Requirements for Topology in 3D GIS

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Abstract

Topology and its various benefits and functionality are fairly well understood within the context of 2D Geographical Information Systems. However requirements in 3D have yet to be defined, with factors such as lack of familiarity with the potential of such functionality of 3D systems impeding this process. In this paper, we identify and review the requirements for topology in three-dimensional (3D) applications.

Utilising existing topological frameworks and data models as a staring point to guide the review process, three key areas were studied for the purposes of requirements identification, namely existing 2D topological systems, requirements for visualisation in 3D and requirements for 3D analysis supported by topology. Application areas reviewed included those traditionally associated with GIS, such as Earth Sciences and Urban Modelling, as well as others including medical, biological and chemical science. Requirements for topological functionality in 3D were then grouped and categorised.

The paper concludes by suggesting that these requirements can be used as a starting point for the implementation of topology in 3D. It is the aim of this review to serve as a focus for further discussion and identification of additional applications that would benefit from such functionality.

1. Introduction

One of the earliest identified instances where topology, the study of properties of objects including **adjacency**, **connectivity** and **containment** (McDonnell and Kemp, 1995), was used for analytical problem solving is the Konigsberg Bridge problem solved by Euler in 1736. More recently, topology has gained increasing importance in the context of Geographical Information Systems (GIS) as GIS move from simple data capture and visualisation systems towards more analytical applications and decision-support tools (Theobald, 2001, van Oosterom *et al.*, 2002). Three-dimensional (3D) GIS are also becoming an increasingly important tool, with more and more data being captured in 3D as functionality becomes available.

To date, 3D GIS applications have commonly focussed on visualisation functionality, such as that described in Nebiker (2003). The prevalence of visualisation in 3D GIS applications is also evidenced by the number of related papers published, including Dunbar (2003), Grunwald and Barak (2003), McCann (2002) and Jasnoch *et al.* (2001).

According to Gong, Cheng and Wang (2003) the key problems in developing 3D GIS are 3D model design, visualisation and interaction. Billen and Zlatanova (2003) examine the evolution towards 3D GIS, and note that habitual use of 2D systems is also an inhibiting factor. This paper proposes a further element for consideration – a lack of understanding of the potential applications for 3D GIS, and in particular for the analytical functionality that could be provided by 3D topology. The success of 3D GIS in general depends on the ability to perform the analysis that users currently expect from a 2D system. This is, of course, a circular argument – if the functionality were available, usage would increase, and if requirements were identified, analytical functionality would be developed.

This conundrum is can be addressed by reviewing the requirements for such functionality, making a first attempt at identification of functional requirements for three-dimensional Geographic Information Systems. In particular, the paper focuses on those requirements relevant to, or that can be delivered through, the use of topology.

The paper is organised as follows: Section 2 provides a brief description of analytical topology as applied within the GIS context and gives an overview of the frameworks for 3D topology used in the analysis process as well as of approaches to implementation. Section 3 presents a review of functionality identified from a review of existing topology systems in 2D. Section 4 provides an overview of how visualisation of 3D data can be linked to topology, and in particular to topological data models. Section 5 presents a review of 3D applications potentially requiring topology. Section 6 presents the results of the application review process, identifying a summary list of requirements for topology in 3D systems. A discussion concludes this paper, describing the outcome and limitations of the current research and avenues for further investigation.

Before turning to the body of this paper, it is noteworthy to explain the methodology that was used in this study. Initial investigations reveal that very little literature exists that clearly and explicitly links 3D systems with analytical functionality as supported by topology. Therefore a combined theoretical/application-based approach to requirements identification was taken. A full range of requirements cannot be gleaned from application research only due to lack of usage of 3D data in general. An overview of the requirements analysis process is given in Figure 1 below.

[Figure 1- an overview of the requirements gathering process]

The first part of the requirements identification process consisted of a review of theoretical frameworks of topology for 3D systems, in order to provide guidelines to the type of analytical functionality that could be provided by such systems. The various approaches to implementation of topology in GIS were also reviewed for a similar purpose. The framework guidelines and implementation approaches were then used to provide a backbone and reference framework for a literature review of 3D applications that may benefit from topological functionality. This included a review of 2D systems currently supporting topological functionality, to identify any generic requirements that may be relevant for the 3D situation and a review of approaches to visualisation of 3D data to identify any commonality of approach with topology.

