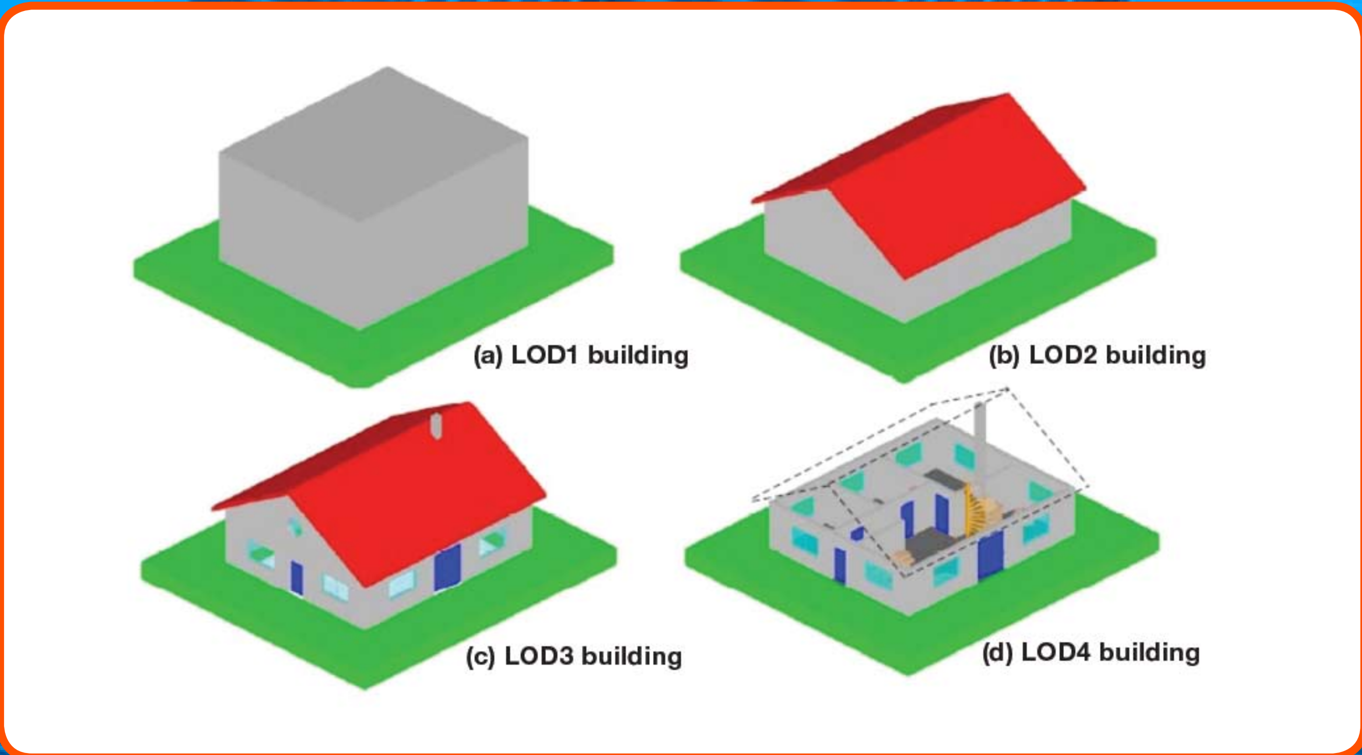


In the case of buildings, there is a good correspondence between their meta-model and CityGML (figure 4). CityGML classes (in yellow) can be integrated easily in our ontology model, e.g. a CityGML “room” is a specialisation of our “internal free sub-space”, etc. Nevertheless, some modification can be introduced when following strictly our ontology.

Indeed, CityGML considers five levels of details (LOD) of which four are directly linked to the representation of buildings (figure 5):

- Level 1 (LOD 1): buildings are modeled as blocks with flat roofs. Models are generalised and no texture is applied. The accuracy of positioning on this side of 5m.
- Level 2 (LOD 2): models of (parametric) roofs and (photorealistic or synthetic) textures are added. The accuracy of positioning is 1m in planimetry and 2m in altimetry.
- Level 3 (LOD 3): Beyond an improvement in the accuracy of positioning (to 50 cm in all directions), the difference with level 2 is in the recognition of openings.
- Level 4 (LOD 4): identical to level 3 for the outside of the building, but allows the modelling of the inside of buildings (constituent elements and openings). An accuracy of 20 cm positioning in all directions.

