Building Information Modelling

Impacts and Opportunities

for Land surveying and the Cadastre

by

Ferenc Acs

K6L - UTAS

Declaration

This report contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and to my best knowledge and belief, contains no material previously publishes or written by another person, except where due reference is made in the text of this report.

Signed

Ferenc Acs

Student Number: 114522

Date: 22 October 2015

Abstract

Land surveyors are using sophisticated digital equipment and the best available technologies to make observations in the field. These three-dimensional data are rigorously tested and adjusted in the office using advanced mathematical and software tools.

In the case of surveying data provided to architects and engineers, a common workflow is for the surveyor to derive representations of surfaces such as terrain in a 2.5D TIN format and to deliver products to clients as 2D vector drawings. From these representations, architects or engineers, reconstruct these simplified 2D drawings into a 3D terrain object.

The latest technological advances of building information modelling (BIM) methods create exceptional opportunities for the land surveying profession. The utilisation of BIM not only preserves the spatial integrity of the 3D components of the field observations but also offers numerous additional opportunities. BIM allow the creation of 3D terrain objects which can be used directly by the other stakeholders on the project. Terrain models within a BIM environment can be equipped with attachments and attributes and therefore used to store supplementary information. Custom made additional objects can describe certain features of a property in 3D, such as a building envelope, easements, underground services or even soil layers. Relevant addition data, such as long- or short-term climate data, precipitation and wind conditions, sun-path, and shadow-casting data can be attached or linked. Customised 3D objects can indicate the internal space-structure of a building, and thus support an Indoor Navigation system. Other customised 3D objects may indicate the ownership or strata title, consequently supporting a future 3D Cadastre registration with accurate spatial data. BIM procedures are automatically recorded therefore the BIM models are legally transparent and traceable.

The project seeks to investigate the impacts and opportunities presented by Building Information Models for land surveyors, and argues that the 3D modelling and common data environment provided by BIM creates important opportunities for land surveyors and for the surveying industry and profession.

Acknowledgements

I would like to take this opportunity to thank everyone who has provided assistance to me throughout the course if this project.

Supervisor

Dr Jon Osborn	*UTAS*

Technical Assistance and constructive comment

Veronika Vincze	*ABC Hobart*
Johanna Acs	*UWA*
Ken Webster	*UTAS*
Trevor Parry	*UTAS*
Dallas Wilson	*DWDD Hobart*
Michael Kinsella	*IDDS Hobart*

Table of Contents

1 Introduction

Architects, engineers, builders and construction industry professionals need detailed spatial information to support and manage their projects. Every natural or man-made feature or object on a building site can influence the whole project. A meticulous three-dimensional representation of the area of interest underpins reliable decision-making for all stakeholders. Surveyors are amongst the first on every building site; their work is an integral part of the building industry. Moreover, there is a growing demand to document the existing or 'as built' stage of buildings and their surroundings. Real estate owners, operators, property managers, financing institutions, insurance companies, city councils, fire departments and others require detailed reliable spatial data sets that can be stored, analysed or distributed digitally. During the lifespan of a project a great number of digital 2D and 3D data are created and published. The latest developments in information technology allow the processing, storing and distribution of high resolution, fully three-dimensional spatial data even in large file sizes.

The building industry design procedure produces and makes use of a collection of annotated digital vector data with various attributes attached including their spatial distribution in a coordinate system. The more complicated or complex the subject of the project, the more 3D data is produced. A correlated group of 3D data can be organised as a digital object so that it can be identified, interrogated, manipulated or visualised when needed. The spatial resolution of an object can be set for its purpose; it can be very low or extremely high. Countless attributes, written documents, drawings, images or digital files can be linked to an object whenever required by the project. A series of linked digital objects, i.e. one produced and shared collaboratively as a representation of the physical and functional characteristics of a facility in order to form a reliable basis for decisions, is called a Building Information Model or BIM (Agar et al. 2014).

Architectural and engineering software can deliver three-dimensional virtual models with very high precision and accuracy. These software tools are also capable of attaching attributes and links to the objects within the model. The objects can be changed, modified, analysed, visualised and presented as a virtual reality (VR) model that represents the terrain and objects at a particular epoch. Various data, including 2D plans and elevations can also be derived and exported to other software packages. The data exchange uses specific file formats, accessible data storage and an integrated 3D model-based process as a common platform. Any change or improvement of the BIM model can be accessible in real-time and almost simultaneously for the stakeholders involved. The BIM model can be used for various analyses, simulations, budget monitoring and documentation at any stage of the development. Off-the-shelf objects can be added, or previously created objects can be re-used if required. The coordinated data flow is traceable and accountable as both a whole and in detail. This collaboration utilises various computing capabilities and tools in order to improve the quality of the product and save time and resources for the project.

Nowadays digital collaboration between professionals is a common practice. The use of networked computers is a daily routine; 3D digital maps, on line land-information services, satellite navigation, Google Earth and Street View, and mobile applications have not only generated more demand for a three-dimensional representation, but also built an awareness of the advantages of complex digital features such as BIM amongst trades and professionals.

This projects investigates the current status and capabilities of Building Information Systems and explores the integration of BIM into building design and construction, with a particular focus on the role of the surveyor.

1.1 Brief history of BIM

The Australian Institute of Architects define BIM as (Agar et al. 2014):

> *… a digital representation of physical and functional characteristics of a building. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; from inception onward (buildingSMART)*

Historically the physical and functional characteristics of a building as well as the three-dimensional appearance of a future project were all in the head of the architect or builder. Sets of drawings, plans, elevations, sections, sketches or perspective drawings were used as representations of the appearance and as a communication tool between the participants of the building process. The architect or the builder could be considered a ‘walking database’, holding a conceptual understanding of the building and a substantial knowledge of the details of the construction (Czmoch & Pękala 2014). The client or the other professionals had to cognitively recreate the 3D appearance of the object using the presented 2D drawings. To imagine an object in 3D from several related drawings, to ‘read’ the drawings as it were, can be an intimidating procedure. To make the procedure easier, a scaled model of the future project was often crafted. The museum of the Royal Institute of British Architects (RIBA) holds a large number of scaled timber models. As **Error! Not a valid bookmark self-reference.** shows, several different models can be prepared for the same project according to the needs of the presentation.

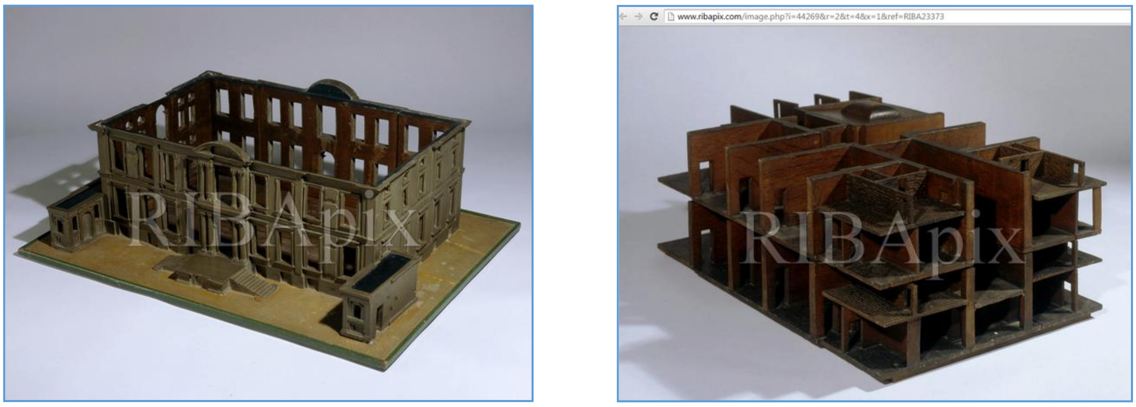


Figure 1 Design Model for Easton Neston (17th century) from timber. Designer N. Hawksmoor, (Source: www.ribapix.com)

The models can be a very detailed representation of the exterior appearance. In the past whole new buildings were erected just to test complex structural elements or the strength of building materials. The *Tempietto* (Figure 2) was built in order to model in a real-life situation the structural composition of the central dome of the St Peters Basilica (Lehmer 2013). Constructing scaled models or three-dimensional sketches for presentation is a routine procedure of architectural design.

Figure 2 The "Tempietto" in Rome (Source: www.studyblue.com)

The scaled models however have several disadvantages. First of all, the models are generally observed from a bird's-eye view which is not the natural vantage point for a human. In addition to this, constructing and frequently modifying a scaled model is a time consuming exercise. The construction of scaled models has become an industry in its own right. Up until recent times, specialised firms produced 'artistic impressions' of future projects. These elaborate models, however, are used mainly for marketing or to create publicity (Figure 3).

It is easy to understand the enthusiasm of the architects, engineers and the construction industry professionals (AEC) when the first virtual reality (VR) objects appeared on high-resolution colour monitors. The end of the 20th Century ushered in the beginning of a new area. Tools and equipment never seen before suddenly become part of everyday reality. The 21st Century has also seen GPS, high-speed internet, wireless communication networks, smartphones and high performance computer devices used commonly and routinely world-wide.

Figure 3 Models created for publicity (Source: www.portermodels.com.au)

A BIM is a complex network of virtual objects created and stored digitally. Therefore, the early history of BIM is strongly connected with the capability of computer hardware and software. In the early 1960s at the MIT Lincoln Laboratory a Human-Computer Interaction experimental software was running on a room sized computer (Sutherland 2012). The program was called “Sketchpad” (Sutherland 1963). This software already possessed the basic features of modern computer aided design (CAD) software, such as the following: constraint or object-oriented programming, graphical user interface (GUI), interactive drawing pen (“light-pen”) and keyboard function control. The computer screen could simultaneously and interactively display the designed object as a:

- top view (Plan)
- front view (Front Elevation)
- side view (Side Elevation)
- axonometric view (3D representation)

The design could be represented in ‘wireframe’ form or as a ‘solid object’. The ‘solid objects’ could also be multiplied, zoomed in and out of, or even ‘subtracted’ or ‘added’ to each other. A series of operations could be semi-automatically executed following a visualised flow chart (WGBH-TV 1964; https://youtu.be/USyoT_Ha_bA). The Pandora’s Box of the digital 3D modelling had been opened.

The notions of extensive use of digital 3D models, the semi-automated geometric data extraction of models, the library elements and the building database or Building Description System (BDS) appeared in the mid-1970s (Bergin 2011). An important next step, from the author of BDS, Charles Eastman, was the concept of Graphical Language for Interactive Design (Eastman & Henrion 1977), from which most of the characteristics of the recent BIM platform originate. The results of the research were however decelerated by the very high costs and relatively low performance of computer hardware at that time, and the lack of specialised personnel. An unforeseen breakthrough came from private companies in Eastern Europe where well-educated programmers had extensive experience of producing sophisticated software which could run on low budget hardware (Arnold 2002). The end of the Cold War and the appearance of personal computer hardware created the opportunity to start the ArchiCAD software of GraphiSoft in 1984. This software introduced the idea of a 'virtual building' that could be constructed from fully 3D parametric objects and library elements. Within a very short period of time ArchiCAD has become an international corporation, one of the leading forces behind BIM worldwide.

The other major player, Autodesk, was the principal CAD software producer for engineering from the early 1980s. By the time AutoCAD R12 was released, the software had an advanced 3D solid modelling capability. At that stage of the software's development an object could only be built manually from node-to-node. The objects were static, as opposed to the dynamic or parametric objects that maintain associations with other objects within a model. With the acquisition of the object oriented and parametric REVIT software, Autodesk literally entered into the new millennium. A whole family of parametric software products are now produced by Autodesk, with REVIT the dominant software of the global BIM market (Bergin 2011). The use of parametric objects as a design tool has become an integral part of almost every software used by the AEC industry.

The nature of software development is constant change and the periodic hype of a new software invention. Architects, engineers, construction professionals, facility operators and owners (AECOO) and the authorities need to be able to make informed and sophisticated decisions about if, how and when they will adapt their work practices and workflows to take advantage of these new technologies and capabilities.

1.2 The Building Information Model

The concept of a future building is usually formulated in the head of the designer or architect while interpreting the requirements or brief described by the client. The design is fundamentally three-dimensional, a virtual object ‘stored’ in the brain. Until recently, various tools were used to transform the design ideas or the solutions into 2D drawings or scaled models. The client or other professionals are ‘reading’ these drawings, plans, elevations, sections and details in order to recreate the virtual object again. Every change in the project, every modification or improvement goes through this procedure again and again. The more complex the project is, the more time consuming this procedure can be.

The Building Information Model is an attempt to create a model of the design that captures every aspect of every detail. The BIM is a virtual realisation of the project. When a BIM environment is used, the designed building or building elements are not drafted but virtually built in the computer:

- The scale of the virtual model is 1:1. Every element, the footings, the wall, the slab, the roof and even the terrain around the building, is a fully three-dimensional virtual object equipped with all the necessary attributes needed for the project at any stage of the development.
- Every stage of the virtual building procedure is recorded and can be visualised in 3D immediately or as required.
- The attributes of the objects can contain all of the necessary information including the cost.
- Prefabricated elements, such as windows, doors, furniture, light fittings etc. can be downloaded from the manufacturer’s digital library and customised or just simply added to the project. The parametric nature of the custom designed or the library elements (objects) allow a consistent relationship between the elements, which may result in a seamless workflow and accelerate the virtual building procedure. On-line BIM libraries allow direct access to the product with all specifications, costs and the latest version in real time. The attached attributes, as the part of the structured data, allow ‘custom-reading’, i.e. the customised semi-automatic mass extraction of quantities or attributes at will. This procedure allows the interrogation of the current

design at any stage. Almost every detail of the designer or the manufacturer of the enquired objects (or library elements) is traceable, which can be important regarding the security and the quality assurance.

- The virtual building can at any stage be transferred or distributed to other consultants or to the client. This procedure can be a direct digital transfer, or via a structured and secured cloud-database. The transferred BIM does not have to be recreated; it can be read and visualised immediately. The architect or the builder does not have to be a ‘walking database’ because all the necessary details are attached to the BIM. The individual files, objects, even 2D drawings can be hyperlinked (similar to a web hyperlink) which enables an efficient navigation within the complex file structure. This way the designers and the builders save time and reduce the risk of errors in the building approval and construction processes.
- The fast and efficient collaboration between the different fields of engineering and the construction professionals is the result of on-line communication achieved through networked computers. One of the major advantages of the BIM environment is that it utilises already existing hardware devices and software. The file exchange and the collaboration can be executed from a simple e-mail attachment, via the popular social media or ‘cloud’ services (e.g. Skype, Facebook, Dropbox) to professional LAN facilities. This feature allows user-friendly communication between professionals or with the client, even for very small companies. Moreover, personnel who have freshly entered the job market often have extensive knowledge and experience of various forms of on-line communication. The next generation is also accustomed to the various different product families and able to engage with the rapid and frequent adaptation of new digital equipment and software.

1.3 Land Surveyors and the potential impacts of BIM

The profession of land surveying has a history that dates back thousands of years. Observations have been recorded and presented in every epoch through the means available at the time. In ancient Greece, geometry and map making became a sophisticated science. Five hundred years ago surveyors already used triangulation (Gemma Frisius 1533) and the map makers were using the Mercator projection (Crane 2003). The use of points, lines, distances, angles, mathematical calculations and visual observations has enabled us to measure and represent the terrain for centuries. By the end of the 19th century arduous tasks, such as the triangulation of India, were completed with rigorous precision by a small group of professionals with the use of simple optical instruments (Keay 2001). With the invention of photography, the use of aerial cameras enabled the collection of large amounts of data within a short period of time. Elaborate optical instruments and methods had to be developed in order to extract the required information from the images. The next step in the 21st century is the common use of digital instruments and methods, which will enable the production of far more precise and accurate survey data almost instantaneously and in full 3D. The past demonstrates that the surveying profession is quick to integrate the latest developments of science and technology[1].

Land surveyors are working almost invisibly at every stage of a building construction. Various tasks, such as cadastre surveying, site surveying, setout-surveying, construction surveying and as-built surveying are an integral part of the AEC industry. Land surveying is a mature science that possesses its own highly sophisticated and up-to-date digital technology. The use of the latest communication and data transfer tools is a part of the daily routine of the spatial science professional. The integration of Building Information Modelling seems to be a natural step for land surveyors. The surveyor's observations are usually points with xyz coordinates and attached attributes. The observations are rigorously adjusted and evaluated. The observations are then further processed, interpreted, and various lines such as alignment, boundary lines, edge lines or breaklines are added in a proper projection using specialised software. A digital terrain model (DTM) is generally created using a triangulated irregular network (TIN) typically based on the Delaunay triangulation. The TIN surface is usually overlaid with contour lines. A traditional survey product is a vector drawing that contains various points, lines and polygons equipped with annotations. The product is usually exported into a commonly used digital CAD file format.

Within the BIM environment surveyors are able to produce the terrain as a parametric object with attributes such as the survey points, reference points, alignment lines, projection, the TIN or the data validity calculations attached. Services such as utilities on the surface and underground can be added as library parametric elements. Control survey points or a temporary benchmark (TBM) also can be represented as objects. Natural terrain features such

1 http://www.alifewithoutlimits.com.au/

as typical trees can be library elements, and can include information such as trunk diameter. Existing buildings can be surveyed and added as custom-made BIM objects or point-cloud data. In the near future it is likely that underground geological layers, masses, rocks and even water bodies can be represented within a BIM. All the objects and their attributes can be semi-automatically obtained from the model, including every change of the terrain, such as Cut and Fill volumes and the surfaces of roads and walkways. The direct link between the BIM environment and the GIS dataset may open the possibility of incorporating the outputs of various GIS operations.

The BIM object oriented methods combined with the results of as-built surveying offer useful information for the 3D Cadastre. The results of the 3D Cadastre combined with other mobile digital technology might be used for an integrated Indoor Navigation within buildings or dense built city environments. The Indoor Navigation solution might positively influence the efficiency of Facility Management (FM) and Security and the Emergency Services (SES). While further development of the BIM environment might be the task for the AEC industry professionals, site surveying, underground service surveying, 3D Cadastre and Indoor Navigation might need the assistance of spatial science professionals.

1.4 Why BIM?

Although a large number of great historical buildings have been erected in the past, design and construction were for a long period of time a hands-on exercise. Scaled models, empirical experiences, traditions and trial and error construction methods were used until the early 19th century. The development of material sciences, structural engineering, the steel industry and the introduction of Portland cement can be considered the beginning of the modern building industry (Kurrer 2012). By the end of the 19th century, complex engineered structures such as the Eiffel Tower could be erected. By the 20th century the building industry had become accustomed to mass production where a team of experts, architects, various engineers and construction professionals were involved with the design of buildings. Sets of 2D drawings and various written documents were used as the main communication tool between these professionals. Even though by the mid-90s early digital equipment and CAD software presented the opportunity for digital communication and data exchange, the 2D nature of the data exchange remained the norm in the building industry. The flow of information between the stakeholders remained time consuming and difficult to follow (Figure 4).

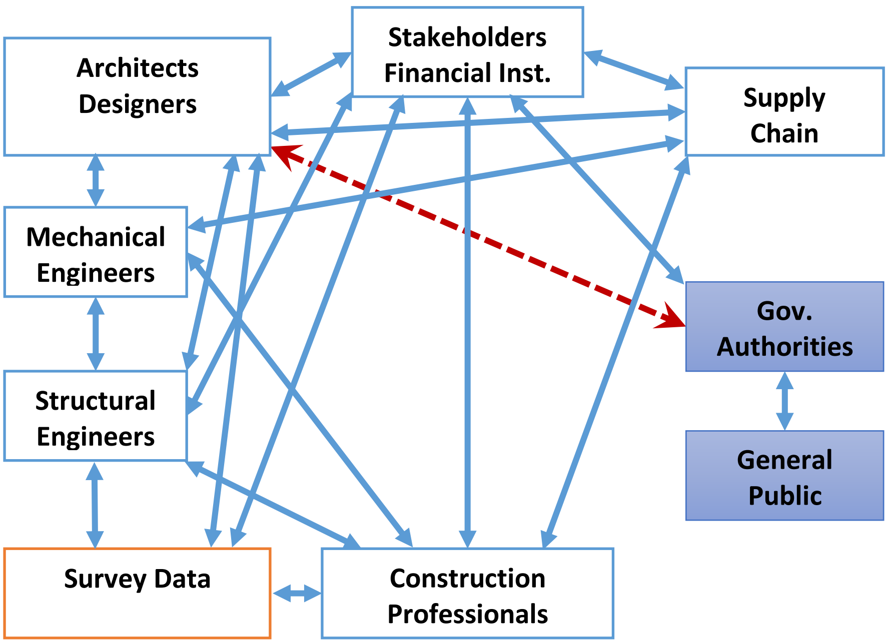


Figure 4 The flow of information and data during the design process of a building without using BIM environment (Plotted by: Ferenc Acs)

Usually the architect receives instructions from the client and creates a design program. The surveyor passes the site survey to the architect, who prepares the first sketches or a preliminary design. These sketches are circulated to the engineers, builders and building material suppliers for an initial budget estimate. When the initial building permission is received from the local authorities, the future building is designed in detail by the architect, in cooperation with other engineers and the owner. When the authorities approve the final design, a lot of detail drawings are prepared in order to be able to finalise the bill of quantities, the logistics, the time schedule flow-chart and the budget. The flow of information usually has a very similar pattern between the various departments of the local authorities or between the professions on the construction site.

The characteristics of the BIM environment are a rationalized data flow and data exchange procedure (Figure 5). A 3D virtual building contains many 3D elements such as footings, slabs, ceilings, roofs walls, doors, windows and so on. An element can be composed from several parametric objects.

