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BLOCK VII: 3D BIM MODELLING

Title: 3D Modelling Concepts

1 – Aims

The main goal of this tutorial is to address an overview of object - based parametric modelling

2 - Learning methodology

The teacher will give an explanation about: (1) history of digital 3D modelling and their chronology to explain their inception and evolution and (2) an explanation about object - based parametric modelling and rules as well as some non – geometric properties and features.

3 - Tutorial duration

It will last 1 teaching hours.

4 – Necessary teaching recourses

Computer room with PCs with internet access.

5 – Contents

5.1 Introduction
5.2 Bim geometric shapes and their modelling
5.3 Parametric modelling
5.4 Objects and information in BIM models

6 - Deliverables

The students will answer a questionnaire.

7- What we have learned

What are the advantages of object modelling, parametric modelling, the role of information in BIM, the relationship between information, individual objects and geometry.

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5.1. Introduction

Nowadays, it has become possible to apply BIM technologies in several industrial sectors. BIM technologies are gradually evolving into a process in which, in addition to traditional building design, there is an opportunity to adapt to information technology solutions, data analysis, automation and virtual space or even artificial intelligence solutions.

Object-oriented modelling is the most important key element in terms of BIM.

The aim of this chapter is to provide knowledge not only about object modelling, but its fundamental differences from CAD systems. Students will get acquainted with the advantages of object modelling, parametric modelling, the role of information in BIM, the relationship between information, individual objects and geometry.

5.2. BIM geometric shapes and their modelling

3D modelling concepts have developed from early 2D and 3D CAD representations which were mainly composed of 2D or 3D lines. The first 3D wireframe models were an extension of 2D drafting where 3D lines were manually drawn to create a 3D wireframe model. This could be used for visualisation and to create orthogonal views. These early 3D wireframe models had no mass properties and it was not possible to add features such as holes (Figure 1) .

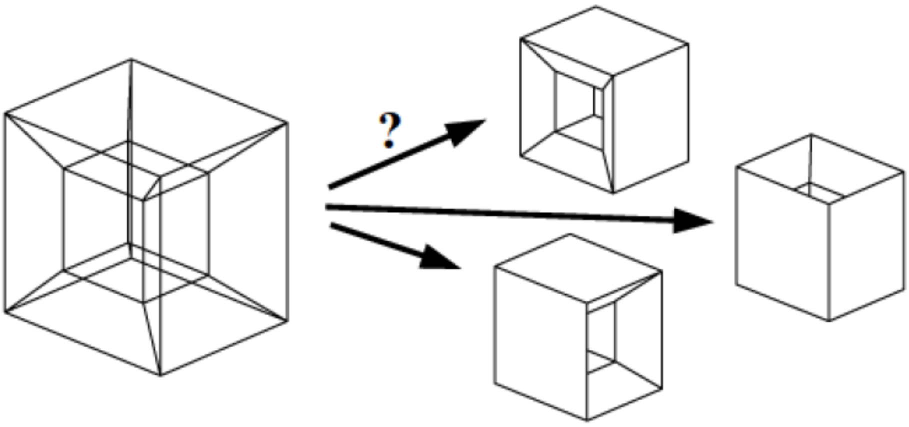
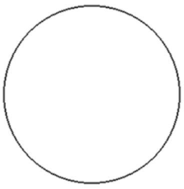
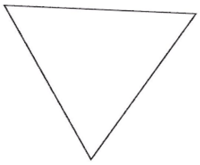


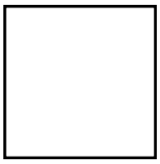
Figure 1 – Example of 3D wireframe models

Spatial geometry shapes are an integral part of BIM. In order to move from drawing in traditional CAD platforms to the modelling of specific construction objects, it is natural that the objects could be drawn as realistically as possible. If the drawing does not provide any information about the layout of the geometric shape, it may not be possible to obtain it in 2D CAD drawings. Especially when it comes to the height of buildings. When working in a 3D CAD environment, these complexities are largely solved. It is important for the practitioner to understand how the relationships between geometric shapes, internal parts of software and information in both 3D CAD and BIM modelling applications are constructed. Figure 2 shows an example of the principal spatial geometric shapes and their processing forms.