The final part of the review involved 3D applications requiring analytical functionality. Application areas reviewed consisted both of those traditionally associated with GIS as well as those not normally considered to be within the purview of this field, and included archaeology, geology, chemistry, biology, medical sciences, cadastral and urban mapping and others.

2. Topological Frameworks and Approaches to Implementation

Worboys (1995) contrasts the mathematical study of topology (equating to the 'study of form') with that of geometry ('measurement of the earth'). Mathematical topology is a broad-ranging science, but within the context of GIS, topology is defined in the context of properties, which in turn define relative relationships between spatial elements, including **adjacency**, **connectivity** and **containment** (McDonnell and Kemp, 1995). Determination of these relationships forms a key component of the analytical functionality provided within current two-dimensional (2D) GIS. However, to understand the representation of these relationships within a digital environment, it is necessary to consider the possible topological frameworks. A number of frameworks have been devised to model all possible theoretical topological relationships between three-dimensional objects. Key amongst these in 3D are the Dimensional Model, devised by Billen, Zlatanova, Mathonet and Boniver (2002) and that described by Wei Guo *et al.* (1998), who also identify a number of issues with extending Egenhofer and Franzosa's (1991) 9-intersection model into 3 dimensions.

The frameworks provided a useful theoretical basis for the identification and understanding of the topological requirements for the various applications identified as part of this analysis, facilitating the process of understanding related application requirements.

However, when analysing functional requirements from the end-user perspective, there are issues with the complexity of the various frameworks (Clementini *et al.*, 1993). In 3D, to provide a comprehensive overview of relationships, frameworks need to examine relationships not only between 3D objects but also between 3D and 2D, 3D and 1D and so on. Furthermore, in Clementini *et al.* (1993) and the Dimensional Model (Billen *et al.*, 2002), the dimension of the common part between the two objects also allows differentiation between two relationships. Therefore from a theoretical standpoint, the relationships shown in Figure 2 are different.

[Figure 2 – These topological relationships are different]

For the above diagram the terminology required could include phrases such as:

- The edge of the lower cube touches the edge of the upper cube
- The corner of the lower cube touches the corner of the upper cube

In both cases, the cubes are **next to** each other in some way.

As can be imagined, the total number of possible relationships between 0, 1, 2 and 3 dimensional objects is high, with the differences between some of these relationships requiring complex descriptions when phrased in terms such as ‘next to’, ‘inside’ and ‘on’ which relevant to the end-users.

In many cases, these distinctions may not be relevant or require the generation of different query results from an application perspective. Therefore, Clementini *et al.* (1993) propose that a grouping approach is applied to reduce the number of relationships to a practical, manageable number. This approach also facilitates understanding of topological functionality from the end-users’ perspective.

However, It should be noted that during application review the detailed theoretical frameworks were not discarded entirely – in fact, the possibility that differentiation of relationships such as that shown in Figure 2 may be required was considered at all stages.

Whilst the frameworks provide the theoretical underpinning of digitisation of topology, in the implementation stage there are important decisions that can influence the specific application. Thus, knowledge of the different approaches to implementation of topological functionality was also used to identify relevant functional requirements during the review process.

Topological relationships in GIS (adjacency, connectivity, containment and so forth) can be determined in two ways – “on the fly” (where relationships between two objects are determined as required) or pre-calculated. In the latter case, the identification of the topological relationships between a pair of objects is undertaken as the objects are captured, and the results are stored in a topological data model (as described in Worboys, 1995). This model can be can then be quickly and efficiently queried to determine the topological relationships. Three broad approaches to modelling the results of topological relationship determination can be identified:

- **Matrix based** approach – for example a matrix of adjacencies can be created for a group of objects

- **Graph based** approach – similar to above, but a node/edge graph model is used, with nodes representing the objects in question and the edges representing the adjacencies of the objects

- **Topological primitives** approach - this involves the deconstruction of objects into their constituent elements, known as topological primitives (nodes, edges and faces). An object is then defined by its bounding primitives. The identification of primitives shared between objects results in the determination of the topological relationships.

In general, pre-calculating the topological relationships is more efficient as the relationships are identified once and the results then queried many times. However, the initial process of transformation and restructuring of the data into the selected topological model can also be time-consuming, particularly where the data is rapidly changing.

3. Topological Functionality in 2D

Whilst our focus is on 3D topology, the requirements identification process commenced with a review of topological functionality in 2D, as this may be directly relevant to the 3D situation whereby the 3D is an extension of a 2D situation. Hoel *et al.* (2003) provide an overview of such functionality, which includes support for network analysis, buffering, on the fly querying of topological relationships, and the identification of the topological relationships between two objects.