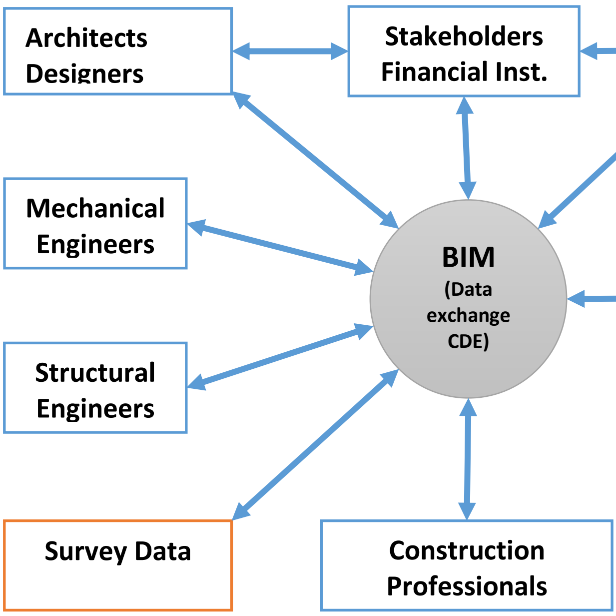


Figure 5 The flow of information during the design process using BIM environment (Plotted by: Ferenc Acs)

Each object has a 3D geometrical description including its location within a reference frame and can have several attributes and documents attached. The objects can be custom made by a particular software or imported as prefabricated parametric library elements that are either part of the software package or imported from a third party. The parametric nature of the objects allows them to be altered or modified and that variation is automatically applied to objects related to the modified object. Any object or virtual building element can be exported using an independent file format. At the time of writing (June 2015) the Industry Foundation Classes 2 edition 3 TC1 (IFC2x3) file format is recommended for data communication within BIM environment (Liebich et al. 2007). The current major BIM authoring software such as ArchiCAD, DDS, LISTECH NEO, GLODON, REVIT, and TEKLA[2] can read and write the IFC2x3 file format[3].

The 3D virtual model and the attached attributes and documents including 2D drawings and images can be distributed from a common database, which enforces a 'single version of truth' type of data in a structured and controlled manner. The BIM platform is accessible 24/7 from the very moment it is published. Every event, login, upload or download is recorded; consequently the data flow is transparent and traceable. Variations, updates, issues and events are simultaneously available for the designated participants. The data exchange or distribution can have, but does not require, new hardware or network infrastructure. The BIM platform routinely uses the already existing broad-band internet (ADSL2 in Australia) and the widespread and commonly used, mostly free web applications and 'cloud'[4] services such as OneDrive, Google-Drive, Dropbox, provided that sufficient data storage and security is offered. Tablet and smartphone apps for BIM, among others the BIMx or SlimBIM2go, are already available for off-the-shelf mobile devices. These apps do not require special training or exclusive knowledge to use. The mobile variant of the documents or even the 3D model are accessible using already existing mobile devices, and thus require no further investment. The use of mobile devices and real time and simultaneous access to the data can also be an advantage on a building site. Although the architectural or engineering data are distributed in indexed packages sorted by reference number, the drawings - even the drawing fragments - or the designated 3D elements can be hyperlinked. This feature makes a swift and target-oriented navigation through the vast amount of data. Similar to the web-page hyperlink feature, the hyper-linked documents can be physically located and stored in different databases at will. If the security allows it, there is no need for the committed use of a particular 'cloud' service.

[2] http://www.buildingsmart-tech.org/certification/ifc-certification-2.0/ifc2x3-cv-v2.0-certification/participants
[3] IFC4 has been released but not widely used yet
[4] 'cloud' is a general term which refers to an online digital mass storage space where the data is stored securely on servers. The data is available 24/7 for the authorised participants

For the reasons mentioned above, the BIM environment can be considered a valuable contribution to communication. The BIM concept and 3D models contain far more than a 3D geometric representation of objects. It is an organised prototype of the building in terms of footings, floors, walls, roofs and the attached attributes and documents (GSA-US 2007)[5]. The BIM model can be considered an index of the physical and the functional characteristics of the design and construction. The BIM model is 'computable' and can be visualised by other building analysis applications. It can be used directly for countless third party BIM compatible software such as cost estimating, energy simulation, building code checking, collision checking, and structural analysis. The exchange of data and the transferable records of building information across the platform are intended to last throughout the lifecycle of the building. The BIM environment should serve as an updatable and reliable source of information for analysis and decision-making in design, construction, operation and maintenance. The BIM is also a catalogue of the design, construction and the operational status of the building (GSA-US 2007). Every participant, modification, change of event and data exchange is recorded and traceable. The data is organised in time sequence, often called the fourth dimension (4D) of the BIM. The 4D models support visualisation, coordination and optimisation of the construction sequencing and supply of resources. The various stakeholders, organisations, construction managements and facility management (FM) supply chains can obtain exact, up-to-date and traceable logistical information from the start of the design to the end of the lifecycle of the building (GSA-US 2009).

The cost estimate, budget and cash-flow monitoring can also be modelled or visualised when the 3D BIM objects are logically linked with the 4D time sequence of information. This derived product is usually called the 5D BIM model. This model enables integration of the construction activities and related costs over the time (VICO 2014). The benefits of the 5D model are that it provides a traceable, up-to-date documentation of cost planning and budget control. This derived dataset can be a source of cost planning from a single owner-manager to the financial institutions specialised for budget management of the construction.

Although the 4D/5D/6D/7D coding was probably introduced as a marketing 'term' to target particular groups of professionals, it is widely accepted and used within the AEC industry

5 U.S. General Service Administration (GSA) (http://www.gsa.gov/portal/content/105075)

worldwide. The acronym of 6D BIM is assigned to Facility Management (FM) (Agar et al. 2014), although a paper from Europe allocates the 6D to sustainability assessment and the 7D for FM (Czmoch & Pękala 2014). The 8D BIM is connected to Hazard Assessment and Accident Prevention Through Design (Kamardeen 2010).

The growing number of '*n*'D BIM demonstrates that the BIM data is palatable for a wide range of professionals. The structured information derived from a BIM model is capable of serving several disciplines. Currently, the '*n*'D BIM operators may utilise the capabilities of the free BIM-viewer software. Most of the free model-viewer software can open and interrogate several BIM objects from different sources simultaneously. A wide range of comments, screenshots and conflict detection notices can be located and saved. 2D and 3D surfaces and polygons from (earlier version) CAD software also can be added, visualised and saved into a single file together with the 3D objects. The capabilities of viewers seem to be increasing rapidly. Free BIM-viewers can be a great help for a small business, FM professionals or for the owners who otherwise would not be able to visualise the accessible data. Free BIM-viewers also might help the professionals when the quality of the BIM model is initially assessed. The errors, omissions (E&O) can be visualised or interrogated even on mobile devices before the job is allocated for further process.

Although the shift from drawing table to CAD drafting was a spectacular, almost dramatic, change, it also coincided with the honeymoon stage of the digital age. Practically everyone wanted to see or have a desktop computer. Labour intensive tasks such as printing or copying became very easy as the mutually compatible PDF file format could be used. The product, the printed drawings, and especially the annotation, all appeared to be sophisticated and visually pleasing. The drawings started to be transferred via the Internet and the drafting table receded from view. Since most CAD software has 3D capabilities the use of 3D parametric objects may seems to be a step that only requires a simple upgrade of the of the CAD system. This however is not the case; the transition to a BIM environment interrupts the design process from its commencement. The BIM model of a building is not drafted, but digitally built in the virtual space. The building elements (parametric objects) are the virtual realisation of the real building elements.

Therefore widespread changes should be anticipated within the AEC industry:

- The design, construction and building application approval processes require BIM compatible authoring or viewer software
- The BIM environment, due to the settings of the attributes for the 3D objects, requires far more initial attention than a CAD drawing
- The designated BIM authoring software require the essential third party library elements of the specific building code jurisdiction
- The collaboration requires BIM-ready partners
- The third party library elements should be ready for download from the manufacturer's websites or databases
- Government Authorities should be prepared to receive and accept BIM documents
- The legal profession will need to deal with the issues of the acceptance of the BIM objects as part of a legally binding contract.

As indicated, the technological background, the hardware, software and network environment are ready for the adoption of BIM. The transition to BIM however requires a greater level of participation and changes to professional practices. Although the benefits of the transition are generally acknowledged amongst engineers and architects, it is only cautiously being adopted within the AEC industry. The land surveying profession as an integral part of the AEC industry can expect to be substantially and directly affected by the growing role and importance of the BIM environment.

1.5 **What is BIM**

The CAD systems use simple vectors such as points and lines to compose drawings or 3D elements. A design generally contains a great number of vectors, which are often created and organised in a three-dimensional Cartesian coordinate system with a local origin. In a traditional CAD system every shape, surface or object is drafted individually. When a feature or drafted object is changed or a new component added, all the related drawing elements need to be tediously modified one by one. The CAD model may contain the geometry of the design features, however the product is principally static, contains annotated plans, sections and elevations as separate groups of drawing entities. The use of a three-dimensional design tool such as BIM authoring software could be seen as a logical next step in the development of CAD systems. The introduction of BIM has the potential to reshape the building industry by literally adding a new dimension to the AEC industry practice.

There are several characteristics of BIM that makes this development significant.

- Parametric objects
    - BIM authoring software defines 3D objects with its parameters and relations with other objects. A parametric object maintains consistent interactions between the objects and the model; if an object is modified the related objects automatically implement the changes via the changed parameters (ISA_Project_Team 2008). Each object can carry attributes, attachments and hyperlinked uniform resource locator (URL) addresses. The active link between objects and the digital network (Internet or local network) make the parametric objects exceptionally useful compared with a static CAD system

- Library Elements
    - Prefabricated Library Elements allow construction of accurate models. A library element is the virtual representation of an industrial product, such as a steel beam or a sewer pipe. Most of the library elements are produced and distributed by manufacturers, therefore the object represents the latest model, which contains the actual attributes and specifications including its price. The library elements are the direct interactive link between the designer and the available building materials and fixtures.

- Visualisation
    - The BIM model can be visualised in high resolution at any stage of the lifespan of the project. An always available and accurate model can be a powerful aid for swift decision-making. A realistic representation of a

project can be a valuable tool in order to maintain communication between professionals, clients, operators and the general public.

- Zoning – Indoor Navigation – 3D Cadastre
    - The 3D geometry of the enclosed spaces within and around a BIM project are called 'zone-stamps'. The zone-stamps are usually stored on a hidden layer within the BIM authoring software and are programmed to store metadata about the area and immediate surroundings of a particular room or space. The linked zone-stamp objects can be considered as the skeleton of a project. While the various BIM, such as the architectural, structural or mechanical models, can be significantly different within a project, they are all directly linked to the chain of zone-stamps. Since the zone-stamps are the skeleton of the project the AEC professionals are using this property as an internal navigation tool within the project. The features (it can store hyperlinked data) and the parametric geometry of the BIM zone-stamps can be a valuable tool for indoor navigation systems. Moreover, the coordinated and purpose built zone-stamps have the potential to be the basic elements for 3D Cadastre systems.

- Simulations
    - At the very early stage of the development of BIM software the programmers realised the potential of the parametric objects for various building simulation. Recently almost every BIM authoring software contains integrated simulation processes, such as Energy Evaluation, Fire Rating, or Shadow Casting modules. The structural software can simulate effects of various static and dynamic loads and vibrations in order to find the best solution for a particular project. The BIM authoring software are capable of connecting to other software or software modules as well, therefore simulation can be governed by a remote, third party software via the Internet.

- Clash Detection
    - BIM compatible software or BIM viewers are usually equipped with clash detection capabilities. This feature is used to semi-automatically detect intersections or connections between 3D objects. This feature can be increasingly advantageous when several complex models from various sources are interrogated in order to detect the physical relationships between objects. Similar to zone-stamps, special 3D objects, referred to as an ‘aura’ can be created around a particular object (or object group) which indicates certain characteristics, such as extreme heat or other hazard zone or zones. Moreover certain rules, such as a Building Code or Fire Hazard also can be coded using additional parameters to the zone stamps or other groups of objects. A modified clash detection procedure therefore can be applied in order to be able to investigate the clashes with the rules of a particular jurisdiction.

- Collaboration
    - One of the most beneficial features of a BIM is the capability for communication and collaboration via the Internet. The Common Data Environment (CDE) allows exchange of 3D models in commonly recognised file formats. The parametric objects are equipped with machine-readable data which allows extraction of attached attributes semi-automatically. As was indicated previously, a BIM utilises the already existing mobile communication and social media resources in order to facilitate a wide range of methods of the collaboration which are familiar to both the professionals and the general public.

- Traceability
    - BIM software are programmed to record every step of the design procedure and the data transfer in a time sequence. Consequently the BIM environment by default can be considered transparent and traceable.

1.5.1 Parametric objects

Within a CAD system two points create a line, and three points create a triangle. The area within the triangle can be considered a two dimensional surface. Four points can compose a three-dimensional surface or an object called a tetrahedron. Three-dimensional objects also can be created using polylines and 'extrude' or 'revolve' commands (Figure 6). The objects can also be 'added' or 'subtracted' from each other in order to form the shape required by the design.

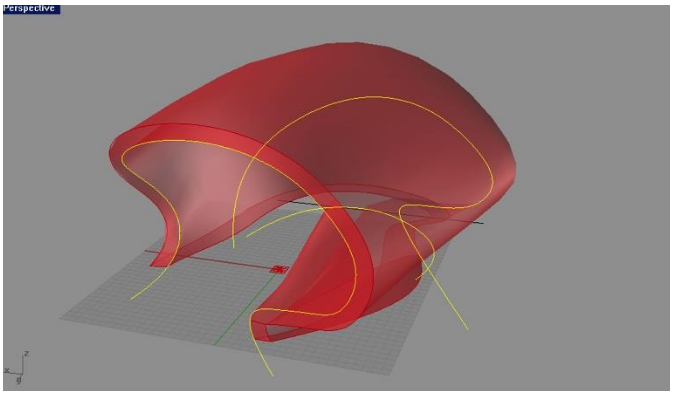


Figure 6 Free-form three-dimensional shapes can be produced with mathematical precision using polylines and the REVOLVE command (Source: http://api.ning.com/files/Hcd6BcljSXcZ8RklX1*UDzn9nzFqAdRh3sQJy3kvKSVcytNlCvZk9ad9cuWpttxtLGYZePksyWElpQmBdMeAWCxSiV06o7rN/2.jpg *)*

The objects created by a CAD systems are static; every modification has to be executed step-by-step manually, whereas the object oriented parametric design technology embeds all the features and capabilities of CAD systems into an integrated process-based solution:

"The geometry of a parametric object is defined in terms of named and interactive variables instead of fixed values…" (Model-Support-Group 2015a).

The parameters can be defined or modified interactively via an intelligent and user-friendly GUI. The relationships of the parameters within the object and between the objects are determined by the algorithm of the software.

"*Any change, even the modification of a single parameter is automatically transformed to all related objects within the entire project.*" (Model-Support-Group 2015a)

As a result all relevant parameters of the other objects are influenced and updated. The parameters of the (parametric) objects can be altered by the operator:

- with the use simple adjustments,
- by applying complex ‘what-if’ rules, or
- by executing Boolean operations within various constraints and criteria.

The operations within the software are configured, pre-determined and prearranged by the software manufacturer. The designer is afforded a wide range of customised rules, operations and modification. The configurations can be adjusted to specific tasks, according to the definition of the software or by means of the operator’s knowledge.

Structural calculations, energy simulations, sun studies or visual impact assessment can also be executed via an intelligent GUI, which invokes the appropriate variations of the parameters and processes. Consequently the same object, or the whole project, can be altered, modified or developed by architects, structural engineers or construction professionals. The various industrial standards and local variations of the regional building regulations can also be added to the software via the selection of the appropriate parameters, which further customises the design procedure.

1.5.2 Library Elements

A building is generally constructed from standardised building materials and manufactured using off-the-shelf elements such as rafters, bearers, beams, columns, lintels, doors, windows, plumbing fixtures, various pipes and wires. All of these elements can be stored digitally as parametric objects and stored in an on-line catalogue which, in BIM terminology, is called the library. Even complex composite (multi-layered) walls, roofs, ceilings or footings are stored as parametric library elements. The parametric library elements are fully three-dimensional, hence the designer is not drafting, but digitally constructing the virtual building.

Every step of the virtual construction invokes an immediate update of the whole project via the parametric nature of the design environment. When a library element is updated, replaced or modified (variations), this latest version appears in the project instantaneously. The collection of imported and customised library elements becomes an integrated part of the local library and is ready to be re-used in other projects. These objects and their linked web sites are gradually replacing the printed product catalogue library of the designer offices. Moreover the digital library elements can contain the latest upgrade directly from the manufacturer or can be replaced with other products without producing waste, and saving costs and time.

1.5.3 Visualisation

An object, a small detail of the building or the whole project, can be simultaneously visualised, rotated, and zoomed in or out of on the split screen of a computer. Objects are usually colour coded in order to enhance the visual navigation within the virtual space. There is no current general rule for the colour code; offices apply their own policy. The surface of the objects however, can be wrapped with high-resolution photorealistic images for better navigation or for presentation purposes. The high-resolution images usually represent various surfaces such as face brick, blockwork, concrete, timber, stone or rough rendered surface, all of which are provided by the software vendor. The painted surfaces also have their own colour surface catalogue (library) which can be updated from the paint manufacturer's website (e.g. Dulux-online 2015).

Most of the BIM authoring software are equipped with accurate sun path data and shadow casting capabilities. The local origin of the project can be linked to the exact geographic location, which is usually expressed using longitude and latitude values. The sun position is determined by the software when the local date and time (including Daylight Savings) is keyed in. Some currently available software is able to emulate ambient light conditions or add artificial light fixtures for night-time conditions. All light fixtures are proper parametric objects and the default characteristics of the emitted virtual light, such as light direction, angle, colour and fading are all pre-set by the manufacturer.

The precise position of a virtual camera also can be interactively determined. The settings of the integrated virtual camera via GUI mimics a realistic digital camera. In the preview the actual scene can be monitored. The process allows production of photorealistic images in perspective projection for presentation purposes. Several virtual camera positions can be linked to a path in order to produce animated videos if required. The virtual camera settings allow the capture of images of a future project from given positions of the camera and the sun. These images can be merged with actual images of the building site in order to determine the visual impact of the building. This technology allows the user to produce augmented reality images, in which the images of real scenes can be enhanced with the objects created in the BIM software.

The augmented reality images produced by BIM authoring software are not ‘artistic impressions’ or sketches, as all properties including the geometry of the objects are representing the exact three-dimensional positions determined by the designer. Parametric virtual cutting planes produced by the software enable the user to visualise the project in sections and consequently the traditional plans, elevations and sections can be visualised and printed out ‘on demand’. The software also allows the user to temporarily change object properties such colour or transparency in order to facilitate the visual investigation or enhance the virtual navigation between the objects (*Figure 7*). Objects that are occluded or underground, such as stormwater or sewer pipes, can be visualised using this method. The exact future location of the objects, such as the inverts of a stormwater line, can be ’seen’ directly and instantaneously from the BIM model at any point if required

Figure 7 An augmented virtual reality map of the Las Vegas underground services on mobile devices (VTN Consulting, Source: http://connectedconstruction.org/post/31047854052/bim-augmented-reality)

1.5.4 Zoning (Indoor navigation)

A building is conventionally organised by floor levels or storeys. For a designer, the Floor Level (FL) value determines the vertical separation of the sheets of plans, which may also be referred to as Ground Floor Plan, First Floor Plan and so on. The architects and engineers customarily design each FL or storey separately. The BIM authoring software allows the user to see the storey below or above as a 'ghost-storey' in order to establish the relationship horizontally (registration) between the storeys. The FL is usually a height value given in metres above the temporary bench mark (TBM) of the project. In Tasmania, when the TBM is linked to the site survey map by the land surveyor, the values are given as Eastings, Northing[6] and AHD83[7]. In BIM authoring software a building is virtually constructed using parametric objects such as footings, slabs, walls, windows, doors, roofs and so on. The objects usually enclose areas or spaces with various functions such as living room, bedroom, bathroom or corridor. The 'air space' of a room can be considered an empty cell with a usable function.

Within some BIM authoring software, an enclosed space or cell is treated as an object. In order to distinguish this special 'empty' object, it is often called a zone-stamp. By default a zone stamp object is a three-dimensional cell, which exactly matches with the inside area enclosed by the walls, the floor and the ceiling of a room (Figure 8). The zone object is mainly used for internal navigation within a building.

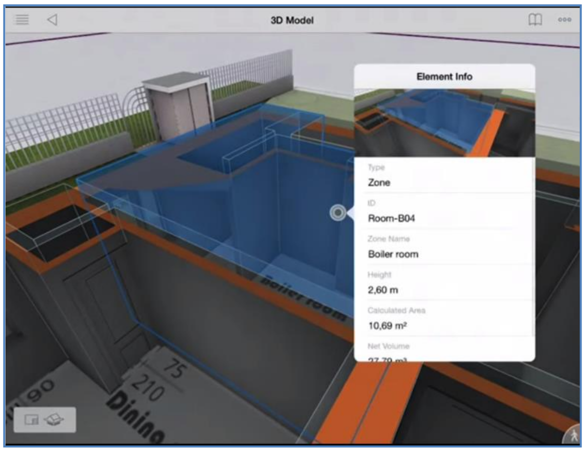


Figure 8 The ZONE object is indicated with blue colour within the 3D horizontal section of the building. (Source: GraphiSoft BIMx tutorial)

[6] Map Grid of Australia (MGA) zone 55 EPSG: 28355
[7] Australian Height Datum 1983

Every zone object has an ID number that matches with the room number used in traditional CAD drafting. The Zone object is predominantly used to extract the list of rooms, as well as calculate specific surfaces such as floor (e. g. carpet) and wall or calculate the air volume. Zones can be colour coded to indicate the different functions of the zone. Colour codes can be used to indicate various attributes such as fire rating, price range or ownership, etc. Zone volumes are also used for the energy evaluation or for the design of the MEP features.

When the doors, the windows and indoor obstacles are attached as parameters to the zone object, it can be used as a basic unit for Indoor Navigation. The software can calculate or simulate the lengths, the direction and the cross section of the evacuation path for security design purposes or for Emergency Services. The parametric Zone object will change its shape automatically whenever a related object is altered or a new object introduced, and can as a result update all related objects, calculations and design features.