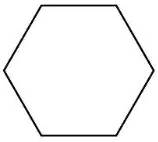
Geometric shapes: circle, triangle, square, rectangle, hexagon, rhombus, pentagon, and so on.

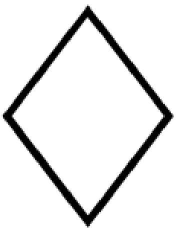

Circle

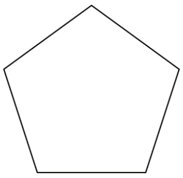

Triangle


Square

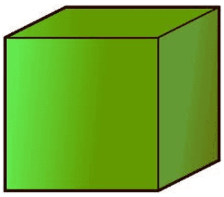

Rectangle

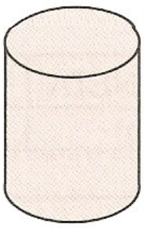

Hexagon

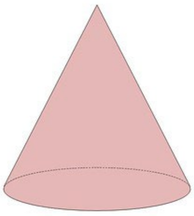

Rhombus

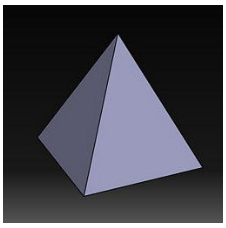

Pentagon

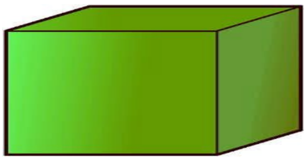
Spatial shapes: cube, cone, rectangular parallelepiped, quadrilateral pyramid, triangular prism, ball, roll, triangular pyramid, sphere, torah.

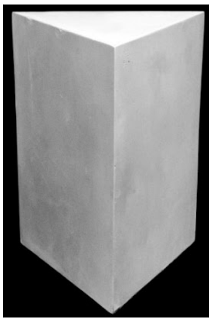

Cube


Roll

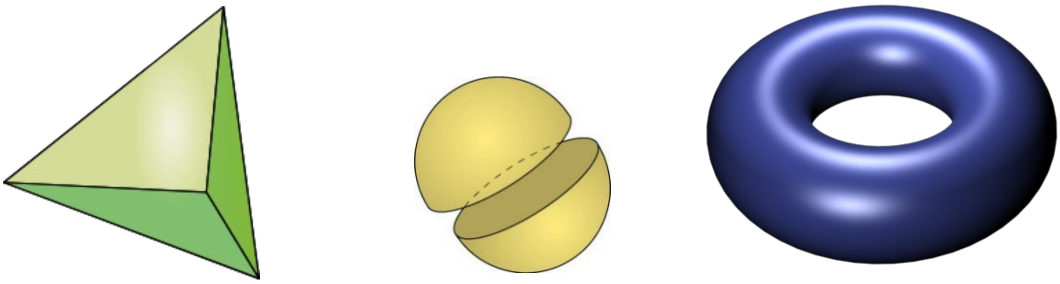

Cone


Square pyramid

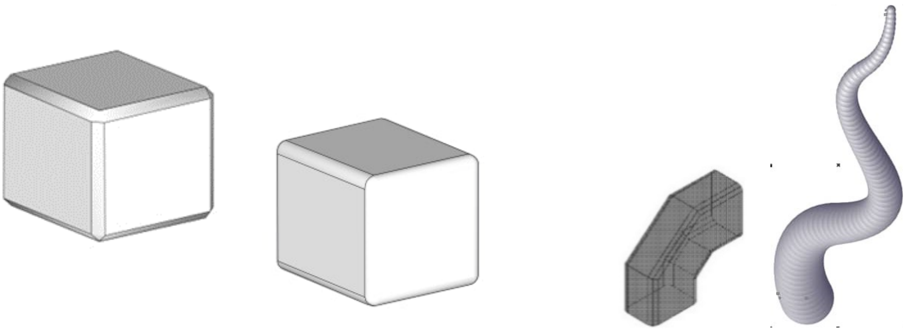

Rectangular parallelepiped


Triangular prism


Ball



Triangular pyramid Sphere Torah



Rounding Oblique Extrusion Curve extrusion

Figure 2 - Spatial geometric shapes and their processing forms.