A key consequence of implementing topology is also relevant here. As described in the previous Section, unstructured object geometry is usually transformed into a specific topological data model in order to improve the performance when identifying topological relationships between objects. This transformation and restructuring process can be utilised to provide data validation functionality, particularly when associated with a rules-based approach allowing the interaction of individual feature types to be validated alongside the geometry validation process. For example, a rule could be established to ensure that two building polygons (or polyhedrons in 3D) do not overlap. Similarly, a subterranean geological block should be completely surrounded by other structures.

A number of potential applications that could benefit from this concept have been identified. Lin *et al.* (1995) note that despite the general complexity of 3D geological models, there are some topological patterns that can be identified within a geological structure – for example, rock type A may always be found adjacent to rock type B. While not all geological model building processes can be automated, they stress the importance of topology as a required enhancement to the functionality provided by 3D geological systems. In practice, the topological patterns would be set as constraints on the data transformation process and as with the 2D equivalent, manual intervention will be required to resolve ambiguous cases.

Similar principles apply in terms of archaeological applications, with Jacobson and Vadnal (1999) describing the importance of ensuring that no unintentional gaps are introduced into virtual reconstructions of archaeological sites. Although they focus primarily on visualisation of sites, they also outline the importance of object placement, i.e. the adjacency and containment properties of the objects in question. Again, rules-bases along the lines of those proposed above could be used to ensure that the reconstruction is as correct as possible.

4. Visualisation of 3D Data

Visualisation of 3D data is a fundamental requirement of a 3D GIS. Sheppard (1999) and Haklay (2002) note that Computer Aided Design (CAD) and Military requirements have driven initial interest in 3D visualisation and GIS. El-Hakim *et al.* (2003) and Afshar *et al.*,

(2002) describe the use of 3D visualisation to support reconstruction of archaeological sites to provide an image of what they would have looked like. Applications requiring support for 3D visualisation also include 3D city modelling and cadastral modelling, as described by Jarroush and Even-Tzur, (2001), robotics and hazardous environment navigation and for radiotherapy treatment planning (Schiemann *et al.*, 1993)

The second part of the requirements analysis process involved a review of the process of visualisation of 3D data and identification of whether this could be supported through the use of topological models. Support for visualisation is an area of topological functionality that is not currently utilised in 2D due to the existing efficiency of 2D visualisation algorithms. In fact, data stored in 2D topological format is considered inefficient for visualisation due to the requirement to reconstruct objects from their topological primitives (such as nodes and edges). However, in the most common 3D visualisation and graphics implementations, polygonal meshes (described in Watt and Policarpo, 2001, pages 36-51, and in Slater, Steed and Chrysanthou, 2002, pages 162-184) are used to approximate objects. These meshes, used widely in gaming and virtual reality software, are constructed from topological primitives - nodes, edges and faces - which correspond to the topological primitives identified by topological as applicable to GIS.

Many visualisation engines require the presence of these topological primitives to support the display 3D objects, with the data currently being stored primarily in proprietary file formats for performance purposes. It may therefore be possible to provide support for visualisation in 3D as part of the implementation of topological functionality, by modifying and enhancing the topological primitives model to support visualisation. In addition to this, the use of standard databases such as those currently utilised to hold GIS data, should also be considered to open the topologically structured data to both query and visualisation. This may provide one possible solution to the problem of passing large data volumes to a visualisation engine that is currently being encountered by the 3D visualisation community.

As a consequence of data volume issues, many 3D visualisation applications utilise varying levels of detail to describe objects at different scales. This process reduces the quantity of polygon mesh data passed to the visualisation engine as the user moves away from a particular object. El-Sana and Varshney (1998) describe a process of utilising the topology intrinsic in the mesh data to perform this simplification process.

5. Analysis of 3D Applications

Analytical functionality is the third avenue explored to identify functional requirements for topology in 3D. Use of topology here focuses on the properties of geometrical objects in terms of their adjacencies, connectivity and containment – in other words, classical topological analysis.