These BIM zones are potentially significant for land surveyors. Within a project more than one group of zone-stamp objects can be produced. When a strata title is composed by property lawyers the document clearly describes the '*metes and bounds*' of the property. Consequently, a set of customised zone-stamp objects can be created that follow the 3D boundaries of the ownership within the area of interest. The ownership zones can be extended to outdoor easements, the common owned areas, or below surface to indicate easements for underground services within the boundaries of the title. When a land surveyor is involved in the creation of the ownership-zones, then in practice a 3D cadastral survey is implemented. Further, an interactive link between the BIM environment and the 3D cadastral survey can be established.

1.5.5 Simulations

Energy Evaluation

Most BIM authoring software can produce an Energy Evaluation simulation based upon the function and shape of the building, the characteristics of the building materials and the finished surfaces. Special add-on software evaluates all objects both individually and collectively within the given climate conditions of the area and the requirements of the local authorities. This add-on software reads the given parameters of the project and implants them into the required model environment. The functions (profiles) of the building are 'read' from the Zoning, and the materials and the surfaces from the object groups. Usually elaborate settings of the parameters can be used such as Surface Heat Transfer, Material Thermal Conductivity, Surroundings Characteristics, Wind Protection, Horizontal Shading, all year Climate Data (sun, wind, temperature, precipitation, due point, humidity), Heating-Ventilation type and Energy Source factors. The software collects the data semi-automatically from the settings of the objects and third party 'cloud' databases acceptable for local requirements (Figure 9). This initial energy evaluation simulation can be run at any stage of the design in order to keep the design within the required local parameters. Although climate related Energy simulation modules are available in almost every BIM authoring software other, more specific simulations can be found in specialised engineering software equipped with BIM authoring capabilities.

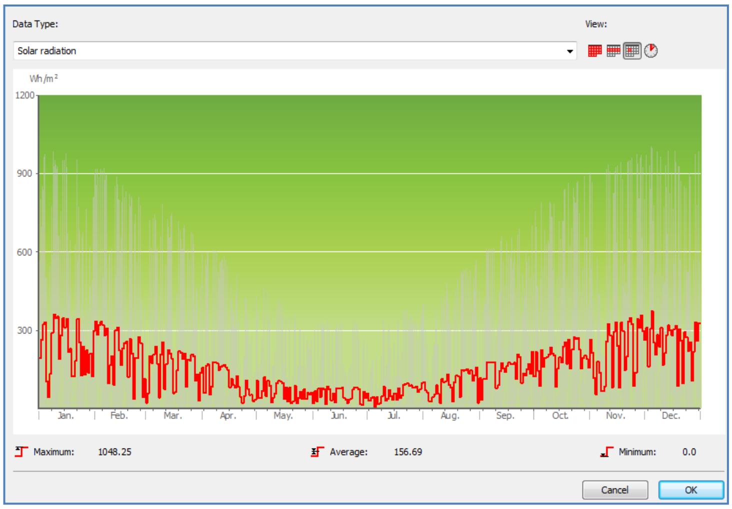


Figure 9 Solar Radiation chart in Hobart TAS produced by the ArchiCAD 18 BIM authoring software Energy Evaluation module via direct link to StruSoft Climate server (Source: GraphiSoft Tutorial)

There are various software available tailored for Structural or Mechanical Engineering. These varieties of software can simulate the deformations or vibrations of the steel, concrete or timber structures under loading or the influence of various fluid dynamics on pipelines. The parametric nature of the BIM also allows a semi-automatic design procedure. The typical and frequently repeated design can be ‘coded’ and customised to the new site adjusting just the parameters. Various simulations can be executed with the ‘coded’ design through using a systematic modification[8] of the parameters in order to find the best solution. The final product is either integrated or linked to the final BIM model, which is the key area of interest for a land surveyor within the AEC industry.

1.5.6 Clash detection

A project may consist of several closely related BIM models. Even a simple building can contain a separate architectural model, a structural model and hopefully a model of the terrain (Figure 10). These models are generally produced by different professionals, who use different BIM authoring software packages. When the various related models are simultaneously interrogated the automatic clash detection can be one of the first steps to execute.

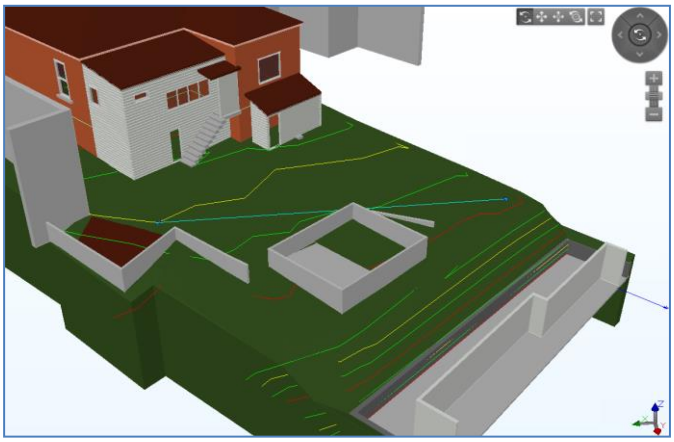


Figure 10 A free BIM-viewer screen capture. The colour coded lines are contourlines (polylines) from a third party CAD software (‘BIMsight’ viewer, Modelled by: F. Acs)

[8] Similar to the Monte Carlo simulation use by GIS analysis

The software visualises and marks the detected clash points and creates an automatic clash detection report. The user can create a section and navigate, orbit, and zoom in and out freely within or around the 3D model. Filtered clash detection procedures are routinely used by designers in order to accelerate the identification and marking of conflict areas between architectural, structural and mechanical engineering models (Figure 11)

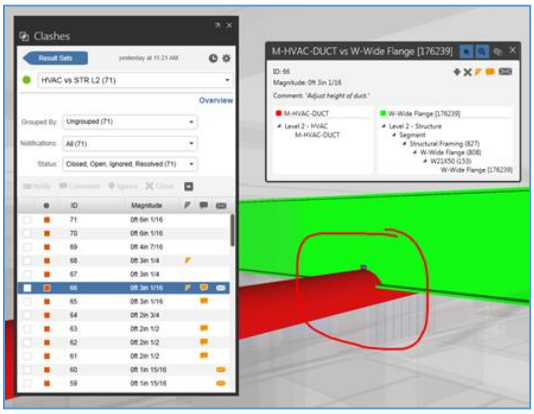


Figure 11 Screen capture of the results of a Clash Detection procedure. (Source: *http://cenews.com/article/7771/the_benefits_of_reinventing_the_wheel* *)*

Land surveyors may identify building elements protruding into easements or areas outside of the building site. Clash detection can also executed between a BIM model and the Building Envelope object (zone-stamp) in order to detect clashes with any height restriction imposed by authorities.

1.5.7 Communication - Collaboration

A project requires communication and collaboration between several stakeholders. Even a small building needs a designer, a structural engineer, a land surveyor, a building surveyor and a builder. The purpose of the communication is to make the information plain and explicit, and as a result the intentions of the design can be unambiguously understood (McNell et al. 2009). The design program can therefore be realised within an expected timeframe and budget. The aim of the collaboration is to perform as a team in order to create a functional, sustainable and aesthetically pleasing building.

The BIM documentation is predominantly digital data stored on various digital mass storage devices. The digitally connected teams exchange project data, models, review and mark-up documents using the Internet and local networks. The collaboration usually is an iterative process where the digital data flows back and forth as the design processes require. Each project stage of the design may be developed concurrently by different disciplines. The design information is translated to a standard data format (interoperability) acceptable within the CDE used for the particular project. The coordinated model view automatically arranges the spatial location of the objects while the hyperlinked documents allow swift navigation. If land surveyors are involved, the local coordinate system of the project can be linked to the relevant projection and datum.

A wide range of available cloud services and communication software allows solutions to be adopted that are suitable to the size and the nature of the particular project. The open BIM might offer flexible and effective collaboration environment through the life-cycle of a project (Sebastian 2010).

1.5.8 Computational Design - Algorithm Aided Design

Recent developments of architectural design increasingly rely on the capabilities of computer technology. CAD systems allow the preparation of very accurate line drawings, which were unachievable on a drafting table. The BIM environment introduces parametric objects and the building simulation. The potential next step, the Computational Design allows creation of very complex objects utilising the resources of more than one software simultaneously (Figure 12). This method opens a new field of geometric possibilities, while the result is highly optimised and the process is fast and efficient (Kotnik 2006).

Figure 12 National Stadium of Beijing Olympics; The Bird's Nest
(Source: https://c2.staticflickr.com/4/3117/2834614731_2027b9a220.jpg)

Typically a plug-in software equipped with custom made scripts and interactive GUI governing a BIM authoring software are used to execute specific tasks in order to create and optimise a series of parametric objects. The plug-in GUI usually contains a custom made network of various task-icons or process-components which act as a visual script. The data and the information flows between the software and the results of the various processes create new objects or change the parameters of existing objects. The design workflow is comparable to a series of simulations and optimisation processes.

Algorithm Aided Design (AAD) is a variation of Computational Design. It also uses scripts and GUIs that contain prefabricated and custom made process components. Within the AAD however, almost the whole building is designed via visual script. While a BIM software constructs every virtual building from scratch, step-by-step, object by object, the AAD script can be swiftly adjusted and re-used almost immediately for another similar project.

For a land surveyor, when the task is to design a difficult cut-and-fill process, or a complex setout plan, employing AAD may be an advantage. The AAD software can automatically extract the geometry of the existing terrain and the future building. The land surveyor may input the basic data as constrains and the criteria for the design, via GUIs, to a prefabricated visual script. The software package creates and optimises the design and may offer more than one solution. Finally a draft BIM documentation can be produced semi-automatically which only requires manual fine tuning and checking before submission.

1.5.9 Traceability

The BIM authoring software records and stores every single step during the entire process into a log file. In the case of a collaborative workflow, the involved hardware-, software-, user-ID, and all commands[9] are recorded in time sequence. The log files permit the execution of multiple 'undo' commands for the designer and allow monitoring of the design procedure in great detail. The log files of the entire procedure make the design process transparent and traceable. The details of the log files may help to improve design procedures and allocation of resources for the management. Besides the details of the workflow, the objects and the

[9] Mouse-clicks and keyed in commands

library elements also contain vital metadata of each of the objects. The land surveyor may attach the required metadata, survey notes and calculations to the relevant BIM terrain object.

The traceability of the BIM objects and library elements might be one of the silent achievers that will make the BIM environment welcome amongst budget sensitive management or owner-operators.

2 Aims and Objectives

Project Topic

Given the background provided in the first chapter of this report, the topic of this investigation is:

An investigation of the impacts and opportunities of BIM for land surveying.

The objectives of this report are to:

i. summarise the characteristics of BIM, the practical use of parametric objects and library elements

ii. provide an overview of the construction of a terrain object and elements of a BIM feature survey

iii. investigate the potentials of 'zoning' for land surveying purposes; the notion of customised zone-stamps such as

   a. 'Building Envelope'

   b. 'Indoor Navigation'

   c. '3D Cadastre'

iv. investigate the use of BIM environment and the 'zoning' using case studies.

3 Methodology

3.1 Literature review

The peer reviewed literature was scanned first, using Scopus, Elsevier (via UTAS library) and Google Scholar, in order to learn and understand current trends of the BIM. The search criteria was narrowed down to the topic of BIM with spatial component. Key words, BIM specific terms, abstracts and reference lists were collected and analysed for an extended research within the 'grey literature'[10], which included:

- online written documents
    - software manuals, tutorials, examples
    - professional magazines,
    - web sites of organisations and government initiatives
    - professional 'blogs'
- online video documents distributed via YouTube
    - academic video lectures
    - video recorded conferences and professional webinars
    - professional video tutorials distributed by software vendors via dedicated 'YouTube channels'
    - video lectures and tutorials by third party professionals

This literature review has informed **Chapter 1: Introduction** and **Chapter 4: Literature Review.**

[10] At this stage of the BIM development the software vendors and AEC professionals extensively use as source of the latest information the online documents (PDF) and the voice narrated, high resolution, multimedia video recordings distributed via Internet, usually on YouTube.

3.2 Simple example: virtual construction with BIM

A small example, the Garage Project was designed to display the basic characteristics of BIM among others the CDE, LOD and the IFC file format. Although the sample project is a building, the focus of the demonstration was intentionally directed toward implications of the BIM environment for terrain modelling and a possible feature survey plan. The example project was used to introduce the notion of employing 3D zone-stamps in order to incorporate specific spatial or land surveying information such as Building Envelope, and prepare a BIM feature survey model to support a future

- Indoor Navigation and
- 3D Cadastre system

These three case studies are briefly introduced below, and then described in detail in Chapters 6, 7 and 8.

3.3 Case Studies: the BIM environment for land surveying

A crossover, an addition, or a new residential building can be considered typical ‘small scale jobs’ within the AEC industry. The size and the subjects of three case studies were intentionally selected in order to demonstrate capabilities of BIM in conjunction with the sophisticated land surveying technologies within realistic and everyday conditions.

Case Study 1 (Vehicle crossover)

A minor project, a crossover to a future carport in a residential area is used to test and demonstrate:

- the visualisation capabilities of BIM in conjunction with GPS surveying and close range photogrammetry

This case study demonstrates how accurate survey data allowed precise modelling that, in conjunction with visually pleasing screen captured images, produce a convincing presentation. Seamless data transfer between file formats of the design, and the regular use of email as data transfer tool, significantly reduced design time. The 3D model helped interpretation of the flow directions of the stormwater and consequently accelerated the Development Application process, saving valuable time for stakeholders.

Case Study 2 (Addition to existing building)

The topic of this case study is an extension of an existing house. The results of a site survey were used to produce a 3D terrain model, the BIM model of the existing building and partly the surrounding buildings. The BIM model was transferred to IFC file format in order to demonstrate the capabilities of BIM viewers:

- for visualisation of the relationship between terrain, an existing building, and a future building and the Building Envelope
- to support derivation of spatial information, such as distances between surfaces or setout data in MGA from an IFC model
- for display of customised attributes, among others the direct link of BIM objects to the Internet via attached URL links.

The visualisation of the terrain and the Building Envelope objects of this case study were successfully used to clarify the spatial location issues for an actual Planning Approval process.

Case Study 3 (New residential development)

This project was used to define the elements of a possible Feature Survey procedure, including:

- the terrain model and
    - links to a map projection
    - additional survey objects, such as boundary pegs, TBM objects, attached 2D contourlines and 2D shape of the parcel
    - additional terrain objects such as a track, a driveway, a crossover, cul-de-sac, stormwater grates and channels

- the terrain model with embedded or subtracted cut-and-fill objects

- customised zone-stamps, indicative door and window objects, step objects and internal pedestrian traffic indicator objects for a possible Indoor Navigation system
- an IFC version of the model, containing parametric objects and custom built zone-stamps to support a future 3D Cadastre system.

This case study was intended to demonstrate the basic elements of a potential future BIM feature survey plan. The elements and the objects, including the customised zone-stamps of this case study contain most of the attachments and attributes that might be required by authorities and a client.

4 Literature Review

The development of BIM is rapid and driven by software vendors or organisations supported by the AEC industry. The latest information, relevant articles, papers, lectures and tutorials are predominantly published directly online, in various websites or utilising the power of the multimedia presentation via the freely available distribution services, such as YouTube. This Literature Review reflects the structure of the sources of information.

4.1 Key articles in the BIM literature

4.1.1 IFCv1.0 (Bazjanac & Crawley 1997)

The early days of interoperability between engineering software that comprised a successful transfer of a 3 dimensional model without loss of information from one software platform to another triggered a professional journal article. Although at this point of time the 3D modelling environment was called a ‘building simulation’ most of the characteristics and features of BIM were already present. The International Alliance of Interoperability (IAI) organisation and an Autodesk demonstration of interoperability in November 1996 was repeated in 1997 at the Philadelphia AEC systems Show. The model transfer used the IFCv.1.0 file format as a common data environment. The article describes a possible schema for IFCv1.5 file format and contains recommendations on how to add new objects or attributes to the existing model.

4.1.2 BIM to Building Energy Model (O’Donnell et al. 2013)

The Lawrence Berkeley National Laboratory (Berkeley Lab) managed by University of California (UC) is conducting unclassified research across a wide range of scientific disciplines. The Berkeley Lab Simulation Research Group (http://simulationresearch.lbl.gov/) specialises in the research of software systems that support the design and operations of buildings. Among others, the ‘EnergyPlus’ energy simulation software was developed in Berkeley Lab. EnergyPlus is a free and open source program which can be used to assess energy consumption for heating, cooling, ventilation, lighting and water use of a building[11]. EnergyPlus enables a 'reproducible' conversion from a BIM model to a building energy model (BEM) in order to be able to process the necessary simulations. Of note however is that, according to O'Donnell et al. (2013), the imported IFC file format BIM model had to be checked and corrected with the SOLIBRI Model Checking[12] (SMC) tool, which found hundreds of errors in the model consequently altering the results of the energy simulations. The article argues therefore that a BIM model should be checked to ensure that it is error free before an energy assessment is undertaken, preferably by a third party model checker before in-built energy evaluation modules are employed.

4.1.3 3D GIS for a mine development (Duncan & Abdul Rahman 2015)

This article, with the title "3D GIS for mine development – integrated concepts", presents a detailed description of the constrained, three-dimensional Delaunay triangulation. The results of the 3D TIN, the tetrahedrons are used for underground navigation purposes and to define the mine shafts and tunnels. Although the authors mentioned the BIM in a reference the article seems to avoid concurrent developments regarding coordinated 3D BIM objects. The use of tetrahedrons are similar to the arguments of another article (Stoter 2004) where polyhedrons were used to define 3D objects. If the definition of a complex 3D object is the subject, above or under the terrain, it seems that the coordinated models produced by the BIM authoring software might offer a suitable alternative solution.

4.1.4 Multi-Level Indoor Path Planning Method (Zlatanova et al. 2015)

Indoor navigation is a fundamental problem in a complex, multilevel urban environment. Although advanced navigation tools are commonly available between buildings, indoor navigation is governed by 2D maps and signage. This article describes the conditions of successful path planning through complex 3D building models using semantic information. A detailed CityGML model was compared to the traditional CAD model. The proposed application automatically extracts the geometrical and semantical information from the

[11] http://apps1.eere.energy.gov/buildings/energyplus/?utm_source=EnergyPlus&utm_medium=redirect&utm_campaign=EnergyPlus%2Bredirect%2B1
[12] http://www.solibri.com.au/products/solibri-model-checker?gclid=CPS87obBoMgCFVQJvAod0FcCzw

3D model and applies a path planning procedure. In order to reduce the amount of the 3D data it uses 'voxel-pillars' or segmented regions (Figure 13). A pillar represents a walkable surface area with the same semantic information. The walkable pillars are evaluated as valid or invalid neighbours. Values are attached to the pillar; the border pillar represents a higher value, while the pillars in the middle or close to the vertical exit possess lower values. The path finding iterative process is similar to a watershed algorithm: the pathway is calculated with the 'floods' from 'highest point to lowest points'(Zlatanova et al. 2015).

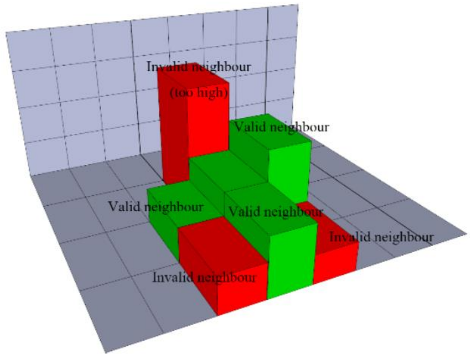


Figure 13 The "voxel-pillars" (Zlatanova et al. 2015)

The article refers to the A*-based path finding algorithm as a tool which is purposely borrowed from modern computer 3D games with navigation mesh.

The shape and the semantic information of the 'voxel-pillars' or segmented regions resembles the 3D zone-stamps used in BIM authoring software for internal navigation within a project.

4.1.5 **Utilising data modelling to understand the structure of 3D cadastres** (Aien et al. 2013)

This research paper attempts to develop a framework for implementing a 3D cadastral data model (3DCDM). The article starts by defining the 3D Cadastre. The spatial, the data management and the legal aspects are discussed in great detail. A separate section is dedicated to the requirements of the 3D cadastre from data acquisition, via accuracy and reliability, to temporal information. There is a valuable description of existing 3D cadastral initiatives before the definition of the proposed 3DCDM appears. From a land surveying point of view this proposal dedicates several separate 'classes' to land survey data, such as

- Title and ownership information (3DCDM_InterestHolder)
- Legal and physical information of 3D objects (3DCDM_PropertyObject)
- Geometrical and topological information (3DCDM_Geometry)
- Survey administrative information (3DCDM_Survey)
- Survey point information (3DCDM_SurveyPoints)

- Survey measurements and observations information (3DCDM_SurveyObservation)
- Other forms of data collection, engineering and architecture maps (3DCDM_ExternalSources) (Aien et al. 2013)

The physical information about the property is treated as objects that comprise legal and physical components. The surveying component is very detailed and the '3DCDM_Geomerty Package' reflects the CityGML data model (Figure 14).