Regarding the quality of the model, geometric accuracy of the elements is a very important aspect, so it is necessary to take care to prevent intersections and errors in the geometric models.

Even specialized software cannot understand and decide for itself what quantities of geometric shape elements need to be estimated in an automated project budgeting. For instance, if the elements of reinforced concrete columns overlap or intersect with wall structures, the project implementation cost will be calculated higher than planned.

Thus, BIM managers or BIM coordinators must ensure the quality of the design of the geometric shapes. This prevent uncoordinated solutions from changing during the construction process and allow an accurate calculation of the quantities of items.

Two important advancements in 3D CAD modelling introduced in the 1970s and 1980s were the concepts Constructive Solid Geometry (CSG) and Boundary Representation (B-rep). CSG uses solid primitive shapes to represent objects (Figure 3). This approach is more powerful than previous wireframe approaches as solid objects can be used to calculate various physical properties such as volume, density, weight and mass. CSG also allows solid primitive shapes to be combined using Boolean operations such as union, subtract and intersect to create more complicated shapes (Dore and Murphy, 2017).

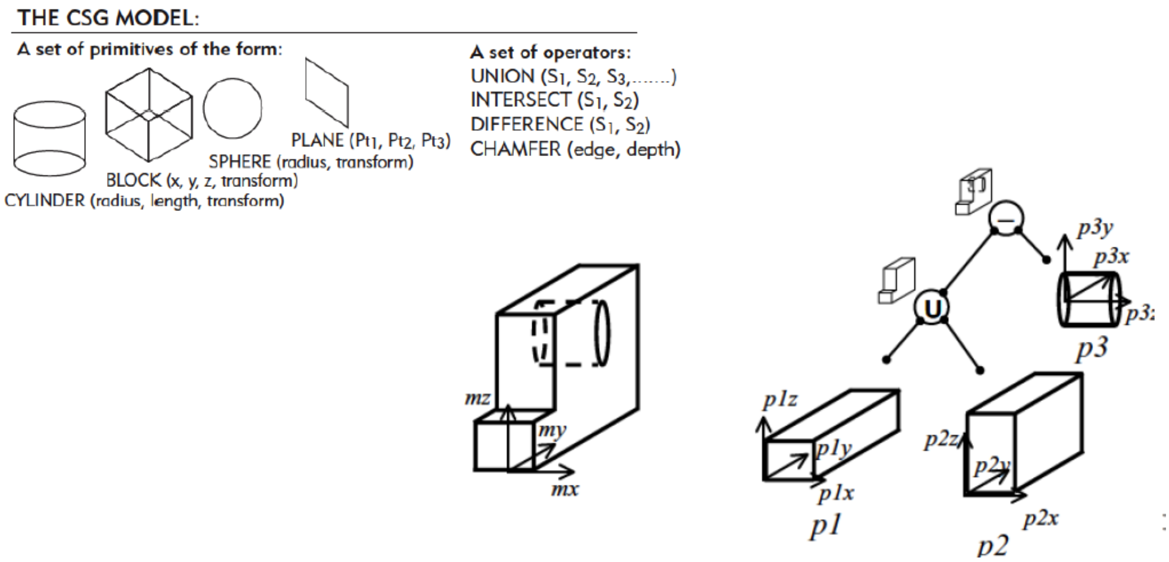


Figure 3 - Constructive Solid Geometry (CSG)

Alternatively, Boundary Representation (B-rep) represents objects by describing their faces, edges, vertices and topology. B-rep also includes operations such as extrude, sweep and revolve which can be used to create 3D shapes from 2D outlines (Figure 4). Many CAD software platforms incorporate both B-rep and CSG modelling concepts to provide greater flexibility for modelling complex objects (Dore and Murphy, 2017).