Such functionality is relevant in applications such as Earth Sciences, including geology, where 3D models are already extensively used. Videla and Knox-Robinson (1997) describe two approaches to geological modelling – knowledge-driven, where models are applied to existing data and used to interpolate a more complete dataset, and data-driven, where relationships between known data are examined. They also note the lack of functionality in existing systems to quantitatively explore gold prospectivity, although existing proprietary systems do provided very good visualisation functionality. In a similar context, Apel (2001) lists a number of queries requiring identification of the topological relationships of adjacency and containment, including analytical queries such as 'which model regions are cut by a particular fault?' or 'which Cambrian unconformities intersect Permian lime-stones?' He comments that current 3D GIS packages are unable to answer these queries due to the lack of true 3D topology. Similar applications including key block analysis (Huseby *et al.,* 1997), engineering mining applications (Lixin and Wenzhong, 2003; Elkadi and Huisman, 2002) and Elroi, 1998), oil and gas exploration (Belloso *et al.*, 1994) and Environmental Science (Sirakov *et al.*) are also described in the literature.

In the military context, Ladner *et al.* (2001) describe the use of topology to generate 3D synthetic environments for use by the United States Digital Mapping, Charting and Geodesy Analysis Program (DMAP). Synthetic environments are utilised in applications such as flight simulators, and also support the US Marine Corps with mission preparation and onsite awareness in urban areas. The topological model is used to maintain adjacency in what the authors term 'non-manifold objects' - those objects that cannot be modelled in a 2D topological model.

Within the context of archaeology, Spikins *et al.* (2002) describe the importance of 3D analytical functionality for the identification of phasing on pre-historical sites, again expressing a requirement for true 3D GIS tools. Barcelo *et al.* (2003) also describe the importance of identifying precise topological relationships when capturing 3D archaeological data, discussing processes involving analysis of artefacts found within and on top of a particular layer of stratigraphy. Gaiani *et al.* (2002) detail requirements for analysis as well as visualisation when using virtual worlds for archaeological restoration in Italy.

Cadastral and urban modelling provides the most prevalent literature in terms of applications requiring topology of 3D objects. Modelling the increasingly complicated urban scene, including underground land use, multi-layer buildings such as those described in Grinstein (2003), and their corresponding usage and ownership cannot adequately be undertaken using 2D systems. Stoter and Salzmann (2003) also describe a number of situations relating to infrastructure above and below ground and discuss the conceptual requirement for a full 3D cadastre without overlaps or gaps in 3D space. They provide a short list of suggested queries on the 3D cadastre. Similar approaches are described by Onsrud (2003), with the requirement for a legal framework and directional adjacency documented by van der Molen (2003).

Support for Emergency Response teams is a specialist application within the urban modelling arena, with authors including Kwan (2004) and Takino (2000) describing applications requiring routing through three-dimensional models of buildings for rapid determination of emergency exit paths. Both authors suggest a network-based analysis tool where a path through the 3D structure is modelled as a topological connectivity network – each room is represented as a node on the network, and each path between rooms represented as an edge between the appropriate nodes. This approach allows for the application of existing network and shortest path analysis tools to the problem.

The requirement for topology in less traditionally-GIS environments is also worth mentioning. In electronic chip manufacture, ASE Global (www.aseglobal.com) report the use of topology to improve the packaging size on a multi-chip module, which integrates processor chips and memory chips in three dimensions to maximise packing density. Nanda (2003) describes requirements for network topology simulation of packet routing algorithms. In medicine, Gross (1998) and Kalra *et al.* (1995) describe the importance of topology with respect to the use of computer graphics in medicine, in particular to surgical simulation and modelling human anatomy. Gross stresses that the topology and geometry of the model must be volumetric, as the simulator must model more than the surface. The simulator should also include functionality such as the repositioning of individual pieces of soft tissue. Brown (2002) describes the use of topology in identifying and distinguishing the chemical bonding properties of atoms, Martin (2000) describes uses of network topology in modelling protein structures and Kramer (2002) describes applications of topology to the modelling of biological development processes.

6. Requirements for Topology in 3D

To complete the identification of topological requirements for analysis, a table was drawn up listing the functional requirements identified through the review. Application-specific terminology was 'translated' into GIS/topology terminology as defined in Section 2. The requirements identified for each application and each area described above were then grouped and a summary list generated. Requirements can be classified into three broad categories:

- Data modelling, upload and validation – functionality relating to the topological modelling, processing and structuring of data into topological primitives
- Standard analysis – relating to the analytical querying of data once it has been structured in topological format
- Other custom analysis – relating to applications utilising the data structured into other specific topological models

It should be noted that no requirements were identified to distinguish between relationships such as those shown in Figure 2. These three categories are analysed in turn:

6.1 Data Modelling, Upload And Validation

Requirements grouped under this heading relate in particular to the utilisation of the topological primitives approach to topology implementation and to the data transformation and editing processes involved in topology creation, primarily **data validation and topology building**. This is a requirement to create topological models of data from the original geometry incorporating custom application-based rules to ensure that the data is correct, the creation of a **rules-based approach to topology creation**. To support the model transformation process, **visualisation of the individual topological elements** may also be required, implying that **each topological element should have some form of geometry**

representation.