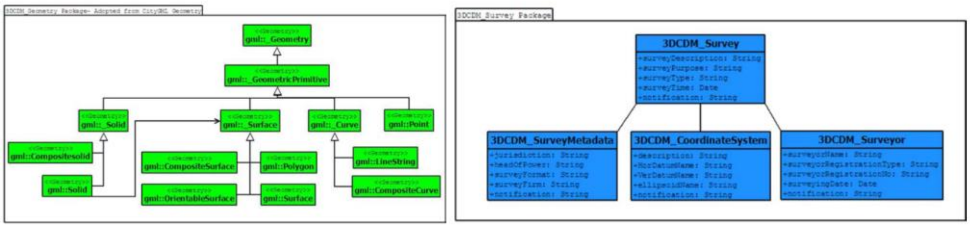


Figure 14 The Surveying component of the 3DCDM (Aien et al. 2013)

The article claims that the proposed 3DCDM integrates the aspects of the 'real world' while the other Cadastre systems are focusing on the legal component. Also, as part of the conclusions, the article suggests that the '*roles of BIM and IFC in 3D cadastral modelling require consideration'*

4.2 **Computational Design – Algorithm Aided Design**

4.2.1 Grasshopper - Rhinoceros

The Rhinoceros (Rhino) and Grasshopper software have been used for architectural design for some time. Training material[13] emphasises the importance of thinking about processes rather than learning a new design tool. While the designer utilises parametric library elements within the BIM environment, the Computational Design uses the computing capability of the computer in order to design the building. The design processes itself parametric; the building is programmed rather than virtually constructed.[14]

---

[13] There are series of tutorial material and YouTube videos available as well. The University of Northern Carolina, Charlotte (UNCC) Computational Methods course web sites (https://sites.google.com/site/unccgrasshopper/home) are a series of video-lectures, online tutorials and practicals, which cover a semester of teaching materials and are freely downloadable (2015 July). The lectures are dated from 2012, therefore some technical details might be outdated but the principles of the computational design may be a suitable starting point for an AEC professional.
[14] https://www.youtube.com/user/nsenske

The various design processes are programmed using the Grasshopper software drag-and-drop visual programming blocks or ‘components’. The ‘components’ have several input-output pins which allow the ‘components’ to be linked into a flexible network structure on the ‘canvas’. Linking or unlinking ‘components’ are in fact acts of visual programming. Every modification on the structure of the ‘components’ or on the ‘components’ are instantaneously visualised in 3D in the workspace of the Rhinoceros software. The complex network of the ‘components’, the visualised program when saved, is called the ‘definition’. There are various types of ‘components’ such as ‘buttons’, ‘toggles’, ‘swathes’ and ‘sliders’.

The results of the visual programming are parametric objects that can be saved as an IFC file from the Rhino software. The Rhino/ Grasshopper products, the purpose built parametric objects with complex geometry and the freeform parametric structures, are very popular among architects involved with large projects.

4.2.2 Grasshopper – Ecotect Analysis (Endesa Pavilion)

As it was previously mentioned, the BIM environment not only improves collaboration between AEC professionals but can be an integral part of the design-built procedure. The aim is to design a better and sustainable building, with a well organised and efficient building process. Using the BIM environment from the design to the end of the lifecycle may reduce the building cost while the product is improved.

One of the advantages of computer aided design is that the objects of the BIM model can be used for building simulation and digital fabrication as well. Already the early CAD systems running under DOS possessed solid modelling capabilities. The computer could be linked to computer numerical control milling machines (CNC) to produce complex three-dimensional shapes usually from metal. There was no need to produce 2D drawings, the milling machines were directly and digitally controlled.

The latest software developments within the BIM environment allow for digitally controlled manufacturing. Moreover the 3D model enables simulation of the design, evaluation of the result, and reshaping of the building in order to achieve optimum performance.

The Endesa Pavilion also known as the Solar House 2.0. (Holloway 2012) was commissioned as a control centre for the 2012 Smart City Expo in Barcelona (Figure 15).

Figure 15 Solar House 2.0 (Source: http://www.fubiz.net/en/2012/09/04/endesa-solar-pavilion/)

The project was supervised by the Institute for Advanced Architecture of Catalonia (IAAC). The design procedure was very similar to Multiple Criteria Decision Analysis (MCDA) available in e.g. ESRI GIS software. Multiple criteria and constrains such as the data for the sun's position throughout the year, the location, the orientation and the size of the building, the characteristics of building materials served as inputs and attractors[15] to the design process model. The design process model, in this case the Grasshopper[16] software (Quirk 2014) was directly linked to Ecotect Analyst 2011[17] which was used as a design and visualisation tool. The design process models' adjustable 'sliders', the interactive elements of the model, allow custom input by the architect (Figure 16). The façade elements of Solar House 2.0 could be treated as a prefabricated curtain wall around a building that could be customised.

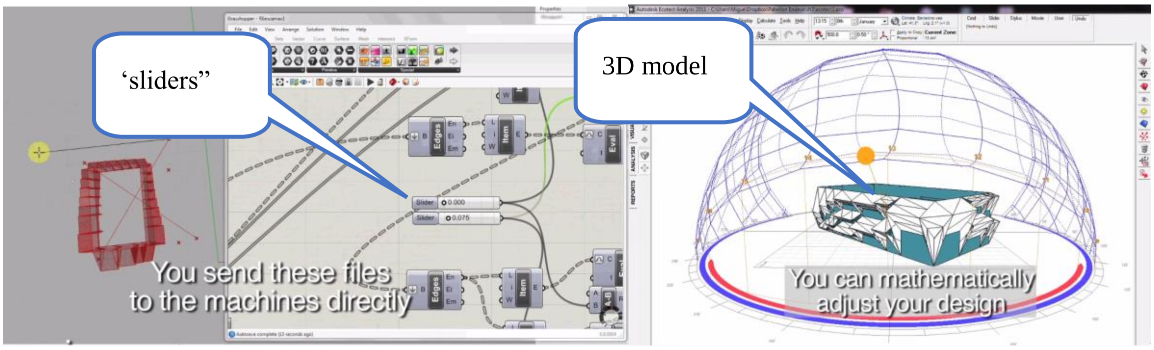


Figure 16 The Grasshopper software govern a 3D modelling software to create or optimise BIM objects. (Source: https://www.youtube.com/watch?v=3R1CBFBxuew)

[15] The 'attractor' has a similar role than a 'catalyst' which trigger and govern the reaction with its presence

[16] http://www.grasshopper3d.com/

[17] http://usa.autodesk.com/ecotect-analysis/

The design process model ‘sliders’ are capable of accommodating another, very different building shape, orientation, sun path data and redesigning the façade for that particular new building. This reusable and adjustable procedure optimises the balance between the prefabrication and the customization, which may positively influence the ROI.

The intelligence of the façade incorporated the size of the windows and their distribution, the solar panels, structural components, the energy calculations for the heating, ventilating and air conditioning (HVAC) and the lighting system. The sensors of Solar House 2.0 are constantly monitoring the energy consumption and production of the building. Every construction element serves this purpose while, due to the computerised manufacturing, the building could be almost completely prefabricated.

The façade elements were cut and prepared using computer controlled laser cutting machinery. The same elements were used as structural and shading components of the façade. The elements were assembled on site like IKEA furniture using a guide plan. This procedure requires a set-out and an onsite 3D navigation within a millimetre tolerance. The land surveyor is the professional who can execute these tasks with the required accuracy and precision. This “coded” design process model contains the idea and the solution. The model is fully three-dimensional and parametric. The code is reusable, can be distributed digitally as a product and fused into another design procedure. The aim of this intelligent design was to demonstrate that an optimal use of resources can be achieved while the building is functional and aesthetically pleasing (https://vimeo.com/46509301 , http://iaac.net/research-projects/solar-house/endesa-pavilion/ , http://www.archdaily.com/274900/endesa-pavilion-iaac).

4.2.3 FME

The Feature Manipulation Engine (FME) is a collection of data manipulation tools to convert, integrate, transform, validate and share data formats, geometry and attributes. The software supports over 300 file formats including various CAD, GIS and BIM files. The FME is intended to streamline the data conversion between various spatial, vector and alpha-numerical data. Similar to Grasshopper, the FME also uses a visual interface with various component icons such as ‘readers’, transformers’ and ‘writers’. The input data use one of the ‘reader’ components where the parameters and the attributes of the data can be filtered, adjusted or switched on or off (http://www.safe.com/). Linking the various ‘transformers’ and manipulating the parameters and attributes allows for a wide range of custom made transformations. The ‘writer’ sets the final format of the data output. Multiple ‘readers’, transformers’ and ‘writers’ can be used within a complex network (Figure 17).

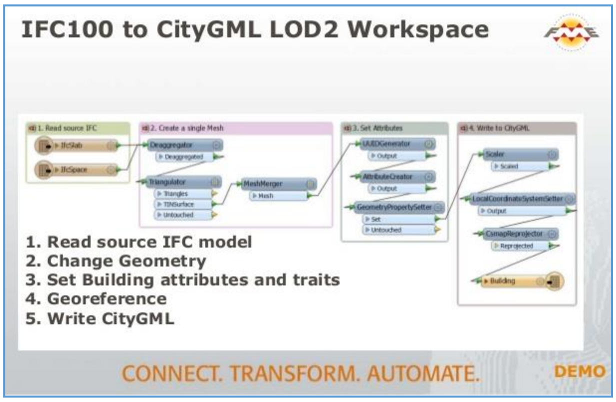


Figure 17 An IFC to GML sample model of FME software (Source: http://www.safe.com/how-it-works/)

Well-constructed FME component networks are important when CAD, GIS and BIM data from various sources have to be processed within the same project. The custom made visual model can be saved as a template for future use. The FME is a sophisticated and versatile toolset; it allows the use of predefined solutions or their swift adaptation to a new problem. The FME allows ad hoc data exchange or collaboration between different software packages and permits the automation of the workflow. Within the BIM environment, FME is used as a BIM authoring tool to create IFC objects and as a BIM-viewer to interrogate IFC objects. The flexibility of the software helps to adopt the companies to the fast changing technological environment, consequently to stay in business, without purchasing the latest editions of the CAD, GIS and BIM authoring software every year.

4.3 Potential indoor navigation tools - Nationalmuseum@

The National Museum in Stockholm used BIM authoring software to design an exhibition as an experiment to replace scaled timber-models. The BIM technician, in order to be able to collaborate with the curators of the exhibition, regularly published the actual stage in BIMx file format. Although this project was conducted at an early stage of BIM development, the curators embraced the technology almost immediately. The online magazine of the museum published the final BIMx model of the exhibition. The downloadable BIMx model enables exploration of the exhibition in 3D virtual reality (http://www.nationalmuseum.se/sv/English-startpage/Exhibitions/Past-exhibitions-/Carl-Larsson--Friends-and-Enemies/A-Tour-of-the-Exhibition-in-3D/). The BIMx enables user-friendly indoor navigation for end-users. Every art piece, even the paintings in their frames were saved as parametric 3D objects (Figure 18). Clicking on the art piece object the pop-up info-box shows all the relevant information about the particular object. For the design of the exhibition, the BIMx model was used as a collaboration tool, as a presentation tool, and the same model was used for the general public as a virtual reality exhibition model.

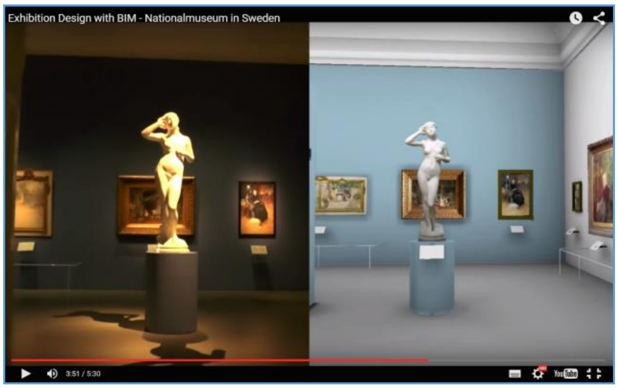


Figure 18 The left image is a photograph of the actual exhibition, the right hand screen capture image shows the BIMx virtual model (Source: https://youtu.be/wAWpckrSBxg

4.4 Return On Investment – ROI

Salih (2012) published a thesis titled “The Impact of BIM/VDC on *Return On Investment* (ROI)”. The thesis provides a comprehensive description of the BIM environment from basic definitions to details of the parametric object technology. One chapter is dedicated to the importance of collaborative meetings and presentations. Dozens of tables present detailed budget data for several case studies. According to the paper, implementation of a BIM should yield between 2% and 3% savings from the total costs of a project. While some of the figures can be interpreted only within the Scandinavian situation, the overall conclusions and the figures provided in percentages can be considered as usable and indicative information about the influence of BIM over the ROI.

Another author (Davis 2013a) analyses and compares the costs of design decisions with the various design procedures, and refers to a graph called the ‘MacLeamy’s Curve’ (Davis 2013a). The origin of the ‘MacLeamy’s Curve’ is the Paulson’s curve which tries to describe the ‘level of influences’ on the cumulative costs within the life cycle of a construction project.

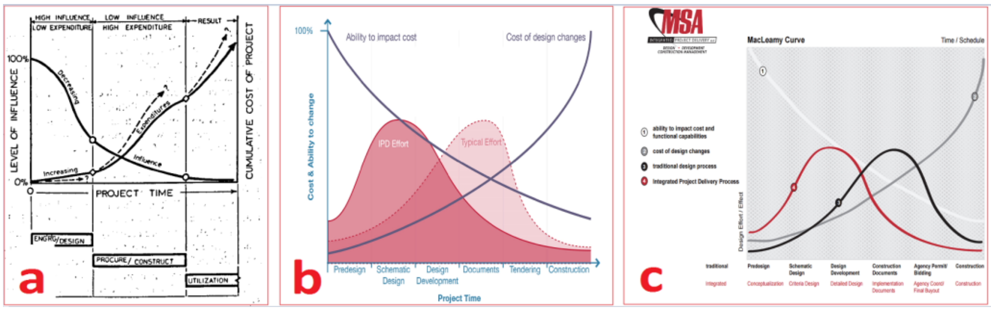
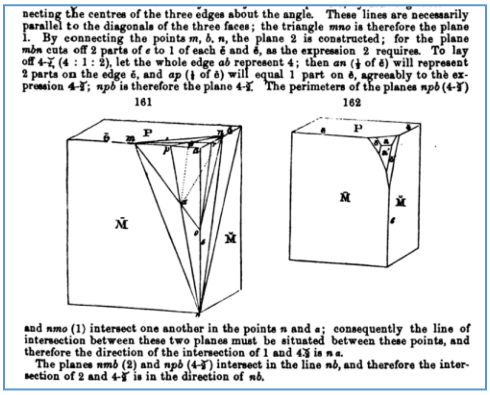


Figure 19 MacLeamy’s Curve illustrates the advantages of Integrated Project Delivery (Sources: a./ Paulson’s Curve (Paulson Jr. 1976) b./ MacLeamy’s Curve (Davis 2013a) *c./ http://www.msa-ipd.com/MacleamyCurve.pdf*

Paulson’s (1976) finding emphasised the ‘tremendous’ impacts of the design decisions on the construction and operating costs. Similar conclusions were drawn by MacLeamy, who was one of the founders of buildingSMART International and the AEC industry (Davis 2013). The MacLeamy’s Curve is widely used to demonstrate the shift of effort from the construction phase toward the design phase within a project in order to prove the usefulness of relocated resources required within BIM environment (Ryan 2014).

4.5 Parametric objects

The term of *'parametric'* originates from the science of mathematics. According to an article published directly on the internet (Davis 2013b) the term 'parametric planes on prism' was used already in 1837 to describe crystals and provisions for their variations (Figure 20).


necting the centres of the three edges about the angle. These lines are necessarily parallel to the diagonals of the three faces; the triangle *mno* is therefore the plane 1. By connecting the points *m*, *b*, *n*, the plane 2 is constructed; for the plane *mbn* cuts off 2 parts of *e* to 1 of each ĕ and ė, as the expression 2 requires. To lay off 4-ž (4 : 1 : 2), let the whole edge *ab* represent 4; then *an* (½ of ĕ) will represent 2 parts on the edge ĕ, and *ap* (¼ of ė) will equal 1 part on ė, agreeably to the expression 4-ž; *npb* is therefore the plane 4-ž. The perimeters of the planes *npb* (4-ž)

and *nmo* (1) intersect one another in the points *n* and *a*; consequently the line of intersection between these two planes must be situated between these points, and therefore the direction of the intersection of 1 and 4-ž is *n a*.
The planes *nmb* (2) and *npb* (4-ž) intersect in the line *nb*, and therefore the intersection of 2 and 4-ž is in the direction of *nb*.

Figure 20 Impact of changing the edge chamfer ratio. Instances of James Dana's crystal drawings. The original paper was published in 1837. This figure was copied from a later edition. (Dana 1854)

The article (Davis 2013b) also cites a possible parametric equation of a catenary curve as a sample to describe the role of parameters when geometry is determined :

$$x(a,t) = t$$
$$y(a,t) = a \cosh\left(\frac{t}{a}\right)$$

"The first equations set quantities, in this case 'x' and 'y' in terms of a number of parameters:

'a' *controls the shape of the curve*

't' *controls where along the curve the point occurs*

The outcomes; 'x' and 'y' are related to the parameters 'a' and 't' through explicit functions. This is the origin of the term parametric: a set of quantities expressed as an explicit function of a number of parameters" (Davis 2013b).

The article also refers to the writings of Moretti[18] , who created a special organisation in 1957 to study the possible uses of *Parametric Architecture*[19]. Some architectural models

[18] Luigi Moretti: Works and Writings (http://www.angusrobertson.com.au/books/luigi-moretti-bucci-marco-mulazzani-federico-bucci/p/9781568983066) note: L. Moretti was the architect of the infamous WATERGATE complex in Washington.
[19] Instituto Nazionale per la Ricerca Matematica e Operativa per l'Urbanismo (IRMOU)

originated from this institute and Moretti's publications were exhibited at the XII Triennale di Milano in 1960, when this movement achieved its peak. Although the earlier design software, 'Sketchpad' (Sutherland 1963) resembling the 3D parametric object creation procedure was demonstrated three years later the practical use of 3D parametric objects in the architecture has begun only in the 21st century (1.1).

4.6 YouTube Tutorials / Workshops

The YouTube video-sharing web site, founded in 2005, plays an increasing role in education. According to Oxford graduated TED[20] curator C. Anderson the online video tutorials created the "*biggest learning cycle in human history*" (https://www.ted.com/talks/chris_anderson_how_web_video_powers_global_innovation). The 'Khan Academy' YouTube channel was named "*the largest school in the world*" by Forbes (Noer 2012). The Khan Academy is partnered with NASA, California Academy of Sciences and MIT to publish tutorial videos of maths, science, computer programming and history (https://www.khanacademy.org/about). The tutorials usually simulate a one-on-one teaching session with a tutor, where the content of the lesson can be repeated again and again. Universities swiftly adopted the idea of online lectures and unlikely popular superstars such as Walter Lewin, Professor of Physics at MIT (Clark 2008) emerged.

The significance of this media has been recognised by the AEC industry participants. Every noteworthy software vendor maintains YouTube channels in order to distribute information about their latest developments. The videos are organised by YouTube into 'channels' according to their subjects. The physical appearance of a video-channel is designed and updated by YouTube and looks almost identical (Figure 21).

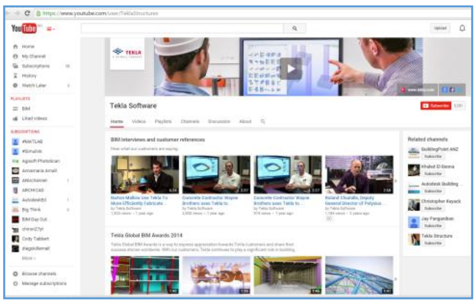


Figure 21 TEKLA software tutorials on YouTube (Source: https://www.youtube.com/user/TeklaStructures)

[20] Technology, Entertainment and Design –TED (https://www.ted.com/about/our-organization)

The following list contains a few examples of the available YouTube channels which can be considered as relevant information sources for this report.

4.6.1 B1M

"BIM one million" (B1M) is an online resource channel for building information modelling launched at 2001 in the UK (http://www.theb1m.com). The company maintains several YouTube video channels and propagates its content in the social media web sites (https://www.youtube.com/user/TheB1MLtd/dfeatured). B1M claims to be watched in close to 150 countries around the world (Mills & Payne 2015). The short videos explain the most important aspects and latest developments in the BIM environment. A series of university lectures are recorded and published on the YouTube B1M-University channel which is supported by four UK universities (http://www.theb1m.com/b1m-university). B1M is a valuable source of information about the latest developments of the BIM.

4.6.2 ArchiCAD (Architectural BIM authoring software)

GraphiSoft maintains a YouTube channel for its product, the ArchiCAD software (https://www.youtube.com/user/Archicad/featured). ArchiCAD is updated every year and the tutorials of each release are published on YouTube. Video interviews are published regularly with 'great architects'. A series of third party video tutorials contain over 25 hours of live video recordings. These include:

- "*Lectures of Z. Egginton*[21]" (https://www.youtube.com/playlist?list=PLnXY6vLUwlWXU-TpC0x9TtRE6h8W3qg0z),
- "*Basic Training from E. Bobrow*[22] (https://www.youtube.com/user/EricBobrow)
- "*ArchiCAD Tips - Shoegnome*" (https://www.youtube.com/user/ShoegnomeLLC)

[21] Unitec Institute of Technology in Auckland, New Zealand.
[22] Over 2 million views

4.6.3 REVIT (Architectural BIM authoring software)

The Autodesk software vendor's YouTube channel is called Autodesk Building Solutions (https://www.youtube.com/user/AutodeskBuilding). Similar to ArchiCAD the channel offers a wide range of lectures from software vendor and third party sources. The channel called 'AutodeskEd' (https://www.youtube.com/user/AutodeskEd) is dedicated to basic education for potential customers of Autodesk.

4.6.4 TEKLA –Trimble (Structural Engineering BIM authoring software)

TEKLA was founded in 1966 in Finland as an advanced engineering and automatic data processing software company specialising in structural engineering and road building (http://www.tekla.com/company/about). In the late 1980s TEKLA successfully combined the geometry of structures with a relational database and has become the frontrunner among the modern digital structural engineering software companies. By 2013 the company had sold close to twenty thousand licences globally, merged with TRIMBLE, and become a technological driving force behind the BIM environment. The TEKLA 'BIMsight' free viewer created a new breed of software which enables utilisation of the benefits if BIM for a wide range of users who do not possess highly specialised authoring software licences. TEKLA claims that over 8 million BIM models have recently been opened and investigated using 'BIMsight' alone. The 'BIMsight' supports Windows, IOS and Android tablets and interactive smart-boards[23] with touch detection for corporate presentations.

TEKLA use the YouTube video format extensively to promote its software solutions and distribute tutorials and help-materials (https://www.youtube.com/user/TeklaStructures). Literally hundreds of YouTube videos and tutorials are available in order to explain every aspect of the functions and the workflow of the various TEKLA software. The "Learn more" site contains very detailed explanation (http://www.teklabimsight.com/learn-more/what-is-tekla-bimsight) of the BIM environment and the role of the free viewers which, according the website were downloaded by close to two hundred thousand users. A series of intuitive web pages are dedicated to explain the benefits of BIM in general, and the advantages of TEKLA solutions within the BIM environment (http://www.teklabimsight.com/what-bim).