The B-rep method conveyed shapes as closed, formed from individual surfaces in contact with each other. The shape itself was defined by a set of rules to ensure that contacting surfaces completely closed the volume inside. This set of rules determined how those surfaces should merge and connect, how to navigate, their orientation in the environment and how their continuity should be ensured. In addition to these spatial volume creation functions, functions for extruding shapes along an axis or curve have also been developed.

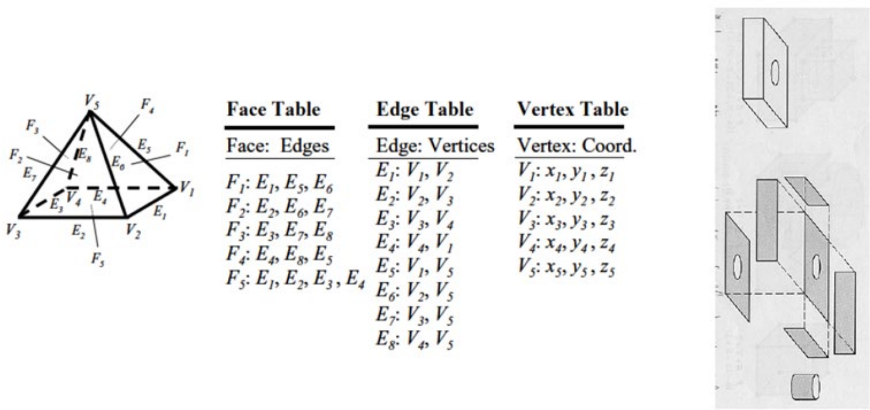


Figure 4 - Boundary Representation (B-rep)

B-rep's edge representation method for describing geometry models is dominant in CAD and BIM software.

One of the first and up-to-date formats for storing B-rep geometry is the STEP format. The number of possible geometry modification transactions is greater than in models. The B-rep model shall only be stored as a final result and the geometry design travel shall not be retained.

Modern 3D CAD systems allow detailed parametric modelling with B-rep models through the mathematical description of curves or even a typical B-splines description of the NURBS (Non uniform rational B-Splines). The B-rep model has two types of information: geometry and topology. Geometric information is the mathematical definition of curves, surfaces required to form a geospatial body.

Topological information allows to link geometric elements to each other. There are also two types of entities in B-rep models:

• Geometric subjects - Volume, Surface, Curve, Point;

• Topological subjects - Solid, Face, Edge, Vertex.

The differences between these concepts are presented in Table 1 and illustrated in Figure 5.

Table 1. Difference between geometric and topological objects.

Geometric object	Topological object	What is different
Volume	**Solid**	Volume is usually considered to be an object created not from primitives, that is, extruded according to a curve, surface, etc., and a solid body is usually composed of geometric shapes.
Surface	**Face**	Surface may be defined by curves which vary in shape in space and Face refers to a flat surface consisting of only straight sides, e.g. the top of the cylinder is not considered to be a Face but a Surface, unless it is segmented as a polygon.
Curve	**Edge**	A Curve is defined by points and a function that controls its position in space. Edge is considered to be a line segment between two Vertices.
Point	**Vertex**	A Point describes a specific point in space with its specific coordinate according to the applicable coordinate system. A Vertex is just a reference to that point. For example, multiple tangent polygons that have individual vertices, but can identify the same point.

The application and alternation of these operations allows the creation of several geometric spatial volumes. At the same time, functions emerged that made it possible to merge individual volumes or cut one spatial volume from another. These actions are defined as Boolean operation. One of the first application for such modelling is the modelling of machine parts, which often consisted of typical volume primitives and join / cut operations.