In addition to the standard data build and validation processes, a requirement has also been identified to **construct topology without geometry**. Not all models include true geometrical data – particularly for applications such as chemistry and biology. As a consequence of this, s**upport for attributes associated with the individual elements of topology** is also required, to handle cases where geometry does not exist or where individual elements would be differently attributed.

S**upport for multiple topological models** is also important. This implies that topology should be built not only using the traditional topological primitives representation (node/edge/face) structures but also to allow network analysis of 3D objects, using nodes to represent the 3D objects. This requires the ability to create and use the two types of topology for the same geometry, and is particularly relevant for emergency applications where routes out of a 3D building can be modelled as a network.

S**upport for 3D visualisation** utilises the topological primitives approach to store the results of topological analysis, requiring the presence of topological primitives such as node, edge and face, and the opportunity exists to implement the topological model in such a way as to support any visualisation requirements alongside the analysis requirements described below.

Focussing in on the use of the topological primitives model, the **requirement to model curved and planar surfaces** was also evident. While man-made objects tend to incorporate planar surfaces, naturally occurring objects tend to be more curved in structure.

The **requirement to model the topological relationships of simple or complex geometry** (simple geometry is defined here as that having no holes, cavities or tunnels) was also identified. A **hierarchy of topological relationships** should also be identified to support this. It was determined that complex objects are prevalent in 3D data, both for man-made objects such as those encountered in urban modelling and also for naturally occurring objects such as those found in Earth Science Applications.

These requirements are summarised in Table 1 below.

[Table 1 – Data Modelling, Validation and Upload Requirements for topology in 3D systems]

6.2 Standard Analysis

These relate to analysis queries carried out once data has been structured topologically. Key requirements amongst these included the requirement for **adjacency**, **intersection**, **connectivity**, **containment** and **disconnectedness** analysis. In addition to standard adjacency a requirement for **directional adjacency** was also identified. Users, particularly those in the Earth Science and urban modelling sectors, need to know not only what is next to an object, but also whether an object is above or below another.

The requirement to **identify the topological relationship between two objects** was also identified – this answers questions such as 'are these objects next to each other or not?' and 'of all the relationships modelled, which apply to the two objects selected?'

Functionality to **describe the topological structure of an object** is also required, again in particular to support Earth Sciences and Natural Resources exploration**.** This type of analysis answers queries such as 'how many holes, or tunnels does the object have?' and 'is the object solid and continuous?'.

Emergency Response operations and urban modelling in general require **network connectivity and shortest path analysis** functionality to support navigation through 3D environments.

Legacy 2D data is also of importance when considering analysis requirements. Systems should be able to support **queries between 2D and 3D datasets** – for example 'which 3D buildings are in this 2D county boundary?' Many users have invested heavily in their 2D data and would perhaps not be willing to countenance the expense of an upgrade of this data to 3D.

Although as discussed above **on the fly determination of topological relationships** is more computer-intensive than querying the results of the analysis stored in a model, a requirement for such functionality has also been identified, in particular to support queries such as 'I am planning to build a tunnel of diameter X – what rock will the tunnel boring machine need to cut through?' or 'which 3D buildings will widening this road impact?'.

These requirements are summarised in Table 2 below.

[Table 2 – Standard Analysis Requirements for topology in 3D systems]

6.3 Custom Analysis

The requirements described in this section also form part of analytical functionality supported by topology. However, they are more closely related to specific graph and matrix models of topology, and have been identified as custom requirements for a number of specific application purposes. They are described here to provide a complete picture of the results of the application research process, and reflect requirements in application areas such as chemistry, biology and emergency planning. Requirements include **network modelling and analysis** (determination of the isomorphism of two networks), **matrix manipulation tools** (connectivity matrix derivation, generation of normalised incidence matrices, adjacency matrix derivation) and **custom model building** (Delaunay triangulation, creation of a tetrahedron model of topology from point data sources, Voronoi tessellation).

These requirements are summarised in Table 3 below.