[23] Digital whiteboard

4.6.5 FME - Safe Software Seminars

Safe Software (4.2.3) regularly produces video tutorials and software seminars published on YouTube FME Channel about various issues regarding data translations and integrations. In one of the numerous available presentations about BIM *(https://youtu.be/YUfCAxPlJzE 26 Aug 2015<18 min)* the guest presenter, A. Karman, talks about an experiment, a new method to extend CityGML with 'embedded semantic links'; in other words URLs[24] of the Internet. The intention is to add additional data to CityGML without a dramatic increase of the file size. The hyperlinked CityGML dataset therefore will be able to utilise the power of the search engines and the available data offered by the World Wide Web. The solution, the hyperlinked documents stored in cloud services is very similar to the solutions already used within the BIM environment. While current BIM solutions are intended to use on the scale of a project, the hyperlinked CityGML elevates this solution to the level of a city. In the second half of the same YouTube seminar the director of DBI Architects Inc. talks about a study related to a collapsed bridge in Minneapolis (https://youtu.be/osocGiofdvc). As part of the investigation, the I35W Bridge was reconstructed as a virtual model in Revit software. The BIM environment and the use of the FME software allowed attaching a large amount of data from various sources in an organised and structured manner. The searchable dataset greatly helped to establish the cause of the collapse and the sequence of events which leaded to the catastrophe. Since the FME software supports over 300 file formats (http://www.safe.com/fme/format-search/#!) the amount of material discussed and the lengths of the video seminars are constantly growing.

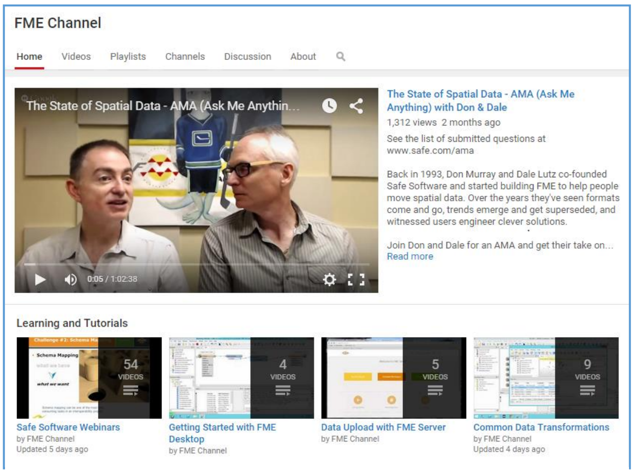


Figure 22 FME channel on YouTube (Source: https://www.youtube.com/user/FMEchannel)

[24] Uniform Resource Identifier (URL) a generic term for names and addresses to refer objects on World Wide Web (WWW)

4.6.6 DDS – MEP

Data Design System (DDS) originates from Norway and is one of the early pioneers of BIM, specialising in the fields of Mechanical, Electrical and Plumbing design (MEP) (http://www.dds-cad.net/company/). Since 2013, similarly to ArchiCAD, the company operates under the flag of NEMETSHEK Group software vendor. In addition to the MEP software modules the Photovoltaic (PV) software is specialised to design, simulate and visualise solar panel grids. The DDS free model viewer is designed to review, convert and print Open BIM projects in IFC, BCF, gbXML, DWG, DXF and VEC file formats.

Particular strengths of the DDS-MEP are specialised methods to convert the relevant 2D CAD data into a BIM model. The conversion is semi-automatic (machine reading), the software recognises materials, walls, doors and windows and applies zone stamps while creating the BIM model. The machine reading capabilities allow production of various pre-set and customised reports and a bill of quantities for the building features or for the designed MEP elements (http://www.dds-cad.net/downloads/product-information/). The company extensively uses the video tutorials on its home page and possesses a dedicated YouTube channel, using several languages. (https://www.youtube.com/channel/UC3A308JIBFYB6zAPe9QSEhg).

4.6.7 Intelligent BIM Solutions TV

The Intelligent BIM Solutions TV is an online video magazine, specialised on the subject of BIM (https://www.youtube.com/channel/UCmX8YsA9q8_coA7VlEWV6WQ). The channel promotes the BIM forums and solutions in general and several BIM software such as Elite Cad, Lumion, DDS, Solibri, VICO and IESVE in particular.

The Elite CAD sub-channel published a BIM terrain module in Aug 2015 (https://www.youtube.com/watch?v=_K1ZJ7P5WfQ). This module includes semi-automatic 'Cut-and-Fill' and 'Road-alignment' capabilities within the BIM environment. Although it seems that the module was programmed for architects, it can calculate volumes and produce parametric terrain objects very efficiently. The modelling tools however cannot deal with data registration and validation, therefore at this stage the results would need to be saved in IFC file format and sent to a land surveyor to finalise the design.

4.6.8 Rhino - Grasshopper / 3rd party video lectures

Jeremy Roh, lecturer at University of North Carolina (UNC) is regularly publishing BIM and computational design (Rhino, Grasshopper, Revit) lectures and seminars on his YouTube channel (https://www.youtube.com/user/zedjr01). The site contains over 10 playlists, among others the playlist for a unit called Computational Practice (Spring 2015) that alone contains 48 video lectures. An attached website, the BIM methods, is a wide-ranging resource library of various tutorials, papers and URL addresses about the BIM environment and computational design methods (http://www.jrohdesign.com/revit/index.html). The summary of experiments to merge the American family house design with the latest design technologies has been published as an e-book[25].

Nick Senske is an Assistant Professor at Iowa State University who also publishes his lectures on his YouTube channel (https://www.youtube.com/user/nsenske/playlists). Similar to J. Roh, the video tutorials regarding the practical use of Rhino-Grasshopper software can be a valuable resource for online learning of the computational design methods.

25 http://www.lulu.com/shop/jeremy-roh/computerizing-an-architectural-design-process-toward-the-development-of-unique-variations-for-the-american-home/ebook/product-17482601.html

4.7 **Blogs**

Every software manufacturer maintains various user group discussion or chat sites. With the time most of these web pages transformed into a better structured and moderated frequently asked questions (FAQ) web site. Some social media channels and specialised blogs however produced a relaxed environment to share professional experiences and knowledge.

4.7.1 Geometry Gym

Geometry Gym is a private initiative to provide and support Open BIM software tools for the building industry professional (https://geometrygym.wordpress.com/). The author, Jon Mirtschin, was born in Australia and graduated at the University of Melbourne. In 2005 he moved to London developing Open BIM tools and plugins for designers and engineers. The website contains several submenus, such as the BLOG and the DOWNLOADS chapters. The BLOG is as a collection of Open BIM online publications that provide news, descriptions and downloadable samples of computational geometry, together with accounts of recent BIM related projects (http://geometrygym.blogspot.com.au/). Regular 'Geometry Gym' sample projects-posts are also published in the form of a blog. Well organised sub-chapters, hyperlinked tags and lists of "Related Links" support the BLOG. The archive is searchable from 2009. The DOWNLOAD chapter contains a collection of links to valuable utilities and plugins, mainly for Rhino, Grasshopper, Revit, TEKLA and OASYS-GSA software. The FORUM submenu is directly linked to a web site specialised for Grasshopper - software user group (http://www.grasshopper3d.com/group/geometrygym).

4.7.2 Shoegnome

One of the most active bloggers related to the ArchiCAD BIM authoring software runs a blog called "Shoegnome". The author, Jared Banks is a licenced architect in the State of Washington and Minnesota (http://www.shoegnome.com/aboutv1). The blog discusses the everyday life of a BIM architect in a great detail and additionally provides a valuable collection of resources, samples and templates for projects using ArchiCAD software (http://www.shoegnome.com/archicad/ Although the tone of the blog is almost always personal the published technological details describe problems and the solutions on a professional level. The blog has its own YouTube channel with close to one hundred videos, which address the most "wanted" practical ArchiCAD tips tailored for architects working in small offices (https://www.youtube.com/user/ShoegnomeLLC).

4.7.3 bimwise

Allan Wise is a Hobart based specialist in modelling structural BIM models. His expertise is utilised Australia wide; among others he was the lead modeller at the beginning of the design of the 'One Central Park' in Sydney (http://www.bimwise.com/2014/11/ctbuh-names-one-central-park-best-tall.html). The 'One Central Park' project was awarded the *"Best Tall Building Worldwide"* title from 88 entries in 2014 (http://www.archdaily.com/565799/ctbuh-names-one-central-park-best-tall-building-worldwide-for-2014/). The Blog contains of the latest news about BIM in general and the REVIT external library elements in detail (http://www.bimwise.com/p/free-revit-families.html). It is an uplifting experience to see how an expert knowledge of BIM in conjunction with the Internet can positively influence the professional career of a person.

5 Virtual Construction with BIM

A building design usually consists of the future building, the terrain within the title, and all the existing or designed objects on or under the building site. The existing and the future buildings are compositions of various building elements. The building elements and even the terrain can be considered to be three-dimensional objects. The BIM environment allows the creation and storage of large virtual objects, such as buildings and the terrain, in complete detail and with great efficiency. A building may contain a large number and variety of 3D elements. Typical and third party parametric objects (elements) are stored in libraries, which is usually a module of the software. Although custom made building elements are created individually, the BIM authoring software engine accelerates the process using semi-automatic modules and GUIs. The product, the group of coordinated parametric objects, can be considered to be a virtual representation of a project. Although each software use its own proprietary file format, all use the parametric objects and the BIM model can be translated into the commonly used IFC file format (5.7.3).

For this investigation, a small project was created to demonstrate the capabilities of the BIM environment and the implication of the processes. The 'Garage Project' starts with the construction of a small virtual building in the BIM environment. The aim is to clarify the use of the customised internal library elements, and the use of parametric objects in general, before the custom made parametric object, the formation of a 3D terrain is described. The next chapter establishes the notion of a BIM survey plan and the potential of the customised BIM objects ('zone-stamps') as a possible tool to link the BIM environment to Indoor Navigation and 3D Cadastre.

5.1 Crafting three-dimensional virtual objects

Traditional CAD software uses points, lines, distances and angles in order to produce a drawing. Two points create a line, while three points can create a triangle or a circle. The area within three points can be considered as a surface. Although the points are located within a three-dimensional virtual Cartesian coordinate system, CAD software typically simulates 2D drafting. The three-dimensional vectors are projected to a plane, the virtual drawing sheet.

BIM authoring software is equipped with all the capabilities of the CAD systems, but the focus is on the three-dimensional representation of the project. Closed polylines and operations such as ‘extrude’ or ‘revolve’ are capable of creating complex three-dimensional virtual objects (Figure 23). Extrusion is a process widely used in the manufacturing industry, in which an object from a fixed cross section is created (Tennety 2007). Polylines can be virtually extruded along a straight, curved line or spline. The digital extrude can be more elaborate, as it can also be executed in an angle where the extruded object can form an expanding or decreasing shape (Hodgson 2008).

The ‘revolve’ operation is rotating (sweeping) a polyline around an axis to a certain angle or full circle in order to create the object. The polyline and the axis have no ‘width’ – they are infinitely thin. A closed polyline, similar to the ‘extrude’ operation, can be a composite of straight and curved lines and the splines. When the axis of the rotation falls outside of the polygon a hollow object is created.

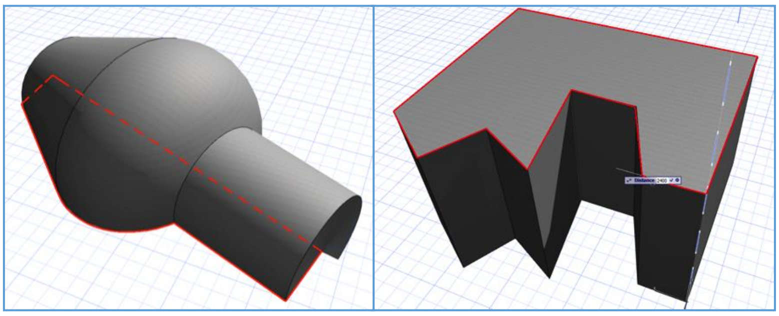


Figure 23 Creating objects with ‘revolve’ or ‘extrude’ operation using closed polylines

Objects can be united and subtracted from each other or an intersection can be created. The use of three-dimensional Boolean operations allows single objects with remarkably complex geometry to be built (Figure 24). The result of the object constructed using 3D Boolean operations is often called a 'morph'. Forming a complex 'morph' object can be an advantage when a model has to be positioned in an angle uniformly, such as illustrated below with the Leaning Tower of Pisa.

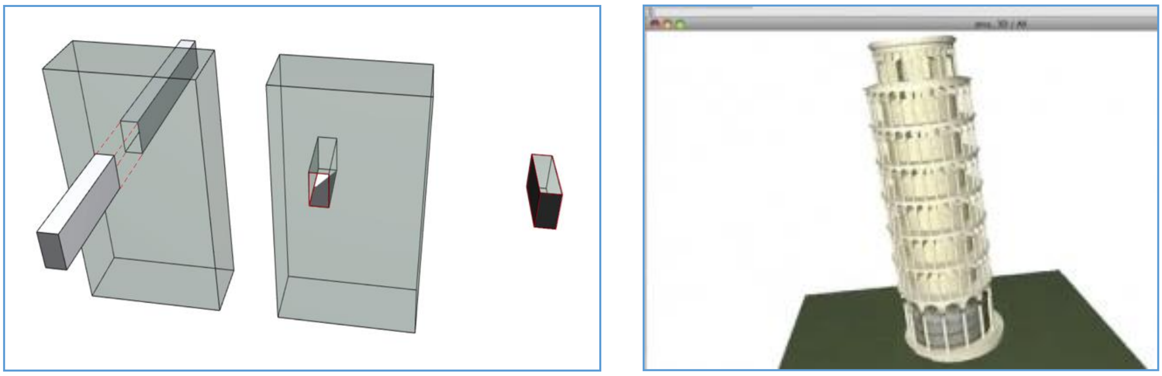


Figure 24 Solid operations: 'union', 'subtraction' and 'intersection' ,
The Leaning Tower of Pisa was reconstructed virtually in 2012 with the extensive use of solid modelling operations. (Source: https://youtu.be/CwLvGpRT11I)

The 'morph' is usually visualised as a 'shaded' or colour-coded element. When the object is highlighted (selected) it reveals the critical geometrical elements of the surface, the 'nodes' (Figure 25). Nodes can be added manually on any point of the surface. Clicking the nodes will trigger an information 'callout' box with the spatial coordinates and the layer information of that particular node. It also activates a series of tools which allow manual customisation or 'fine-tuning' of the object. Similar to the library elements, it is possible to wrap the surface of the morphs with colours or photo-realistic images. Highlighting the morphs may also trigger the attribute setting GUI in order to add or customise attributes of the object.

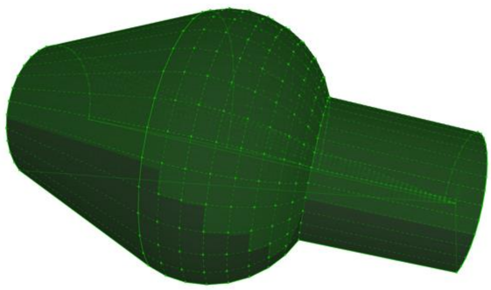


Figure 25 A 'highlighted' object (Plotted by: F. Acs)

The 'morph' can be decomposed into surface lines and points or faces, edges and vertices consequently the model seems to be hollow. The objects are also represented with infinite thin surfaces. The model in this case is bounded by its surface and has an interior and an exterior. The surface of the solid model is composed of faces, edges and line segments. Quite often this boundary representation (B-rep) is called a simplified or 'light' representation of the BIM model. The B-rep describes the geometry and the surface properties but does not contain most of the attached attributes which are normally an integral part of a BIM model. The communication and data exchange with software, which is implemented in Geographic Markup Language (GML) such as CityGML often require surface type geometric representation (El-Mekawy & Östman 2010). The TIN surface produced by professional land surveying software or the DEM surface produced by GIS software can be considered as a surface representation of the 3D model.

The Boolean operations in combination with the parametric objects allow a semi-automatic workflow for certain design procedures. The project can be 'coded' in order to find a suitable design solution, using a series of simulations such as Monte Carlo simulation (4.2.1). Certain complex building elements can also be designed interactively, using more than one specialised software (Figure 26). It is possible therefore to apply a 'what-if' scenario to the design procedure using, for example, an architectural and a structural engineering BIM authoring software in tandem (1.5.8).

Figure 26 The Rhino and Grasshopper software were used to demonstrate the 'coded' modelling of a 3D tessellation, which was completed just in 27 seconds. The Beijing Watercube Olympic swimming stadium is an example using this geometry.

(Source: J. Mirtschin http://geometrygym.blogspot.com.au/search?q=watercube).

5.2 Constructing a BIM of a building

Even a simple building design, such as a garage, typically starts with a preliminary floor plan. The designer, who already has a concept about the future building, selects the appropriate wall type from the BIM authoring software internal library. The default settings can be customised using the interactive GUIs (Figure 27). The geometry of the designed wall object is created by the software using the 'extrude' operation. The predetermined wall layers and geometrically rectangle shaped polylines are extruded horizontally.

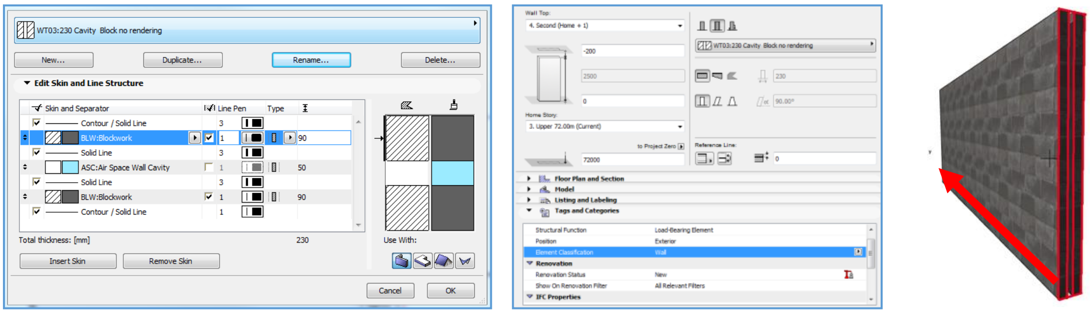


Figure 27 Interactive GUIs determine the wall object. The composite wall (cavity wall) object is automatically wrapped with the photorealistic image of the blockwork. (Source: GraphiSoft – ArchiCAD 19 composite object setting GUIs)

The same horizontal 'extrude' operation is used to create the geometry of the footings and the beams. The roof is also a horizontally extruded composite element which is rotated along a horizontal axis with the angle of the pitch. A floor profile is usually determined by the surrounding walls, therefore a floor object is the result of a vertical extrusion of the floor perimeter. Extrusion can be executed along a curved path as well. These operations are executed in the background, the designer just has to select the suitable library element and determine the desired length or height with simple mouse clicks.

When a complex library element such as a garage door is embedded into a wall, the object automatically cuts the required opening. (Figure 28). At the same time the parameters and properties such as volume, surface and geometry are automatically adjusted. This solid modelling operation is called a 'subtraction'. The garage door object,

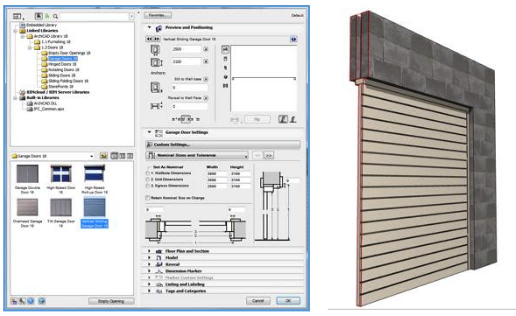


Figure 28 Garage door library element embedded into a composite wall (Source: ArchiCAD 19 Door setting GUI)

which is itself a group of nested parametric objects, contains a hidden element with the geometrical properties of the wall opening required by the garage door. This hidden element is subtracted from the wall element before the door object is embedded to its place.

The model of a future building can be 'sliced'; in other words, sections can be produced (Figure 29). The section module of the BIM authoring software creates traditional sections and can produce and visualise 3D sections of the model. Traditional floor plans (in standard scale) combined with three-dimensional perspective sketches are powerful visual aids and feedback for the designers.

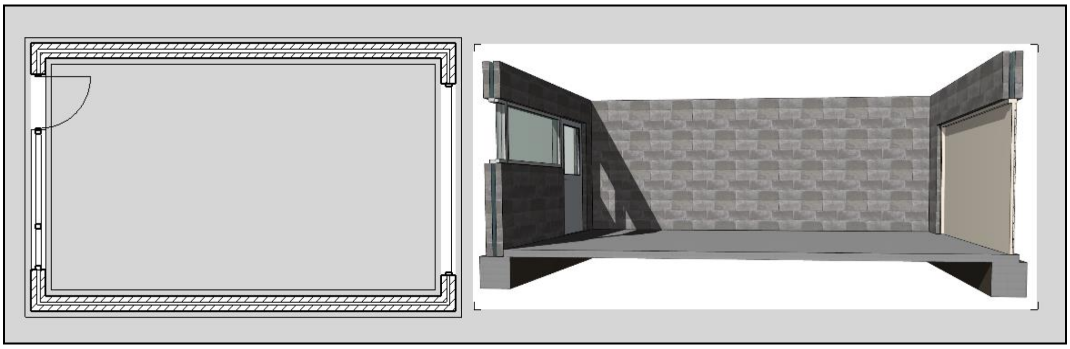


Figure 29 Preliminary design sketches of a Garage-project; a traditional floor plan and a slice of the model in perspective projection (Created by: F. Acs)

Complex operations are coded into interactive design-modules such as the roof maker. The modules accelerate the design procedure when a sequence of standard operations is required. The roof maker module, in this example, created the roof layout plan, the rafters, a rafter layout and the 3D visualisation sketch within seconds (Figure 30). The module requires the definition of the layout of the roof, which in this case can be obtained by a mouse click to each of the four outside corners of the garage. As a result a pop-up GUI offers the default setting of a standard timber roof structure.