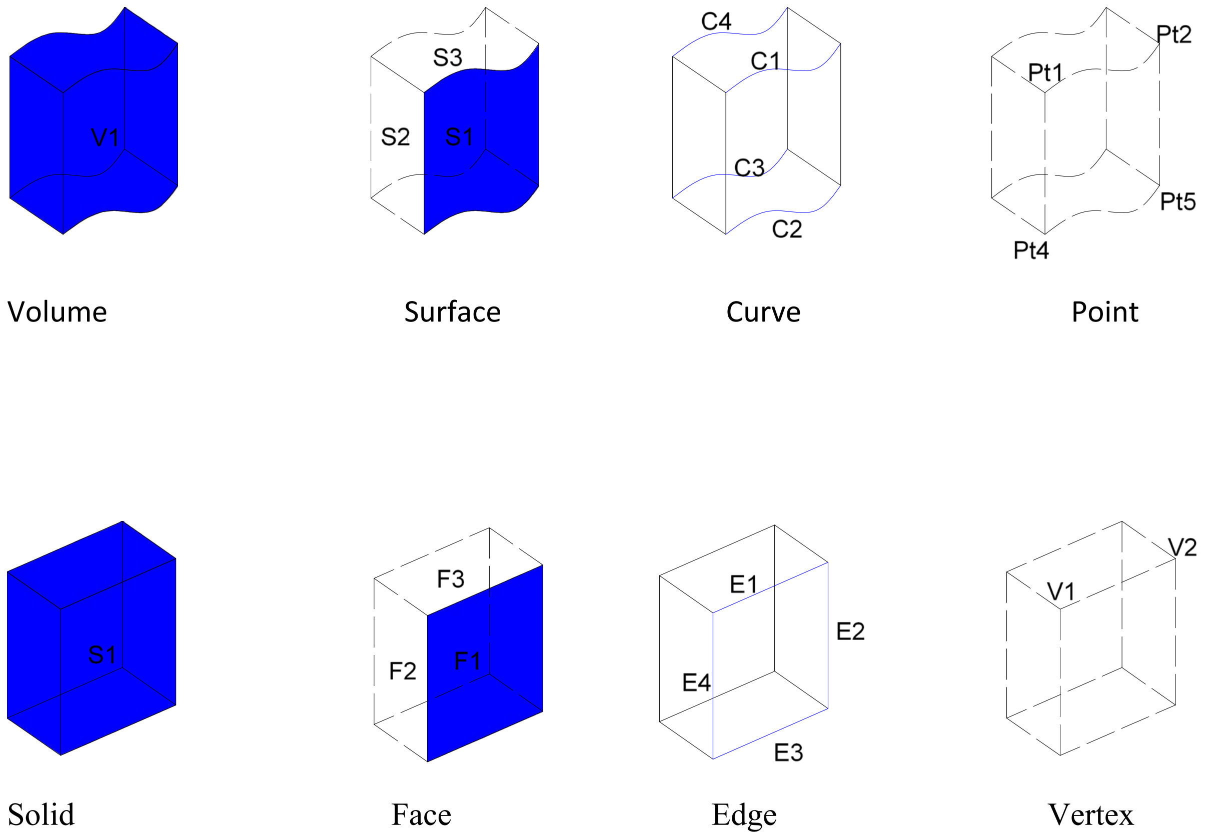


Figure 5 - Entities forming geometry and their topological equivalents.

Because these two methods had different but very important properties, solution to combine the two emerged. This allowed the creation of spatial geometric models by the CSG method, leaving B-rep to deal with the evaluation of the modeled primitives and visual representation. This principle of operation has survived to the present day, which gives CAD and BIM systems their power to quickly and accurately create geometry, edit it and display it on computer screens. In other words, CSG applies to modelling and work, and B-rep applies to rendering, intersection checking, and other non-editing operations. It should also be noted that it was this combination that paved the way for parametric modelling.

Spatial volume modelling and corresponding CAD systems have always been characterized by a very high demand for computer computing power. Even current existing systems are not always able to handle complex 3D models. With the development of computers and the growing progress of the construction sector, the era of spatial modelling began.

3D shapes represented with CSG and B-rep methods exist only as graphic entities and do not have intelligence (Ibrahim and krawczyk, 2004). The next evolutionary stage in 3D modelling was the introduction of parametric and feature-based modelling which introduced a certain amount of intelligence into model elements.