[Table 3 – Custom Analysis Requirements for topology in 3D systems]

7 Discussion

One of the key drivers for this study is that of familiarising the potential users with the functionality that could be offered by topology in 3D, thus breaking away from the circular "requirements-drives–development-drives-requirements" situation. From the three-pronged analysis and review process described above, requirements for topological functionality in 3D have been determined to exist. However, they are not often expressed directly in terms familiar to GIS developers and users. In fact, due to the interdisciplinary nature of study the topological significance of some analysis requirements has been inferred from the descriptions provided. For example, descriptions using phrases such as 'next to', 'underneath' and 'beside' have been interpreted as referring to the topological concept of adjacency. In many cases, it can be said that authors did not recognise the analysis they were describing as topological.

Perhaps due to these differences in terminology, no specific requirements were identified to distinguish between all the theoretical topological relationships as described in the identified topological frameworks. If such requirements are identified downstream, the end-users' understanding of the relationships should be considered before implementing such functionality.

During the analysis process, a very broad definition of topology and applications was used – the review was not confined to applications based on a particular approach to topological modelling, nor to traditional GIS application areas. As a result of this, a number of the requirements identified mirror those existing for 2D topological functionality, but there are others unique to the 3D situation, including support for directional adjacency and the requirement to describe the topological structure of an object.

The analysis undertaken identifies requirements and applications of topology for applications using 3D data, without considering any advantages or disadvantages of topology. It is noteworthy that as the requirements analysis focussed on functionality that could be provided by using topology, requirements identified do not include those relating to data capture functionality and data exploration functionality (browsing) or other standard GIS functionality that may be required in a 3D situation. Applications were examined at a conceptual, focussing on the benefits that could be gained by users, without considering availability of data or whether such applications could easily be implemented in practice.

Directional adjacency warrants further mention here – in 2D topology, there is no widely accepted concept of direction, as ‘left’ and ‘right’ is entirely relative to the direction in which a user is facing. However, in 3D it is perhaps intuitive to describe a concept of above (further away from the centre of the Earth) and below, and a requirement for this distinction within adjacency queries was identified both for Earth Science and Urban modelling applications. Further work is required to translate this definition into mathematical terms that can be implemented within the context of a GIS query. For example, if a building is above another but offset to one side, is it still above?

Another issue to consider is the most appropriate method to handle queries between legacy 2D data and 3D data. Two possible approaches exist, each of which requires further evaluation. The 3D data can be projected into 2D, and topological relationships then determined between two 2D datasets. Alternatively, the existing 2D data could be extruded into 3D and topological relationships identified in 3D.

The similarities between topology in 3D and 3D visualisation models are also worth exploring further as few 3D visualisation tools exist in conjunction with other GIS functionality. Any implementation of topology for a 3D system should, if possible, take into account the requirements of the visualisation model, to allow support for 3D visualisation to be built in conjunction with the 3D topology. The possibility of utilising standard GIS databases to support the visualisation process, as opposed to proprietary storage formats, should also be considered.

Further research is required to quantify and prioritise the requirements identified above. To date, it can be stated that the most prevalent requirements for 3D functionality emerged from Earth Science and Urban modelling fields. However, given the nature of the research no attempt has been made to prioritise quantify the requirements, although it is felt that the requirements described under the heading ‘custom analysis’ could be of a lower priority than the others. Once quantified, the information may provide some indication as to the nature of the uptake of 3D topology.

This paper has aimed to present an initial review of the requirements for topology in 3D. However, the review process is by no means complete. Many other potential application areas could benefit from such functionality, and it is expected that in the near future more applications will emerge.