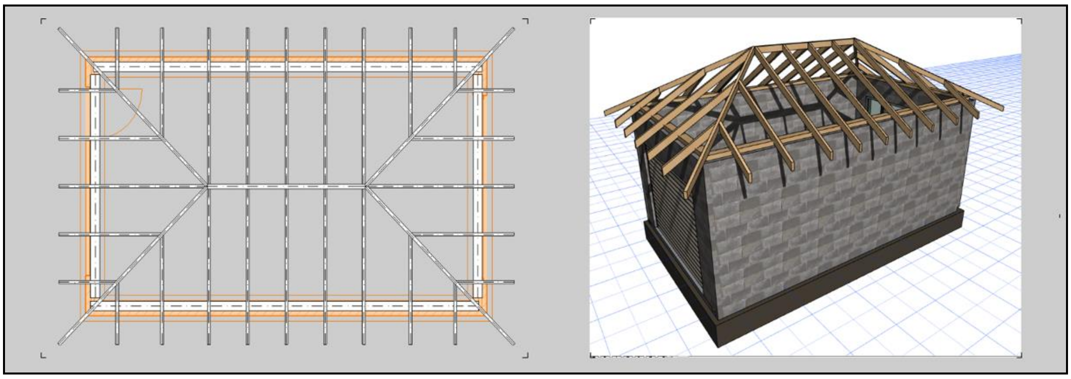


Figure 30 Preliminary design sketches of a Garage-project; a traditional roof structure layout and a model in perspective projection (Created by: F. Acs)

The parameters, such as roof pitch, overhang, or rafter sizes and the structural layout can be modified if required. The module constructs a typical pitch roof from library objects almost instantaneously. The roof can be adjusted or modified later from the 3D window. In the meantime, the software produces a detailed bill of quantity, and records every step of the design into a log file. The virtual construction of a building where the design modules can be applied is a rapid procedure. User-friendly 3D visualisation allows the designer to concentrate on design solutions rather than the construction itself. In a preliminary sketch, such as the Garage-project design sketch described above, all the building elements such as the walls, the garage door, the windows or the roof structure can be linked with the local building material supplier's available stocks. Consequently even a preliminary budget estimate can be a reliable document.

The level of information (LOI) derived or attached from the BIM model, such as project details, the bill of quantity, the budget estimate and attached attributes can be adjusted and customised. The different stages of the design procedure require different levels of development (LOD) of the objects (Lymath 2014). The LOI and the LOD is governed by the requirement of the project and the recommended industrial BIM standards. In Australia the Australian National Building Specification System; the NATSPEC-BIM (bim.natspec.org) gives guidelines for the designers (Natspec 2011; TAS-Dept-of-Health-and-Human_Services 2014).

Various BIM authoring software may use a different software-engine, programmed for building design purposes. Although the emphasis of certain procedures and terminology used may different, the product and the parametric-objects are handled similarly. Moreover, while some software such as ArchiCAD may use terms familiar for EU designers, REVIT, which is a US product, uses an American vocabulary. There are numerous globally publicised initiatives, and there are directives produced by the UK government, which has its own BIM dialect. This report uses mainly the GraphiSoft products for demonstration purposes and quite often follows the terminology of UK resources.

5.3 Creating a BIM terrain model

The shape of a future building is influenced by the terrain of the building site. The map of the terrain is a result of a feature survey conducted by a land surveyor. A typical feature survey drawing describes the lengths and the bearings of the boundaries, contains the contour lines of the terrain and the relevant features of the site such as easements, major trees, driveways, footpaths, existing man-made objects and services. The feature survey observations are usually processed using professional surveying software. Commonly used surveying software such as LISCAD are at this point of time (June 2015) not equipped with tools to export the 3D model into a BIM compatible file format such as IFC.

A Feature Survey Plan of a small residential building is typically transferred via e-mail in DWG[26] and PDF file formats (Figure 31). In the following example, architectural BIM software was used to re-create the terrain into BIM a compatible model.

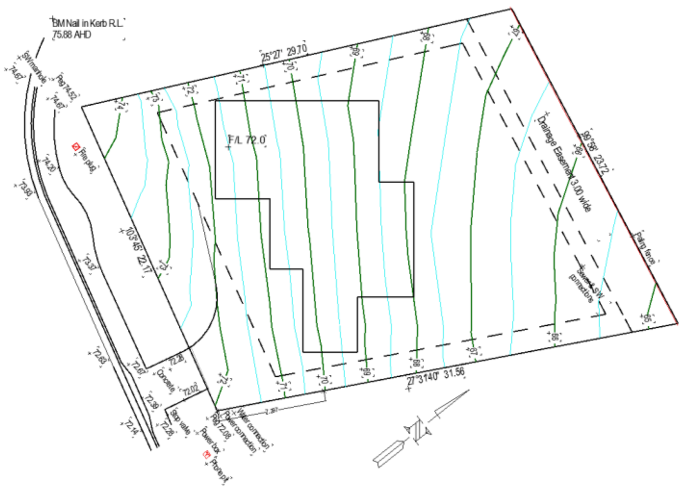


Figure 31 A typical Feature and Level Survey Plan received from the land surveyor in DWG and PDF file formats (Drafted by: F. Acs)

The DWG file format of the received Feature Survey Plan should be merged first into the BIM authoring software AHD layer[27]. The origin of the BIM authoring software is to be set to coincide with the given TBM. The coordinates of the location are set in the Projection Settings GUI.

[26] DWG (drawing) is a proprietary file format of Autodesk, widely used for file exchange between CAD software platforms

[27] The height value of the AHD level is zero.

The terrain is created using the vertical ‘extrude’ operation. In some software, such as ArchiCAD, the mesh-module is used to create the terrain. First a flat terrain, a parametric object shaped to follow the boundary lines, is placed onto the AHD layer of the project. This object should be located and registered on the top of the polylines representing the contour lines.

A series of vertices (nodes) can semi-automatically be created along the selected contour line with a single mouse click on the surface of the flat terrain object. The actual AHD height value is added to the freshly created and highlighted vertices. Consequently the active vertices along the contour line are vertically ‘extruded’ (or ‘elevated’) to the given height. At the same time the 3D terrain object surface is automatically recalculated and adjusted to the given height, while the rest of the surface and the vertices remain intact. This procedure has to be repeated one by one at every contour line. The 3D model of the terrain is re-created from the 2D drawing when all contour lines (series of vertices) are completed.

The terrain model surface in this example is colour coded with green while the series of vertices, including the contour line vertices, with red. A vertex represents a point on the surface with an AHD height value. A contour line is represented by a dense chain of points with the same height (Figure 32). The light-blue mesh indicates a nominated AHD height level, the grid of the mesh indicates the scale and is used as an aid for the designer.

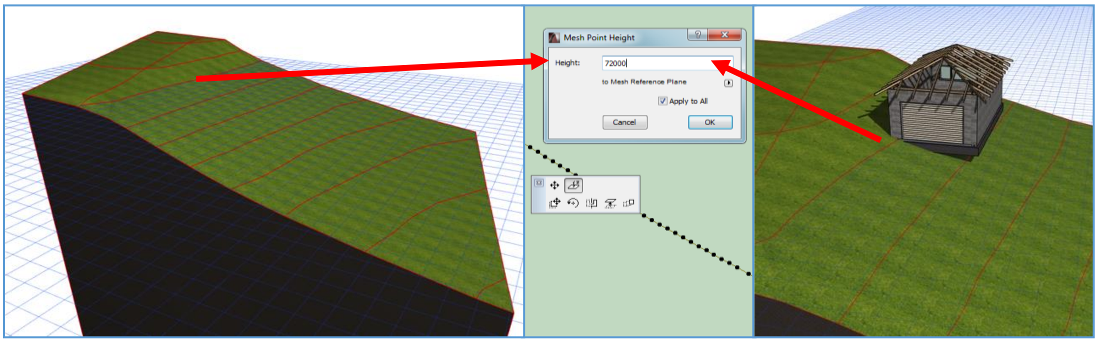


Figure 32 The terrain of the example building site was created using an architectural BIM authoring software. The 3D sketch of the Garage-project is placed in the intended position. The elevation values are shown or edited in the pop-up window. (Created by: F. Acs)

Although the 3D terrain model mentioned above is a parametric object, it is yet to be equipped with the attributes and additional elements which are expected from a proper BIM model. At this stage of LOD, however, it can be used for design and visualisation purposes. It should nevertheless contain the surveyed features on the site, such as boundary pegs, TBM, existing driveways, fences, significant trees, services and easements as parametric objects.

As a general rule a Feature Survey Plan model should be a product of a BIM authoring software tailored for land surveyors.

For practical reasons, the completed 3D terrain model is archived in a ‘hidden and frozen’ layer. A copy of the terrain model, in a different layer, is used for further development in order to accommodate the necessary ‘Cut and Fill’ modifications and the new features.

The ‘Cut’ technically is a ‘subtraction’, where a purpose built parametric object is subtracted from the terrain model (Figure 33). An entirely new object is created and used for ‘Fill’. For volume calculation the results of ‘intersection’ operations are stored on a dedicated layer (5.1). When all the modifications are executed and the new objects, such as the building, retaining walls and driveways are added, then the result is a Site Plan in 3D.

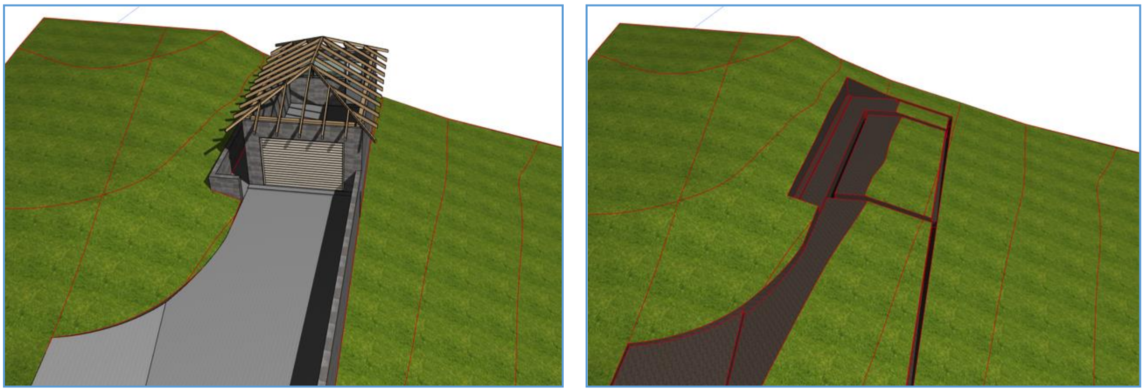


Figure 33 The 3D sketches illustrate the terrain, the future building and the possible Cut and Fill areas of this particular garage design variation. The design-sketch can be zoomed in on and out of, rotated and modified in the 3D window while all dimensions or parametric object properties are accessible on the fly. (Created by: F. Acs)

Conventionally a TIN surface is produced using land-surveying software such as Liscad. The TIN surface is composed of well-conditioned Delaunay triangles, where each triangular surface has a clear aspect (Figure 34). The BIM authoring software uses the points along the contour lines to form a surface (Figure 35). The parametric object is formed by ‘extrusion’, while the narrow triangles are the ‘wireframe’ representation of the surface. The great number of small and narrow triangles is in fact an advantage in order to produce a smooth surface for a parametric object without compromising the geometry of the object. If there is an observation point between the contour lines, (the dot on Figure 35) the ‘wireframe’ surface is shaped accordingly. With a mouse touch anywhere on the surface, a pop-up info-box (‘tracker’) reveals the actual XYZ coordinates of the point. When the terrain model is registered to the Easting and Northing values of the observations, then the ‘tracker’ will show the MGA coordinates. The terrain model heights were created using AHD values, therefore the Z value in the 'tracker' should coincide with the AHD values.

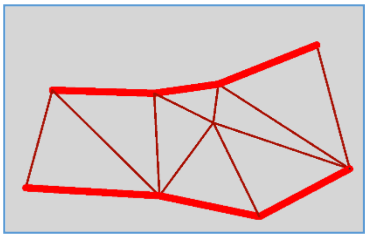


Figure 34 TIN surface created from Delaunay triangles (Created by: F. Acs)

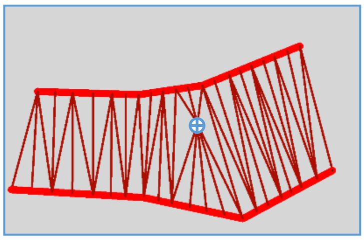


Figure 35 Wireframe shape of a parametric object created from contourlines (Created by: F. Acs)

A new 'node' can be created anywhere on the surface of the terrain model if required. The 'node' or groups of selected 'nodes' can be modified ('dragged') within the workspace 3D window, with the help of the mouse. In this case the required E, N, AHD or relative polar coordinates can be keyed into the pop-up 'tracker' and the point moves to the new position. The terrain object will automatically show its modified shape.

The BIM modelling tools are capable of forming a terrain model with great precision and accuracy. The architectural or engineering BIM software however were not programmed to absorb raw surveying observations for terrain modelling. Therefore:

- the surveying data first has to be processed by a professional land surveying software such as Liscad, where the TIN model and the contour lines are computed
- the derived result, the contour lines, has to be exported to a BIM authoring software where the topography is re-created and turned into a BIM terrain model.

The recently introduced Listech Neo-2015 software claims to be a link between GIS, CAD and BIM. The features of NEO-2015 and the 3D capable Leica Captivate may indicate that in the near future the land surveyor profession will be able to use a BIM authoring software tailored for the specific requirement of surveying and the spatial sciences.

There are several reasons supporting the almost exclusive use of contour lines in order to create a 3D terrain model within the currently available architectural BIM authoring software:

- The contour lines are traditionally used by AEC professionals to interpret the terrain of a building site. The visual identification of a contour line is therefore expected in every qualification level within the construction industry.
- The contour lines are representing visually distinct elements on the BIM model, which helps in the visual navigation within the virtual 3D environment and produces a definite visual association with the scale of the model.
- The colour-coded contour lines of the original survey plan can be digitally superimposed over the terrain for a fast initial visual data validation.
- The contour lines are a product of the TIN model. A TIN surface contains the results of the rigorous survey validations and the surveyor’s considerations of selecting points, strings and breaklines.

5.4 **Creating a BIM feature survey plan**

Although architectural or engineering BIM software are capable of producing high quality modelling in the hand of the land-surveying professionals, these software can be used only as a utility tool to create parametric objects. The data processing of surveying observations, the rigorous computation and data validation, is conducted in professional software dedicated for land surveying. Consequently, for a small land surveying office the second-best option is to employ an available third party BIM authoring software in order to be able create data in an IFC file format.

A BIM Feature Survey plan, even for a small size project, should contain several 2D and 3D elements and parametric objects. The design elements and objects of the BIM model are customarily organised within ‘storeys’ (1.5.4). The ‘storeys’ of a Feature Survey plan contain the following elements:

- A 2D surface on a separate ‘storey’ is called MGA (or MGA z55 in Tasmania). This flat surface can be represented as a ‘fill’ object. The ‘fill’ is a 2D representation of the area of the parcel of the future building site described in the Certificate of Title (‘title’). For practical reasons the MGA ‘storey’ is located below the AHD ‘storey’.

- The lengths and the bearings of the perimeter polygon of the 'fill' coincide with the 'boundaries' of the lot on the 'title'.
- The surface value, which is calculated by the software, should coincide with the size of the lot given by the 'title'.
- This layer contains all points, lines and annotations, which constitute a traditional 2D Feature Survey drawing.
- The TBM and the Survey Control Mark (SPM) Easting and Northing values are used to position and align the 'fill' and the 2D drawing elements within the coordinate system of the project.

- The AHD 'storey' (5.3) which is set at 'sea level'[28] contains several custom made parametric 3D objects or customised library elements as follows:
  - The 3D terrain model constructed with the help of the contour lines (5.3).
  - 3D Survey Marks (pegs, TBM) positioned on the terrain model.
  - The easement in 3D.
  - The existing man-made objects such as existing buildings, sheds or retaining walls.
  - Driveways, footpaths and fences.
  - Objects related to services, such as:
    - Stormwater / Sewer management (Inlets, Pits, Pipes, Manholes, Gutters, Grates)
    - Electric power services (Electric dome, electric pole, meter box, cable)
    - Gas Services (pipes, gas-meter boxes)
    - Fresh-water pipes, water meter, Fire hydrant,
    - Telephone, NBN
  - Additional Information (5.8)
    - Building Envelope in 3D
    - Footpath and driveway zone-stamps (if applicable)
    - Risk and Hazard Indicator zone stamps

[28] The mean sea level of 1966-68 was assigned as 0.00m on the AHD in 1971, adjusted in 1983 in Tasmania (Geoscience Australia)

  - Optional information (5.8)
    - Indoor Navigation zone-stamps
    - 3D Cadastre Information

The various 2D elements and the 3D objects of the Feature Survey Plan are stored in separate, logically grouped layers by the software. When the virtual construction is finished the layers should be locked or ‘frozen’. The ‘locked’ status of the model blocks the accidental change or modification of the survey data. When the site has to be modified for design purposes, a copy of the Feature Survey model is used. The ‘intersection’ of the original (surveyed) model and the modified model shows the changes indicated by the designer. This procedure is similar to the ‘change detection’ procedure used in GIS. The ‘intersection’ model is used as a data source for ‘cut-and-fill’ calculations (5.3). If the model of the future building is available, then the surveyor can prepare a BIM Setting-out plan.

The BIM authoring software exports the result of the modelling, in this case the BIM Feature Survey, as an IFC file. The IFC file is created semi-automatically by the authoring software. The default settings with minor modifications are usually sufficient for a typical project for a small business such as the terrain model above. For the preliminary design the B-rep (5.1) settings within the IFC manager GUI is used. The B-rep version of the BIM Feature Survey contains mainly the geometry of the model with minimal attributes attached. When the B-rep settings are applied the IFC file can be significantly smaller. In addition to this, at preliminary design stage, when the model is not fully completed but the necessary geometry is already available, the B-rep version of the survey can be useful. The IFC model maintains the spatial integrity of the Feature Survey 3D model. When the IFC model is embedded to a third party software by default it will positioned itself using the original, in the example the MGA z55 coordinates.

The origin of IFC model can be embedded into another software using the TBM as well. In this case the third party designer should check the coordinates of the TBM and set the receiving end-user software accordingly. This is not an obvious procedure since the architectural BIM authoring software by default uses a local coordinate system with zero origin. Moreover in most architectural software the default zero angle is set to ‘East’ from the origin, while land surveyors use the ‘North’ as zero degree.

5.5 Creating Library Elements

The BIM authoring software usually possesses a sufficient amount of 'internal' library elements to create a building. These elements usually constitute the integrated part of the particular software package. The software vendors are constantly developing and updating their library collection and improving the GUIs, in order to be able to create customised elements with great efficiency. The collection of the 'internal' library can be extended with pre-fabricated 'external' library elements downloaded from the Internet.

A series of intuitive tools can be used to build new custom designed objects within the software. Solid Boolean operations, such as 'union', 'subtraction' and 'intersection' are available via GUIs (Figure 36). Complex objects can be created using just a few mouse clicks. The 'mesh' library elements are suitable to create objects with non-uniform or rugged surfaces such as a terrain (5.3).

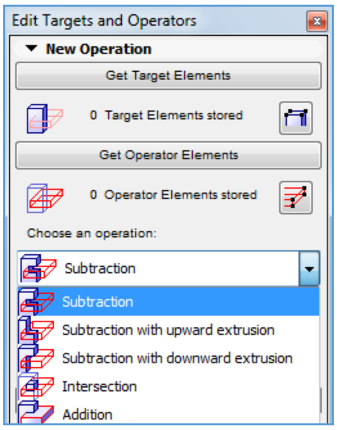


Figure 36 Solid operation GUI (Source: GraphiSoft)

As a next step, various features like stormwater pits, power poles or rocks can be also placed on to the terrain object. A feature, for example a stormwater-pit, is built from several parts such as the top-lid, base slab and the concrete pit. A custom-made stormwater-pit model can be saved as a library element, and therefore this library element acts as a container of a purpose-built group of parametric objects.

When the terrain and all the features are in place, the 3D model of the Feature Survey is completed. The 3D Feature Survey model, similar to a garage door, can also be archived as a single library element (5.2). This custom-built library element therefore encapsulates the particular Feature Survey. The library element version of the BIM Feature Survey preserves the spatial integrity of the group of objects, hence the results of a specific feature survey are within the 'federated' BIM model.

5.6 Level of Information (LOI) - Level of Development (LOD)

Within the AEC industry, 2D drawings of a project usually contain vector elements, such as points, straight and curved lines, also various graphical patterns (hatches) and textual annotations. The line styles and thicknesses, the hatches and the position of annotations, even the size of the letters are regulated and standardized. The technical drawings can be sketches, preliminary drawings, final layouts and detail drawings. The degree of finish, or the stage of completion, of the 2D drawings are subject to the requirements of the project or the local authorities. The (2D) technical drafting was an indispensable profession of its own right, where the discipline of the trade were rigorously taught and maintained. A degree of finish, or a stage of completion of the 3D models, within the BIM environment is called Level of Development or Level of Details; in short form as LOD (BIM Forum 2015; GSA-US 2009). BIM software vendors, third party organisations and the various government agencies are in the process of establishing standards for BIM modelling and the stages of delivery.

In Australia, organisations such as the National Building Specification BIM Modelling portal (NATSPEC-BIM) and the Australian Institute of Architects (AIA) are involved with the adoption and the implementation of BIM (Natspec 2011; Agar et al. 2014). NATSPEC currently embraces the terminology of the American Institute of Architects E202 document.

Table 1 Current LOD definition in the UK and the US (www.evolve-consultancy.com/bim-brief)

UK	US	Description
LOD-1	-	Brief
LOD-2	LOD-100	Concept
LOD-3	LOD-200	Design-Development
LOD-4	LOD-300	Production
LOD-5	LOD-400	Construction
LOD-6	LOD-500	As-Built
LOD-7	-	Facility Management – Asset Information

International organisations are attempting to adapt to fast growing demand and are working on detailed LOD specifications, where the different building elements are specified with alphanumerical codes and the LOD number is further subdivided (Figure 37). Most of the recent LOD definition initiatives (in mid-2015) can be considered as a proposal for further debate.