The next evolutionary stage in 3D modelling was the introduction of parametric and feature-based modelling which introduced a certain amount of intelligence into model elements. Feature-based modelling is an object orientated approach where in addition to geometry, objects contain information about the objects role (e.g. door, wall, window etc.) and how an object relates to other objects. Feature-based modelling allows operations such as creating holes, fillets and chamfers to be associated with objects. This could include a window automatically cutting a hole when placed in a wall or intersecting walls connecting and joining correctly. Feature-based modelling enables objects to interact with other objects correctly and automatically in a spatial environment (Leeuwen and Wagter, 1997).

5.3 Parametric modelling

From constructive solid geometry (CSG) model, the concept of parameters emerged quite early with 3D modelling. However, the initial functionality and capabilities were very limited. A clearer need for parametric modelling emerged only with properties. One of the first properties we can detect in spatial modelling CAD systems is materiality (Sacks, R. *et al.* 2018). It emerged naturally early on, because in order to combine the individual geometric shapes into a new volume by Boolean operations, it became apparent that the way in which the two geometric shapes were connected also depended on the materiality of the elements of their representation. It is not difficult to combine two geometric shapes of the same material. The challenge arises when it comes to deciding which form or primitive to prioritize in the case of materiality.

This perception later developed Boolean operations and the very concepts of spatial modelling and BIM, that modelling takes place by combining features and geometry into an initial basic volume or element.

An example of this in the field of construction is reinforced concrete precast wall panels or other reinforced concrete precast elements. They consist of many separate components, such as fittings, reinforcement, separate layers of insulation and other elements, all of which merely connect to the main reinforced concrete element (Figure 6). The materiality of these components differs from the basic element.

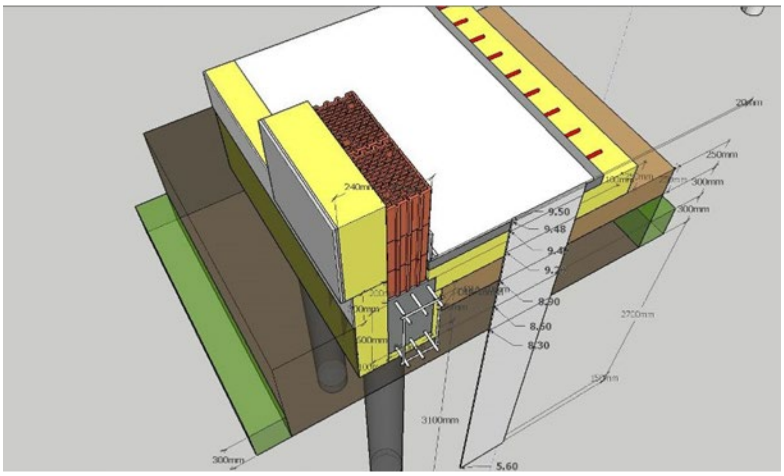


Figure 6 - Example of parametric modelling.

This example illustrates several important aspects related to BIM and spatial modelling. In the real world, everything is interconnected not only geometrically but also by its properties, which depend on the other components around it.

The first principles of parametric modelling emerged, the realization that individual volumes can share a common parameter, as in the example case mentioned - the dimensions of the insulation layer and reinforced concrete slabs. Nowadays, in BIM platforms, it is quite natural that everything is interconnected - the height of the columns with the floor slabs, the height of the walls to the floor, the bottom of the door to the floor, and so on. The perception and emergence of these relationships in the concept of parametric modelling paved the way for a more realistic representation of the built-up space in computer programs, more convenient and faster work. It also gave rise to the emergence of structures for construction objects and all structures, according to the standard. This parametric modelling was not limited to geometry to represent real physical objects, but also touched on various auxiliary and annotation elements such as axis networks, footnotes, and so on. Thus, parametric modelling has made it possible to globally control and perform geometric changes to static models by controlling only a few individual parameters.

It is possible to dynamically edit BIM models in different BIM softwarse depending on the design stage.