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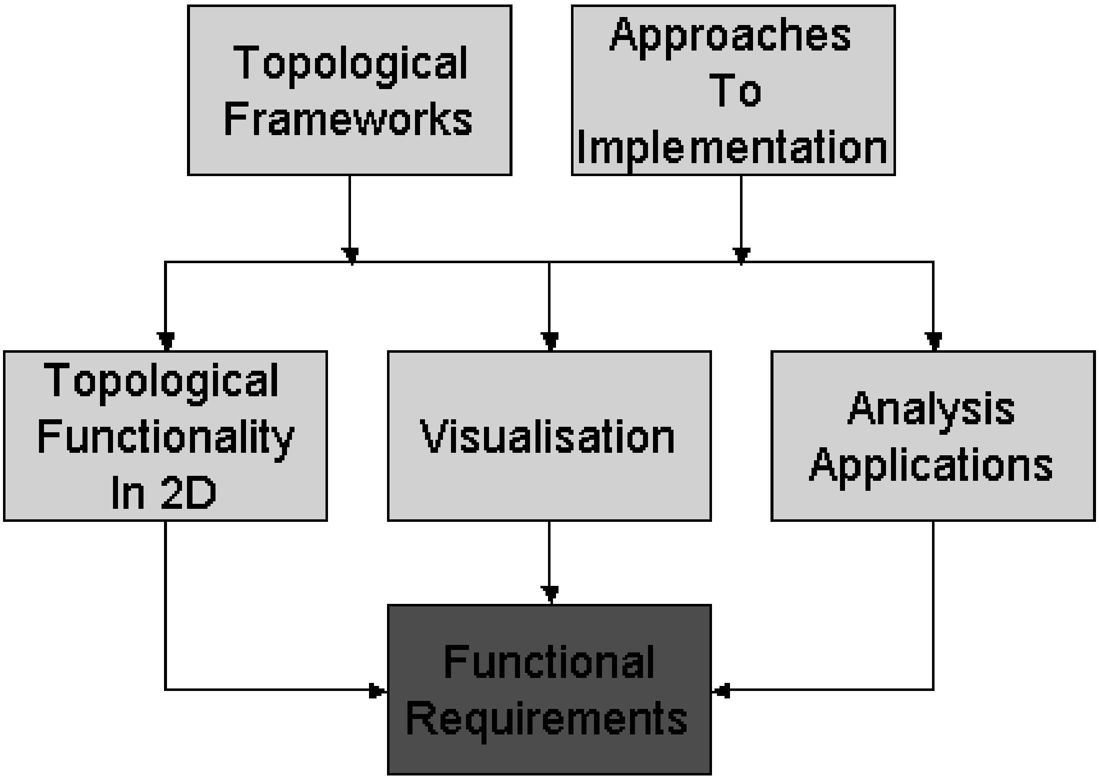