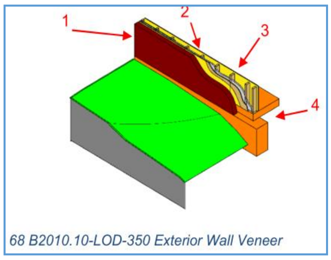


Figure 37 LOD-350 (Source: bimforum.org/lod)

The BIM LOD definitions may have a low impact on the work of the land surveyor. The 3D parametric objects of a future BIM Feature Survey Plan should be upon the surveying observations. The Level of Information (LOI) however could have a wider range of variations. The LOI by definition contain the non-graphic information. In a land surveying documentation the LOI should contain the:

- metadata (datum, location, projections, date, weather conditions, notes)
- observations
- calculations and adjustments, and
- data validations.

The available literature about BIM almost exclusively contains articles and online published materials for the designers, engineers and construction professionals. It seems that the 3D environment is a home ground for the land surveying profession; there is no particular need to change or alter field techniques or survey data calculations. Also the available equipment and technology are capable of supplying the necessary data for the AEC industry. There is a need however for dedicated land surveying BIM authoring software. Currently (mid 2015) architectural or engineering BIM software are used as a substitute in order to create the parametric 3D terrain model. It requires unnecessary investments and the workflow is inefficient. Recent acquisitions, such as Leica-Listech, Trimble-Tekla may indicate that this minor disadvantage might be solved in the near future.

5.7 File exchange - IFC / BCF / BIMx

5.7.1 Common Data Environment and the Federated Model

BIM is a comprehensive term to describe the processes required to create a virtual realisation of a project. The information exchange and the collaboration between the stakeholders are vital elements in order to develop the project efficiently.

Data extracted from a BIM model of a particular authoring software can be submitted to other parties when it is requested, or at 'key' stages of the project. This in-between data transfer is called a 'data-drop' in the UK (CIOB-online 2015). In the case of a small project the 'data-drop' is typically a direct file transfer between two consultants. An architect usually transfers the preliminary design model in IFC file format to the nominated engineer for structural evaluation. The structural engineer builds a structural model of the same building and 'drops' it back to the architect, also in IFC file format. The two related BIM models can create a composite BIM model. When the design procedure is finished, the product - the composite model in this case - will contain an architectural and an engineering BIM model. The composite model will most likely be physically located in the hard drive of the architect's computer. The legal and professional obligations of the 'dropped' information however remains with the author of the particular design. The individual liabilities of the designers (originators) *do not change* with the incorporation of their model into a composite or 'federated' BIM model (CIOB-online 2015). Although the definition of the term 'federated' is ambiguously used within the AEC professionals the intention to define the rights and liabilities within the composite model is clear.

In a more advanced BIM environment the composite BIM model is located in a network server or in the 'cloud'. The 'data-drop' can be seen as an update of a particular part of the composite BIM. The contents or the timing of 'data-drops', if possible, should be governed by the nature of the project. Using a 'cloud' service, the design documents, data and information of a development is available for every participant, consequently the development can be interrogated at will as it progresses. This specific collection and source of information about the project, utilised by the stakeholders is more often called the Common Data Environment.

5.7.2 PDF

There are several options available to assemble and distribute design information for a small designer business. In recent times the drawings and the documents are commonly stored and shared in a PDF file format. Almost every software is capable of producing a PDF file format version of the printable information component. Moreover the PDF files can be visualised or printed out from every commonly used software or hardware platform. The PDF file format was designed to be an electronic 'hardcopy', therefore it is inefficient to retrieve information from it or translate it into a native file format. The PDF can be considered the preferred file format for private, professional, academic or official purposes.

The documents in PDF format are preferably transferred or distributed via an Internet network. The use of the PDF file format as an e-mail attachment is also encouraged by government offices. All Planning or Building Application forms are distributed as a downloadable PDF files from Council web sites. Vital information, such as the Planning Schemes are also made available in PDF format. The lodgement of a Building application is required via e-mail and in PDF file format. The use of the PDF file is practical and convenient. Some BIM authoring software allows drawings or documents to be 'dragged-and-dropped' in PDF format directly from the desktop. The drawings in PDF are to scale, therefore this file format can be used to transfer 2D design documentation into the workspace of BIM authoring software.

The workflow of the design procedure not only adopted the advantages of the PDF and the Internet but reshaped itself as a consequence. The catalogue library room and the printing office has disappeared. The presentation rooms are only for formal occasions. Most of the workstations use wireless network, therefore the arrangement of offices has become flexible and changes can be executed swiftly. Workstations and the mobile devices are linked to the Internet, therefore work can be done 24/7, from remote locations or from home as well. Vital information can be accessed from on-line databases worldwide literally anytime about anything. These resources are available for any size of businesses, therefore even a small office can be well prepared, up-to date and reachable. The geographical range of services can be significantly increased without further investment. The PDF file format has become a stable and reliable medium for information and data exchange.

5.7.3 IFC / BCF

The BIM 3D model and the related information are exchanged via the IFC file format (1.5.7). The IFC file contains and maintains the geometry of the designed building and tangible building components, such as objects, with their attached attributes (Mordue 1994). The IFC is a non-proprietary standard and a neutral data format. The IFC file format is supported by over 150 certified software vendors and organisations and is soon to be an international standard (Model-Support-Group 2015b). The benefit of this file format is that it was designed to support the BIM environment with the focus on the 3D components of the information exchange.

The IFC file format is developed and promoted by *buildingSMART*[29], a non-profit organisation supported by a series of software manufacturers and research groups. IFC is a 'neutral and international'[30] data format, thoroughly documented and royalty-free. (Agar et al. 2014). IFC data files can be saved in three different formats[31]:

- *.ifc the default IFC data format
- *.ifcXML the IFC data in 'XML' document structure (4 times bigger than *.ifc)
- *.ifcZIP compressed file version of the *.ifc or ifcXML

The IFC data format is continuously developed and updated. Most of the current BIM authoring software recognise and use the IFC2x3 TC1 version.

Table 2 IFC versions and release dates
(*Source: http://www.buildingsmart-tech.org/specifications/ifc-releases/summary*)

Version	Release Date	Release Note by buildingSMART
IFC2x3 TC1	July 2007	Strongly recommended for implementation
IFC4-ADD1	July 2015	An updated IFC4 version, with improvements to the Model View Definitions
IFC5	n/a	Improvements to infrastructure domains (Planning phase)

[29] http://www.buildingsmart-tech.org/
[30] http://www.buildingsmart.org/about/vision-mission/
[31] http://www.buildingsmart-tech.org/specifications/ifc-overview/ifc-overview-summary

As has been indicated, BIM authoring software can ‘read’ or ‘write’ using the IFC file format. During the design procedure there may be stakeholders who do not have access to BIM authoring software, or who would like to participate while away from the office. To address this issue, free BIM-viewer software packages and the BIM Collaboration Format (BCF) was developed as an openBIM initiative by TEKLA and SOLIBRI software vendors.

In the case of a small projects such as the sample design of the garage (5.2) the building permit requires the involvement of a structural engineer. Within the BIM environment the architectural 3D information, in this case the garage design and the 3D terrain model, are transformed to the IFC2x3 file format. Consequently, the engineer should be able to open and investigate the terrain and the relevant building elements in three-dimensional virtual space. If the engineer does not possess BIM authoring software yet, then one of the free BIM-viewers such as ‘BIMsight’ can be used for an initial visual investigation (Figure 38). BIMsight allows the user to zoom in and out, rotate and create sections of the IFC model (Figure 39). Building elements can be located, 3D distance measurements executed, marking and semi-automatic conflict detection can be performed with the use of the GUI interface (1.5.6). Computer screen shots, messages and notes can be exchanged online using the BCF file format. The free BIM-viewer allows IFC files from multiple sources to be opened and investigated in conjunction with third party CAD files in the same workspace. If required an ad hoc online meeting can be established using Skype reinforced with BCF messages.

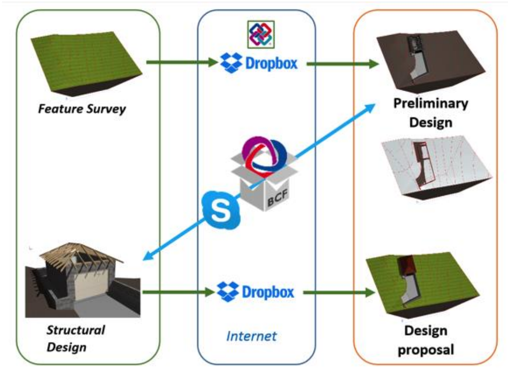


Figure 38 Data exchange of a small project using IFC and BCF file formats (Created by: F. Acs)

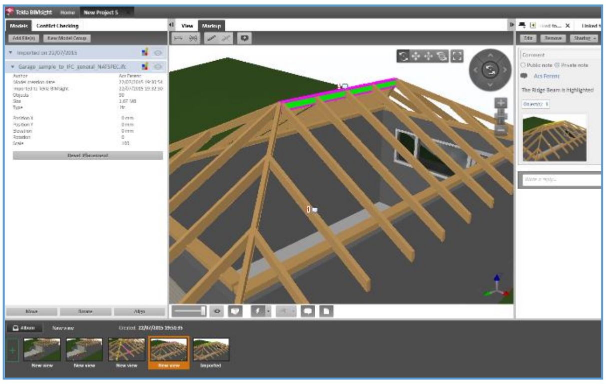


Figure 39 An IFC file of a BIM model interrogated with the ‘BIMsight’ ‘free BIM-viewer’ (Created by: F. Acs)

Free BIM-viewer however cannot substitute for the use of BIM authoring software for a land surveyor. Even the smallest project requires proper 3D information about the future building site. Within the BIM environment the IFC is used as the primary file format for data transfer.

5.7.4 BIM explorers

Building Information Model explorer software are advanced BIM-viewers which can be considered as frontrunners of a new type of BIM application; the BIM-explorer.

During the design procedure, BIM authoring software is used to construct the 3D virtual building. While the designers create and assemble the 3D building elements the software records every step of the procedure. The geometry of the 3D model and countless lists of components are formed and updated at the same time in the background. The software also produces traditional 2D floor plans, sections and elevations. When a design sketch or a development stage is presented for evaluation the 2D components of the project always accompany the 3D model. Within the BIM environment a BIM-explorer is capable of combining the 3D and the 2D components of a project in a commonly available application, which can be run on typical mobile devices.

BIM authoring software possess a publication module, where the 2D and the 3D components of the project are organised for digital publishing or documentation. The 3D model can be published as an IFC file, and perspective-views can be captured by the inbuilt virtual camera. The 2D components, elevations, sections and floorplans are published in a nominated file format such as the PDF. The ArchiCAD BIMx 'publish' module setting semi automatically hyper-links the 2D components with each other and with the 3D IFC model. The hyper-linked elements, including the IFC model are stored in a single file for presentation. Currently, the GraphiSoft BIMx-explorer application is programmed for Apple and Android tablets and a limited version can be run on Windows computers. A similar software, the Autodesk BIM 360 Field 'explorer' is also programmed for tablets with focus on construction details rather than the overall the presentation of the project.

The main advantage of BIMx is fine-tuned hyperlink feature, where the end-user can very swiftly navigate through the whole project. The smooth transition from 2D to 3D and back enables users to scan through a complex file structure without previous experience of BIM models. The building can be observed from every angle, inside out. Touching the building element generates a pop-up window, which reveals the attached attributes, dimensions and volumes. The plans and sections can be seen in 3D while the 2D drawings are superimposed. The 3D horizontal or vertical sections are interactive, and can be established and modified on the fly (Figure 40). The sections in combination with zooming utilise the advantages of the

IFC model. The navigation around and within the building can be executed with one finger, while zooming in or out requires two fingers. The 2D documents, added notes and screen captures can be saved, emailed or printed to hardcopy.

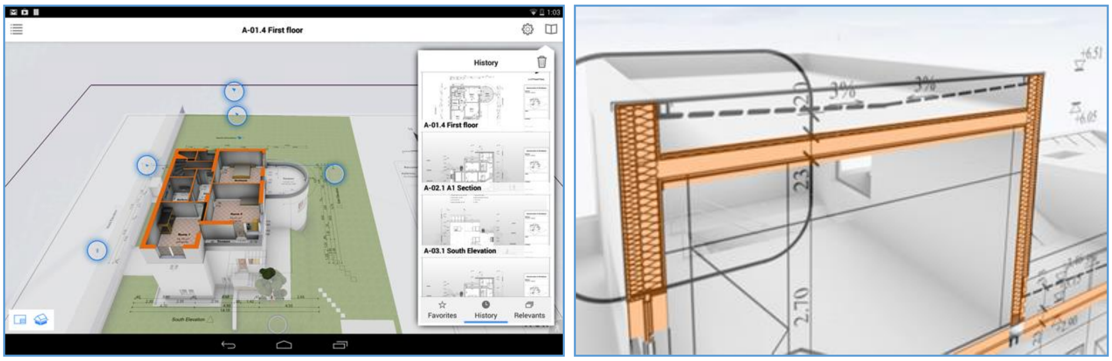


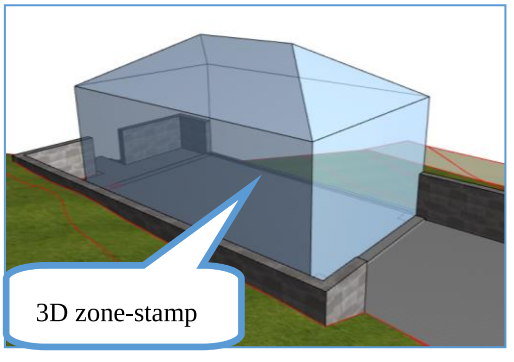
Figure 40 BIMx 3D sections, details and 2D drawings on an Android tablet. The floor plan is superimposed on the 3D model. The hyperlinked elements are indicated with blue circles (Source: GraphiSoft)

The interactive 3D walkthrough uses a rendering engine similar to ‘First-Person-Shooter’ video games. This extensively tested technology is very familiar for the generation who might use the BIMx professionally in the near future. The BIM model can be observed in red/green stereo anaglyph mode as well. The online connection with the BIM server updates the documentation remotely for every end-user at the same time, therefore always the latest version is stored in the mobile device for every stakeholder. A project documentation including a complex IFC model and dozens of A1 size drawings requires just over 10 MB data storage, which means updates can be distributed as e-mail attachments.

5.8 **Zoning**

5.8.1 Zone-stamps

A zone-stamp within BIM authoring software is a three-dimensional parametric object. In the Garage-project example (5.2) the architectural designer would create only one zone stamp which represents the overall volume of the building (marked with light blue on Figure 41). Zone-stamp objects can be used however to indicate the driveway and the footpath as well. The height of the zone stamps represents the values required by the intended traffic: 2100 mm overall height for the pedestrians and 2300 mm for a residential driveway.



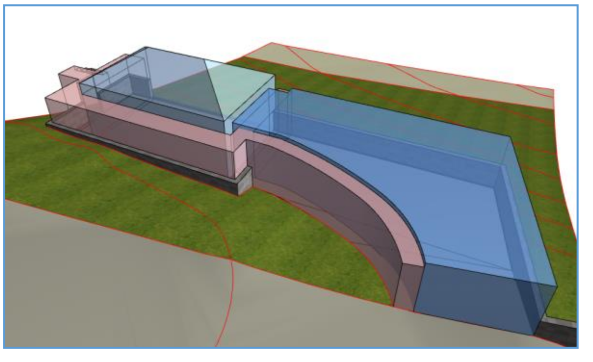


Figure 41 The 3D zone-stamps are colour coded; the light blue represents the Garage-project building, the darker blue stands for the driveway, and the pink for the footpath. (Created by: F. Acs)

The geometry of the footpath or the driveway zone-stamp objects in this illustration illustrate particular functions, and the relationships between functions in 3D. It can be also used to analyse the overall space requirements and the conflicts of traffic flow at this stage of the project. The zone-stamps produced by BIM authoring software can be considered data containers for the functions. Zone-stamp are allocated to every part of the project and can be allocated to areas around the building as well. Therefore, this report suggests that within the BIM environment a Feature Survey Plan should contain vital spatial information about the future building site, such as the Building Envelope or easements as a 3D parametric object. These objects should be the integral part of the BIM Feature Survey Plan package. When the package is exported into IFC file format and sent to the designer's office, the Feature Survey Plan will be one of the composite elements of the 'federated model' of the project (5.7.1).

5.8.2 Building Envelope

In the Garage Project the 3D terrain is assembled from three objects; the road-object, the terrain-object and the easement-object (Figure 42). The geometry of these elements is the result of the site survey conducted by land surveyors. The geometry of the Building Envelope, however, is defined by the local Planning Scheme and describes the setbacks and the height restrictions of the future development. The example Building Envelope object also reflects the local building height constraints, which gives the overall building height limitations and the gradually changing height restrictions toward the left and right hand side boundaries (Figure 42 marked with number '2').

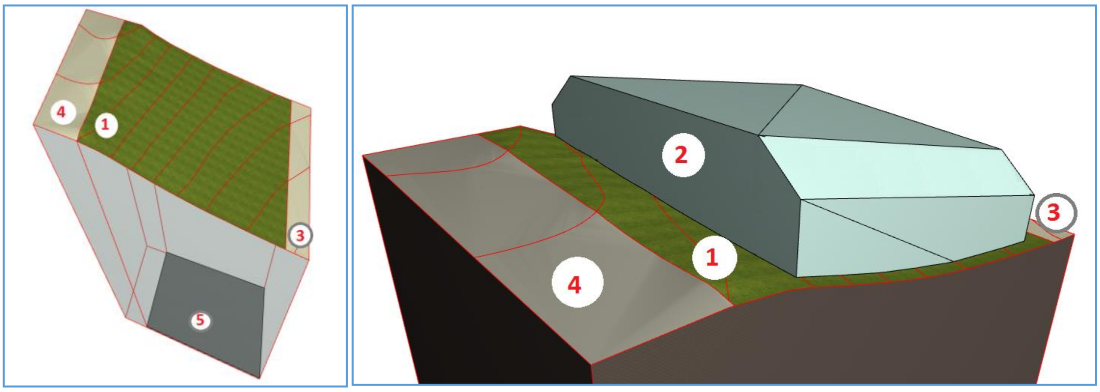


Figure 42 Feature Survey Plan in 3D
1./ 3D Terrain, 2./ 3D representation of the Building Envelope; setbacks and height restrictions 3./ Easement 4./ Road 5./ 2D representation of the building site (Created by: F. Acs)

The Building Envelope object is utilised when the land surveyor has to design a subdivision of a lot. If the Garage-project site is used as an example again, it is obvious that cutting the lot into half is not a feasible option but a two level building (strata subdivision) might give a satisfactory result. Custom made 3D zone-stamps can be used as an initial visualisation of the proposed solution. In this instance the details of the strata title should be emphasised, hence the zone-stamps will be colour coded by ownership. Blue and yellow are used to indicate the private property areas while the building envelope is see-through (Figure 43). The colour coded zone-stamp solution can be used to design and visualise BIM strata subdivision models for more complex cases than a simple subdivision as well.

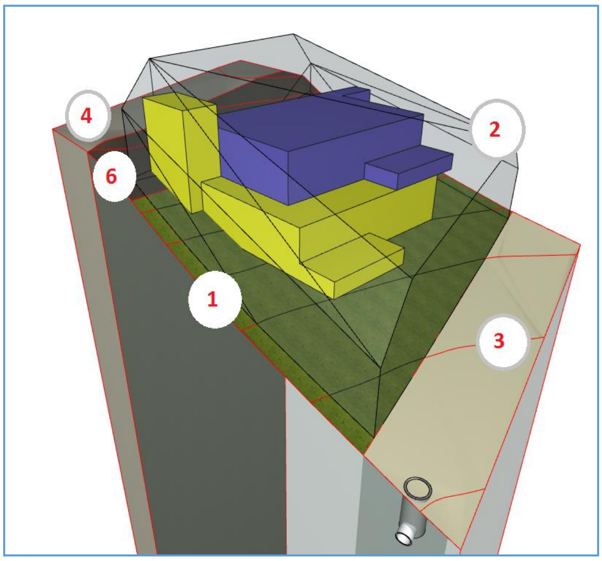


Figure 43 Visualisation of a Strata Subdivision preliminary design using 3D zone-stamps 1./ 3D Terrain 2./ Building Envelope 3./ Easement 4./ Road 5./ 2D drawing (not visible) 6./ Common parking area (Created by: F. Acs)

The 3D model helps to visualise and interpret the legal descriptions of the strata and the limitations of the future building site. The BIM authoring software are programmed to derive proper 2D technical drawings from the model, therefore the extra time which was invested to model building might see some returns in the swift production of the required documents.

As has been indicated, every room or space possesses zone-stamps within a BIM model of a project. These zone stamps are used predominantly for the indoor navigation within the building. The indoor zone-stamps however contain an inherent coordinated link to the strata title zone stamps given by the BIM authoring software. In Australia this local Cartesian coordinate system of the project is associated with the MGA coordinates of the site via the survey drawings. If the 3D zone-stamps are streamlined with the legal documents of the 'title' then essentially a detailed 3D Cadastre document is prepared.

5.8.3 Indoor Navigation

A building consists of a series of rooms or enclosed spaces. Traditionally the spaces are organised according floor levels or storeys. Even a small residential building is divided into a lower level or basement, a ground floor level and an upper level such as a loft or first floor. Bigger buildings usually have multiple levels, corridors on each storey and numbered rooms. Complex buildings are similarly organised. Navigation may be assisted by frequently distributed map diagrams. Although there are several large and small software vendors and apps which present various digital indoor navigation systems, such as the “O”[32] in the Museum of Old and New Art (MONA). These systems are so far mostly working within a local space frame, independently from MGA. The BIM environment however may offer a spatial reference frame which may also use a local coordinate system, but this reference frame is directly linked via the land surveyor’s site plan to the MGA.