Figure 5: Building level of detail in CityGML (Gröger, Kolbe et al. 2007)



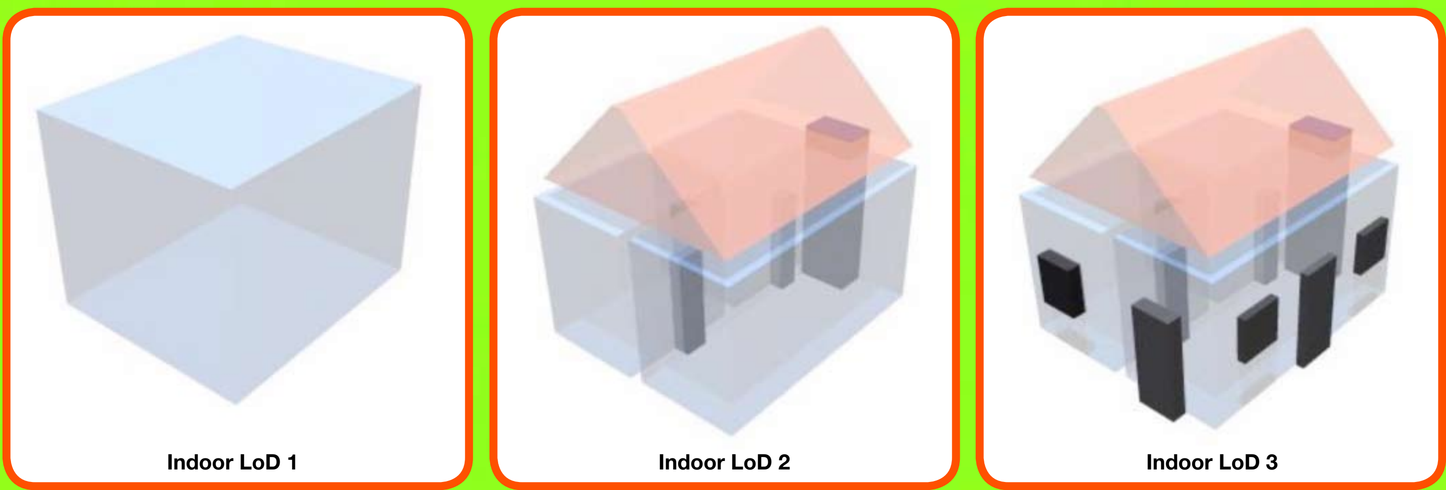
What is the basis of “good” 3D SDI?

What the researchers are proposing is to expand level 4, by envisaging three separate levels of detail related to a building’s interior. As such, they follow their ontology’s logic by considering identical levels of detail for the portions of internal envelopes and external envelopes of a building (figure 6). The three new levels of detail that they propose are outlined below:

- Indoor level of detail 1: this corresponds to one or more internal free sub-spaces generalised by polyhedrons. The internal free sub-spaces can be generalised as a number of superimposed disconnected spaces to give an account of the notion of a floor.
- Indoor level of detail 2: The internal free sub-spaces are all represented according to some geometric generalisation. The openings linking the internal sub-spaces are represented.
- Indoor level of detail 3: this is identical to level 2 but without geometrical generalisation and with the addition of openings on the outside. The connection between the inside of a building and the outside can therefore be envisaged only at the level of detail 3 (internal and external level of detail).

Although this proposition is still open to discussion, it shows how models could be extended by following a specific ontology.

Figure 6: Building indoor LoDs



Conclusions

The major outcome of this research has been as a result of the presentation of the researchers' theoretical ideas to a range of different stakeholders (users, practitioners, scientists, etc.). This process has forced the researchers to clarify some of their views, in order to enable them to be developed. As a consequence of this process, the researchers have explored in depth the conceptual issues in involved in developing 3D urban land register systems, rather than immediately considering the technical and operational issues. As a result, they have defined the fundamental basis of their model in order to ensure future interoperability and integration. By doing so, they have used ontological concepts which have been recently introduced in GIScience. This may well strengthen the basis of the most widely-used 3D city data exchange format, CityGML, and could be used as the basis for an efficient model for developing future 3D SDI, by allowing a wider range of modelling choices through the development of a generic meta-model of 3D urban information.

In addition to the conceptual modelling and technical issues, the researchers have concluded that one of the keys of the success of 3D SDI (or 3D urban GIS or 3D city models, … however how you call it) is to include various types of 3D objects and different level of semantics. And this can be achieved only if all actors (users, developers,…) are ready to begin a fundamental redefinition of the concepts and objects they usually manipulate.

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RICS has a worldwide network. For further information simply contact the relevant RICS office or our Contact Centre.

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