Instead of controlling ordinary numbers, in creating geometry, it became possible to link two geometric elements and later objects, describing their individual points, lines or surfaces as being parallel, perpendicular to other geometric primitives, respectively.

Modern 3D CAD and BIM software has greatly expanded the concept of parametric modelling, where parametric relationships are used now to generate complete model sections, annotation elements, such as dimensions, coordinates, and so on.

However, parametric modelling differs from standard 3D CAD modelling as objects such as primitive shapes are associated with parameters or variables that can instantly change the geometry or other properties of an object. Simple parameters of an object may include an object's length, width, height or radius. Other more complex parametric objects may have parameters that can change the entire structure or geometry of an object depending on different conditions. Parameters of an object can also control the location of an object within a larger model. Parametric library objects (such as doors or windows) allow objects to be reused multiple times in a model or in many different models with varying parameters. This approach is very efficient for modelling elements that are repeated but may contain geometric variation between different instances.

Parametric modelling enables the user to make the necessary changes quickly and fully automate entire digital modelling processes. This is how many modern BIM platforms work, as it automatically sequence the various interfaces between elements, geometry, and annotation components without actively involving the user.

Despite the differences, a modern parametric CAD or BIM system has the following features:

• Parametric volumetric modelling is a parametric functionality where complex geometric shapes can be obtained using several parameters. Geometry is regenerated as soon as parameters are changed or user-initiated. The sequence of operations in many cases is consistent and by swapping certain operations in places, completely different geometries can be obtained.

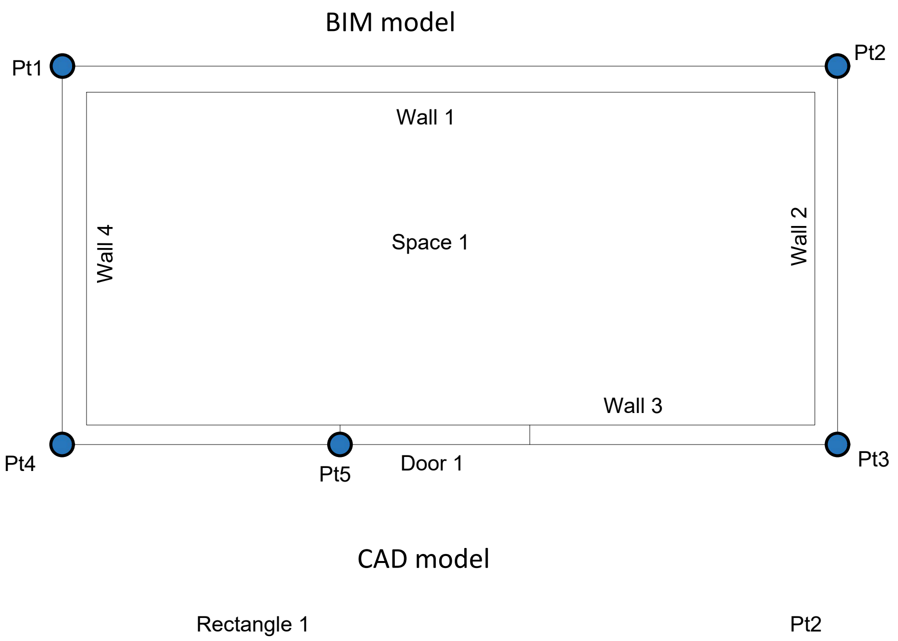
• Parametric modelling of object sets allows the user to create more complex objects that are composed of a variety of other components, allowing them to control their position, geometry and interactions between objects.

• Topological parametric modelling provides the ability to control interactions between objects and their sets with complete sets of instructions, with separate software code. Visual programming environment tools such as the Dynamo, Grasshopper and others operate on this basis. Many modern architectural structures due to their complex shapes, especially facades, are generated using this parametric modelling principle.

The more recent development of the concept Building Information Modelling (BIM) incorporates the main developments in 3D modelling including parametric and feature-based modelling combined with a dynamic 3D database for storing information relating to buildings. The addition of a dynamic relational database for building elements (similar to a Geographic Information System) enables many new applications for managing and analysing building elements. BIM enables building elements to be documented with smart parametric reusable objects that contain rich information about the objects use, semantics, topology, relationships with other objects and further information stored as attributes. BIM can be defined as the assembling of parametric objects which represent building components within a virtual environment and which are used to create or represent an entire building.