Figure 1- An Overview of The Requirements Gathering Process

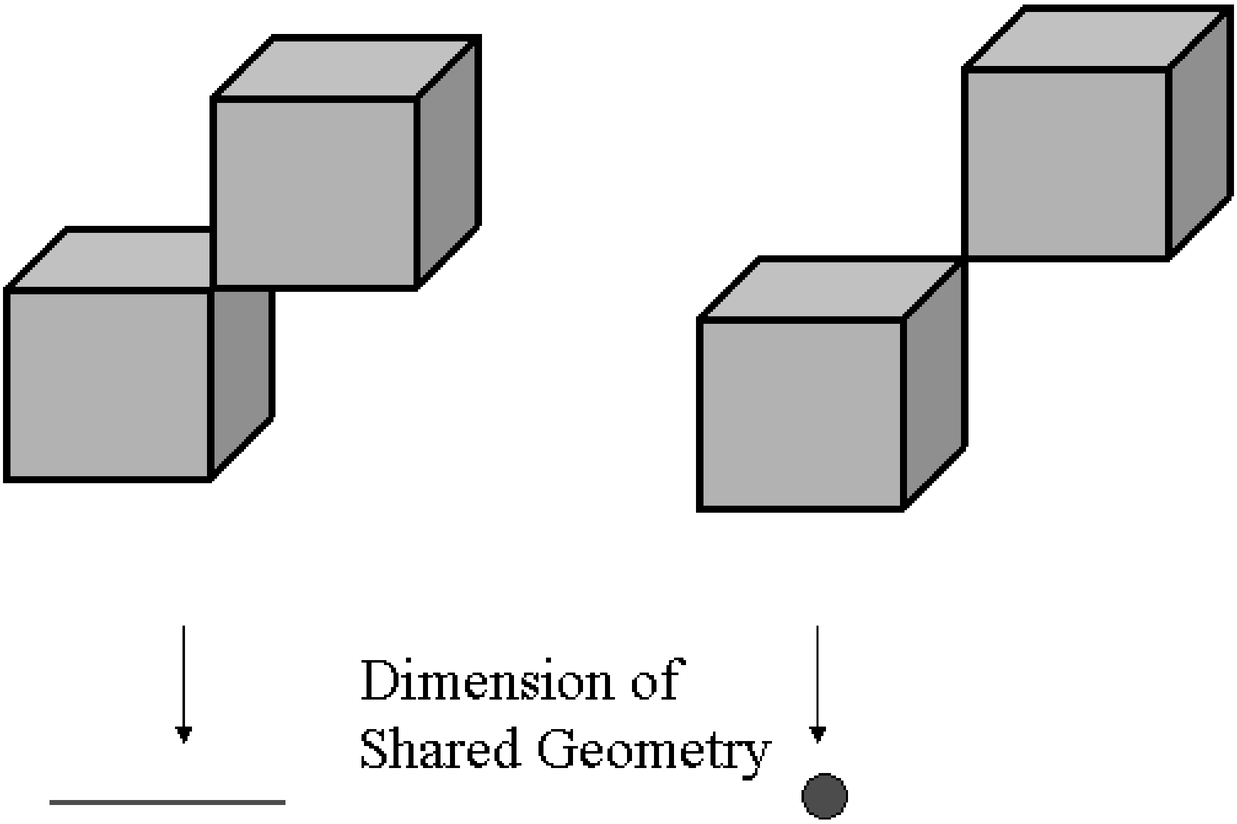

Figure 2 – These Topological Relationships Are Different

Description	**Example Application Areas**
Rules based topological model creation – apply constraints or specific application rules as the geometry is being converted into topology, for both simple and complex geometry.	Cadastral modelling, Chemistry (atomic field modelling), Geology/Earth Sciences, Wireless routing propagation
Visualisation of individual topological elements - for analysis and editing purposes (each topological element should have some form of geometrical representation)	Geology/Earth Sciences, Biology, Chemistry
Construct topology without having links back to the geometry – i.e. insert data directly into a topological model	Chemistry (atomic field modelling), biology (protein modelling)
Allow attribution of nodes and edges in the topological network model so that different models can be constructed from the same topology	Chemistry (atomic field modelling), Geology, Emergency Applications
Support for multiple topological models from the same source data – the models should be able to support standard topological analysis as well as network analysis operations	Urban/Cadastral Modelling, Emergency Applications
Support for 3D visualisation – the model should be extensible to allow support for visualisation of the data utilising standard rendering algorithms	Urban Modelling, Geology, Emergency Applications, Archaeology
Modelling of curved and planar surfaces	All
Modelling of relationships between complex objects – requirement for a hierarchy of relationships	All

Table 1 – Data Modelling, Validation and Upload Requirements for topology in 3D systems

Description	**Example Application Areas**
Identify adjacency of the different polyhedrons in a model, and also between combinations of 0, 1, 2 and 3D objects and between complex objects	Chemistry (atomic field modelling), Archaeology, Oil and Gas, Geology, Transport, Wireless packet routing, Env. Science
Intersection between 3D, 2D, 1D, 0D combinations and also of complex geometrical objects	Cadastral, Geology, Transport, Environmental Science
Connectivity (networking functionality)	Emergency Applications, Wireless packet routing
Containment of geometries of 3D, 2D, 1D and 0D objects and also of complex geometrical objects	Archaeology, Oil and Gas, Cadastral, Geology
Identify disconnectedness of two objects	Geology, Oil and Gas
Directional adjacency – is object B above, to the side or below object A. What is above object A	Archaeology, Cadastral, Geology, Hydrology
Identify the topological relationship between two objects (3D, 2D, 1D, 0D combinations) and also of complex geometrical objects	Archaeology, Cadastral, Geology, Hydrology
Describe the topological structure of an object – how many holes, tunnels, faces etc does it contain	Oil and Gas, Geology
Create a shortest path/network trace route between two nodes	Chemistry (atomic field modelling), Geology, Wireless
3D buffering and on-the-fly calculation of topological relationships	Oil and Gas, Cadastral, Geology

Table 2 – Standard Analysis Requirements for Topology in 3D systems

Description	**Example Application Areas**
Network modelling and Analysis - Determine the isomorphism of two networks	Chemistry (atomic field modelling)
Matrix Manipulation tools - Create normalised incidence matrices for multiple connectivity and adjacency matrices	Biology (embryo modelling)
Matrix Manipulation tools - Derive adjacency matrix from Delaunay triangulation	Biology (embryo modelling)
Custom Model Building - Delaunay triangulation	Biology, Geology
Custom Model Building - Voronoi tessellation and building a connectivity matrix from the Voronoi tessellation	Biology (embryo modelling)

Table 3 – Custom Analysis Requirements for Topology in 3D systems

List of Illustration Numbers and Captions

Figure 1 An overview of the requirements gathering process

Figure 2 These topological relationships are different

Table 1 Data Modelling, Validation and Upload Requirements for topology in 3D systems

Table 2 Standard Analysis Requirements for Topology in 3D systems

Table 3 Custom Analysis Requirements for Topology in 3D systems