5.4 Objects and information in BIM models

In a CAD environment, whether in 2D or 3D, the whole point is focused on geometry and its definition in points, curves, surfaces and solid volumes, and only then attempts are made to associate different physical representations. For example, when we attribute in footnotes that a certain area, defined by lines and filled with some texture, represents something of real life. Providing information becomes secondary. In object-oriented modelling, this is flipped upside down. In the first place is the object itself, which is first associated with the information that describes it. It defines who the object is, what function it performs, defines its dependence, its properties as materiality, bound to C02, describes its position in space and time (building planning 4D BIM) and a myriad of other important aspects about the object. Geometry, it can be said, is just another property that describes an object. Its detail does not necessarily have to be representative of a real physical object, but depends on the need, the stage of the static life cycle in which the BIM model is developed, and other aspects.



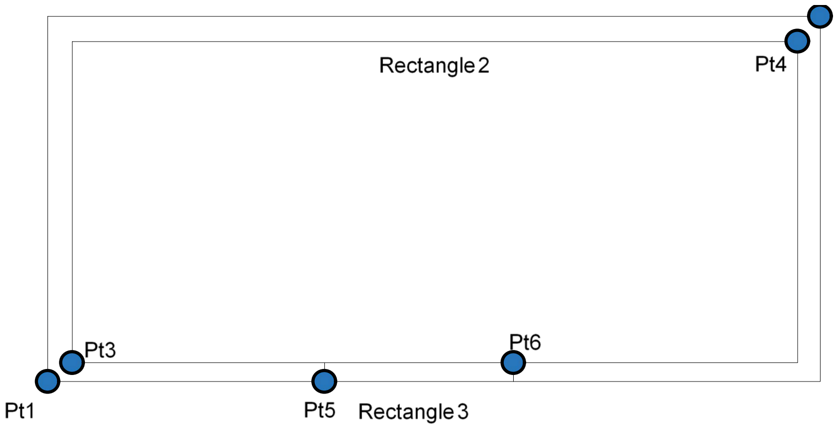


Figure 4 - Composite diagram of an object next to a composite diagram of a 3D geometric model

Geometric information alone is not sufficient to convey all the necessary BIM project information.

Objects are described according to parameters some of which are user defined and others, which relate to its position in a 3D environment relative to other shape objects. The visualisation of objects is achieved through viewing 2D and 3D features, plans, sections, elevations and 3D views. BIM can automatically create cut-sections, elevations, details and schedules in addition to orthographic projections and 3D models (wireframe or textured and animated). All of these views are linked to the 3D model and automatically update in real time so if a change is made in one view, all other views are also updated. This enables fast generation of detailed documentation required in the AEC/FM and heritage industries.

More and more technologies are choosen to represent and convey information as objects that meet the requirements of specific parts of the project. Object-oriented modelling can be understood as a separate concept that adapts to a specific discipline. Not only do the individual disciplines emerge in the BIM concept, but it is especially important, how they come together into a whole that is called a building project. Therefore, in the BIM environment, there are additional requirements for objects that ensure both interconnections and data exchange.

Most BIM software packages have extensive libraries of predefined parametric objects that are used to create 3D building information models. This facilitates efficient modelling as 3D geometry does not have to be created from scratch. Instead existing information enhanced library objects can be used to model the main building elements such as walls, doors, windows, columns, beams, slabs, roofs etc. Parameters of these library objects are edited to match the required dimensions and settings of a project. These library objects are then combined to create a complete model. A major problem for as-built BIM is the lack of pre-defined parametric objects suitable for existing and historical buildings. Most native and 3rd party BIM libraries are focused only on modern buildings. As a result, modelling existing and historic buildings often require many bespoke components to be created from scratch which can be a very time-consuming process (Dore and Murphy, 2017).

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