The zone stamp dedicated to indoor navigation should contain the information about the wall openings such as doors and windows. By default the centre point of the room at the floor level contains the representative XYZ coordinates of the enclosed area or ‘cell’ (Figure 44). The location and the size of the doors however plays a more important role in the indoor modelling (Mortari et al. 2012). The network model is similar to car navigation in a city; the possible flow of traffic creates “streets” and the doors indicate the crossroads or intersections (Breunig et al. 2014). The stairways and the lifts can be considered as special cases of road junctions. Although the nodes of the indoor navigation network can be derived from the architectural design documentation it seems to be imperative to update these data by land surveyors when the ‘As-Built’ model is produced. It is also practical that the ‘As-Built’ model is used as a data source to construct the 3D

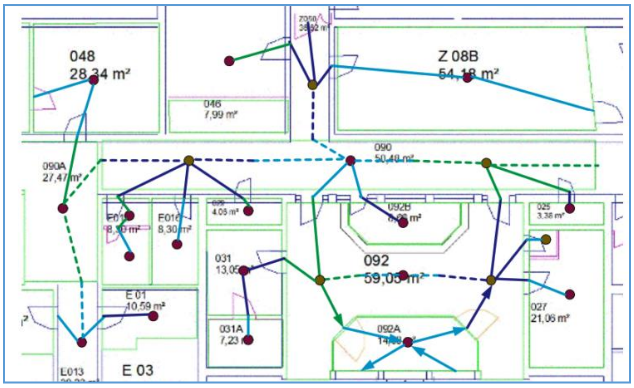


Figure 44 Indoor navigation network (Source: Mortari et al. 2012)

[32] https://www.mona.net.au/theo

Cadastre model and the Indoor Model (Figure 45). The BIM environment and the further use of the 'As-Built' model may reduce the costs involved when indoor navigation networks are established and maintained.

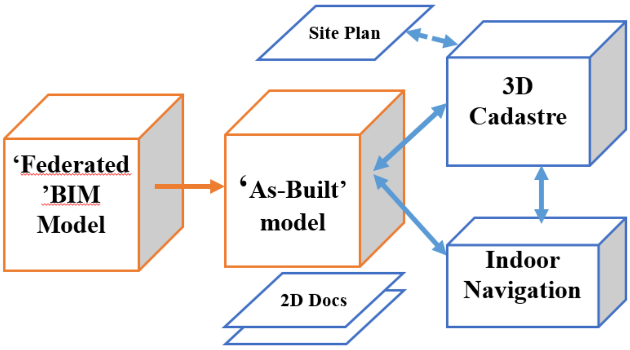


Figure 45 The 'As-Built' BIM model is the source of the 3D cadastre and the Indoor Navigation Model. (Created by: F. Acs)

It is thus beneficial to use the BIM authoring software 3D zone-stamp tool for indoor navigation and for the 3D Cadastre. The zone-stamp tool possesses all the armaments of the 3D parametric objects and the Common Data Environment of BIM including the attached attributes and documents. Moreover, the zone-stamps are established at the very beginning of the design procedure and represent the core components of the building during the entire lifecycle of the project. Consequently the zone-stamps can be visualised, maintained or updated without involving the currently ambiguous LOD definition problem. The parametric nature of the zone-stamps offers an opportunity for programmers to integrate the future indoor navigation systems into the existing street navigation software. Moreover the BIM based indoor and underground[33] navigation solutions in conjunction with the 3D Cadastre database can be valuable assets for local authorities and the emergency services.

The benefits of the BIM environment and the zone-stamp tools however cannot be directly utilised for indoor navigation due to the lack of wireless navigation signals in the enclosed areas of the buildings. Experiments with various digital technologies such as mobile phone triangulation networks or RFID[34] chips are promising, however a solution is yet to be found.

[33] Building elements below terrain surface
[34] Radio Frequency Identification system

5.8.4 3D Cadastre

There are several research groups and institutions preparing for the introduction of a 3D Cadastre in Australia. Various 3D cadastral data models and the attached ‘title’ rights, restrictions, responsibilities (3D RRR) are being widely investigated and numerous 3D cadastre data modelling initiatives[35] have been published (Stoter 2004; Isikdag et al. 2014). The proposed 3D cadastre data models frequently emphasise the following elements:

- 3D RRR
- 3D Geometry
- Survey (metadata), Survey points, Survey observations
- External sources such as Architectural Plans (Aien et al. 2011).

The BIM environment, more specifically a BIM feature survey package, equipped with 3D parametric objects and the attached attributes may be able to support these requirements.

- 3D BIM objects are capable of acting as a searchable and interactive data container to store various attached attributes and documents, thus the 3D RRR can be attached to the objects. The CDE enables further investigation and links within the documents associated with the project. The documentation therefore is transparent and most importantly; traceable.
- The parametric nature of the objects allows them to maintain the 3D geometry of the model, the associations and the correlation between the objects, or to add new objects or documents to the model.
- The hyperlinked documents such as the survey data or the Architectural Plans enable an efficient navigation and (machine reading) quires within the BIM documentation package.

[35] Core Cadastral Data Model, FGDC, ArcGIS-PDM, DM.01, CCDM, ePlan, ISO 19152 LANDM, Ubiquitous 3D Cadastre, etc.

The BIM environment may offer further support for a 3D Cadastral initiative. Some elements of a BIM Feature Survey Plan such as zone-stamps or the Building Envelope model may contain coordinated links to various government-run spatial databases such as ‘TheLIST’. The Cadastral Parcels layer of ‘TheLIST’ online map currently shows the boundary lines of the parcels and the 2D strata title boundary segments of the buildings (Figure 46).

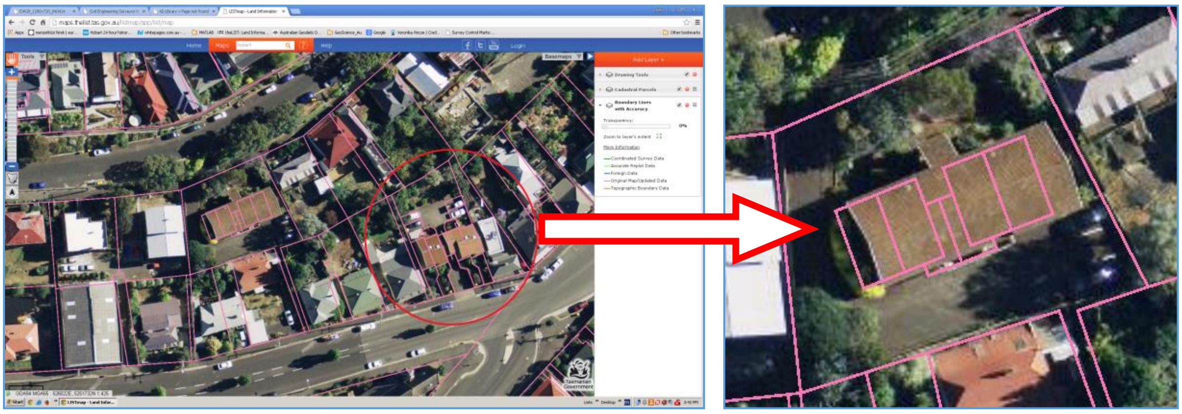


Figure 46 ‘TheLIST’ map Cadastral Parcels layer shows the boundary lines of the parcels and the 2D strata-title boundary segments of the buildings. (Source: TheLIST)

The 2D polygons of the strata-title could be hyperlinked to the BIM zone-stamps (5.8.2). The simple and schematic geometry and the zero-LOD of the zone-stamps are not likely to increase the file sizes significantly, yet they maintain the advantage of the 3D parametric objects. The BIM zone stamps are also capable of establishing a direct link (hyperlink) to the architectural and engineering details of the project. The collection of zone-stamps attached to a particular parcel via a Feature Survey package, can be further extended with parametric objects such as the geological structure or soil layers of the terrain below the surface (Figure 47).

Architectural BIM authoring software also possesses online links with meteorological or public statistical databases used for the Energy Evaluation of a future building. Consequently the terrain object may also contain attributes relating to the local climate and vegetation. These data allow the assessment of the shadow casting or the stormwater flow of the individual lots. The 3D models and the attached data can be the source data of various valuations and assessments, such as the bushfire hazard assessment. The attached local wind pattern, the sun-path and shadow casting data permit to further fine tune the description of the ecological footprint of the future building site.

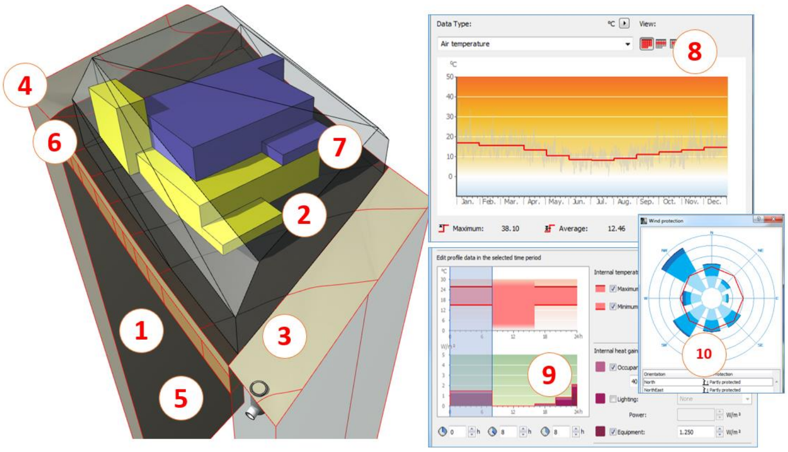


Figure 47 3D parametric objects and attached attributes which may support 3D Cadastre 1./ 3D Terrain model of the parcel including vegetation and existing man-made objects 2./ 3D RRR and Building Envelope object; ownership -strata title- indicated with colour code 3./ Easement + infrastructure 4./.Road + infrastructure 5./ Title - 2D drawings and documents (hyperlinked to 'TheLIST' base-maps and layers) 6./ Geological data and Soil layers of the site 7./ Sun-path and shadow casting 8./ Long-term climate data 9./ Daily climate profile 10./ Local wind and wind protection (Created by: F. Acs)

The file size of the linked dataset or the Feature Survey Plan can be further optimised if the web addresses of the cloud-based datasets are linked or attached to the relevant parametric objects. Furthermore, the maintenance, updates and the integrity of the attached data can be secured when the relevant government databases such as the Australian Bureau of Statistics, Bureau of Meteorology or 'TheLIST' are involved. In addition to this, the log-file of the parametric objects and the attached documents makes the BIM environment transparent and traceable (1.5.9). Consequently a 3D Cadastre model may be not only supported but greatly enriched if it is linked to a BIM Feature Survey Plan prepared by registered land surveyors.

A study from the pre-BIM area of the 3D Cadastre stated that "*a number of non-trivial issues still need to be addressed*" (Stoter 2004). The majority of these "*issues*" might be addressed today (mid-2015) when the capabilities of BIM are available or better known. The quoted sentences in Table 3 are selected to illustrate the potential of a BIM environment when a BIM is implemented for a 3D Cadastre. As was indicated previously, the architectural or engineering BIM authoring software were not programmed for land surveying purposes. Consequently this report should be reviewed and rewritten at the moment when a BIM authoring software tailored for spatial science will be available.

Table 3 Issues of 3D Cadastre

Issues of 3D Cadastre from the pre-BIM area (Stoter 2004)	**A current, second best BIM solution advocated by this report at mid-2015**
"In the survey plans both the 3D points and edges are specified (as required), however there is no explicit listing of faces and the polyhedron itself. It is not trivial to reconstruct the faces and it is possibly ambiguous, especially in more complex cases"	Before BIM the 2D drawings and the 3D survey data were used to create the 3D Cadastre model using simple geometrical elements such as polyhedrons. The registry of the geometry had to be done manually which is a daunting task within a CAD system. The BIM authoring software environment automatically registers and maintains the geometry of every object.
"The validation of the polyhedron is non-trivial (especially if it consists of other faces than horizontal, vertical or triangular faces). Is the volume completely closed? Are all the faces planar (enough)? Is the orientation correct? Are holes or cavities modelled correctly?"	The orientation and the integrity of the parametric objects are automatically maintained within the BIM authoring software regardless of the complexity (holes, cavities, rotated, ellipsoidal or cylindrical) of the object. The 'Check-Integrity' option allows us to check the integrity, if required, for imported objects.
"The Queensland regulations also allow non-polyhedral 3D objects, such as rotated ellipsoids or cylindrical patches. Should these be converted to polyhedrons?	
"Attention should be paid on how to make sure that two polyhedra do not overlap in 3D space (but at most touch in a common node, edge or face) and on how to make sure that there is no 3D sliver between two polyhedra that are supposed to be touching neighbours."	If the 3D Boolean operations are used in order to create parametric objects then the BIM authoring software maintains the integrity of the procedure. If the objects are imported then the 'Clash-detection' option determines the overlaps or gaps between the objects. (Boolean operation: 'intersection')

"It is a challenging task to integrate a terrain elevation model with the 2D surface parcels in order to obtain 2.5D surface parcels which can be combined with the 3D objects	In BIM all elements are fully 3D. The imported 2.5D elements are semi automatically integrated into 3D.
"Technical issues have to be solved to be able to maintain the complex geometry of physical objects in the cadastral DBMS. The geometries of physical objects will (mostly) have to be provided by third parties."	As it was indicated the BIM authoring software has already solved the technical issues regarding of the complex geometry. The third party objects are currently stored and imported in IFC format.
"In the full 3D cadastre volume parcels can be established that no longer have a relationship with surface parcels"	In BIM the 3D parcel object can contain the 2D surface parcels.
The juridical framework in Queensland already provides the possibility to establish volumetric parcels, however the cadastral framework does not provide the possibility to incorporate the (precisely) defined volumetric parcels as part of the cadastral geographical data set in 3D.	Screen-captured images of the BIM model are frequently used as a visual illustration of the cadastral data set when complex strata title is the area of interest
"…a digital description of the 3D property unit in vector format is not maintained in the land registration (only scanned or paper drawings). Therefore the 3D property unit cannot be viewed interactively and the geometry of the 3D property unit cannot be validated."	One of the possible solutions is the BIMx format, where the 3D model of the property and the 2D drawings and the documentation can be viewed interactively, and the geometry and the attributes can be measured or interrogated.

"These solutions therefore do not address technical issues, such as how to store, query and visualise 3D property objects (in 3D)"	The BIM environment allows us to store the data in the CDE. The BIM can visualise the model manually or semi-automatically. Several BIM modules can interrogate the model automatically (machine reading capability).
"...the 3D property units have to be described in survey plans (British Columbia, Queensland)"	The findings of this report fully support these statements.
"Financing of a 3D registration should be supported by good organisation and legislation. In general the benefits should be larger than the costs. Also 3D registration should be cost-recovery at large"	
"The cadastral registration should be connected to the Geo-Information Infrastructure. In that case a 3D cadastral registration can benefit from spatial (3D) information that is maintained by other organisations and in other databases and vice versa, since information can easily be shared".	The findings of this report fully support these statements. The BIM environment has been solved most of these issues. 'TheLIST' website can be considered as the geo-information infrastructure in Tasmania.
"Based on these considerations, we can conclude that a 3D cadastre should incorporate the following functionalities: *• register 3D information on rights (what is the space to which the person is entitled?) and make this information available in a straightforward way;*	In this report the 3D information is represented as parametric object or attached to the BIM model The external database is "TheLIST" (in Tasmania).

<table>
<tr><td>• establish and manage a link with external databases that contain objects that are of interest for the cadastre (infrastructure objects, soil pollution areas, forest protection zones) and viewing the legal status of 3D property.</td><td></td></tr>
<tr><td>“To maintain 3D geometrically structured data within current techniques, 2D primitives defined in 3D embedding space can be used (polygon defined in 3D). 3D objects can be defined either as a body that consists of a set of faces or as a multipolygon defined in 3D”.</td><td rowspan="2">The sample subdivision above also embedded the 2D drawings into the 3D model as a 2D polygon (surface) defined in 3D.

The polygon which represents the parcel boundaries, incl. contour lines as 2D vector drawings, is located in a separate AHD–layer. The terrain object is created with the ‘extrude’ option from this particular polygon (5.3).</td></tr>
<tr><td>“Topological structure management to maintain 3D geo-objects and 2D geo-objects for the 3D cadastre is preferred, but, as can be concluded from this thesis, has to be implemented using self-defined extensions.”</td></tr>
<tr><td>“We experimented with a DBMS implementation of a 3D topological structure: SSM (Simplified Spatial Model) which is a topological structure described in. This topological structure only supports flat faces (as the implemented polyhedron primitive). In an object relational DBMS, the relationships between the high-dimensional (3D body) and low-dimensional objects (FACE and NODE) can be stored. The implementation shows that storing a 3D object and generating a geometrical realisation of the 3D object within the DBMS is not a problem.”</td><td>The use of zone-stamps in the subdivision example above is very similar to the Simplified Spatial Model. The zone-stamp however is a 3D parametric BIM model, which represents a higher-order digital object, not a simplified (FACE and NODE) representation of a 3D body.

Note: In 2004 the 3D parametric objects and the BIM environment, such as the ArchiCAD, TEKLA, DDS and REVIT BIM authoring software were globally distributed and commercially used by the AEC industry.</td></tr>
</table>

"*In chapter 8 an extended overview was given concerning other basic aspects (apart from DBMS aspects) of 3D GIS: organisation of 3D data, 3D data collection and object reconstruction, visualisation and navigation in 3D environments and 3D analysing and 3D editing. Based on this overview it can be concluded that 3D GIS still has to mature. 3D GIS developments are mainly in the area of visualisation and animation*."	Most likely the author of the paper realised that the majority of the current GIS tools are not tailored for 3D modelling and visualisation purposes required by 3D Cadastre. This report advocated the use of the BIM environment for 3D Cadastre as opposed to a tweaked version of the GIS.
"*visualisation of 3D information requires special techniques; characteristics such as physical properties of objects (texture, material, colour), and different levels of detail representations need to be maintained and organised in DBMSs* "	A parametric object within the coordinated framework of a BIM environment possesses all these properties
"*Virtual Reality and Augmented Reality techniques should be incorporated in GIS software to improve interaction with and visualisation of 3D environments*"	
"*Once 3D geo-objects are stored in a DBMS within current techniques, the next issue is how to access and query the geo-objects by front-ends. Three front-ends were analysed to access 3D objects stored in (3D) geometrical primitives in Oracle Spatial 9i: a CAD oriented front-end, a GIS front-end and a self-developed front-end*	The parametric nature of the coordinated BIM environment possesses 'machine reading' capabilities which allows us to interrogate either the individual objects or the objects in a group. This is the first 'front-end' of the BIM authoring software publishing facilities. The second 'front-

using Web based techniques."	end' is the IFC version of the model. One of the WEB based 'front-end' is the BIMx. The FME software, which possesses interactive transformation capabilities to more than 350 file formats, might be used as an additional 'front-end' to various software platforms via WFS, XML, GML, KML file formats and cloud servers such as Oracle, ESRI. Some BIM authoring software possesses direct links to Grasshopper, Rhino, or indirect links to MATLAB, Python and R.
"When integrating 3D geo-objects and 2D parcels in one environment, the height issue needs to be addressed: how to locate the 3D geo-objects with respect to 2D surface parcels in one 3D view. Basically there are two solutions for this: *• z-coordinates of 3D geo-objects are stored within a national reference system • z-coordinates of 3D geo-objects are stored relative to the surface"*	The BIM environment uses by default an automatically maintained local Cartesian coordinate system for a project with a local origin. This local coordinate system is usually linked to MGA and AHD in Australia.
"It is not easy and straightforward to create a good integrated elevation and object model. Several alternatives of a TIN structure were investigated: unconstrained Delaunay TIN, constrained TIN, conforming TIN, and finally refined constrained TIN. After some analyses, the refined constrained TIN, was selected as most appropriate for the purpose of this research."	The TIN surface is created by a professional land surveying software, such as LISCAD which is capable of performing the necessary specialized calculations, adjustments and data validation procedures.

"In the full 3D cadastre prototype environment (based on a 3D polyhedron extended version of the Oracle spatial DBMS), the 3D property survey plans were converted into a spatial representation in the DBMS and the surface parcels were successfully merged with a terrain elevation model." *"The information from the 3D survey document can be used to insert the geo- metrical and topological description of volume parcels in the DBMS. The space is precisely described in a 3D survey document, which offers a uniform way of defining 3D property units. In addition, implementing the full 3D cadastre offers also improvements for cadastral registration in countries and states that already establish 3D property units as volume parcels in the juridical framework"*	Currently as a second best option the TIN surface or the contour lines are imported from a professional land surveying software to an engineering BIM authoring software in order to produce the 3D terrain model. The other objects, such as the Building Envelope are created within the BIM environment. The juridical documents and related 2D drawings are attached or hyperlinked to the 3D model in their original file format. The legal documents and the 2D drawings documents are playing the role of the "Metes and Bounds", which is illustrated with the help of the visualised 3D BIM objects.
"The prototype environment of the full 3D cadastre offers the possibility to query, analyse and visualise the true 3D situation of the properties."	The BIM environment solved the "machine reading" of the whole 3D Cadastre project. Therefore a wide range of 2D or 3D queries can be executed and extracted semi-automatically or automatically The hyperlinked nature of the documents and cloud databases enable us to link, search or visualise almost any type of attached 2D or 3D documents. The visualisation (including orbiting and walk through in perspective projection) of the project is high resolution, photorealistic and immediate. For some software, such as BIMx, the Anaglyph 3D visualisation is a built in feature. The augmented VR visualisation technology is solved.

5.9 Workflow for small business

Managers and business strategists usually try to create structured and highly centralised communication models. The development of networked computers quite often offers efficient and practical solutions without a centralised structure. In commonly used personal computer networks, especially in small offices, computers can 'see' each other via the router. The Internet, wireless mobile devices and 'cloud computing' provide a wide range of choices to communicate or share data. A designer can have a consultation via Skype with a colleague who is in the same building; during the consultation the designer can receive and share images sent as e-mail attachments from the building site, from a mobile phone located in another city, while checking relevant overseas product information. For the duration of the conference talk an application can automatically be synchronising the keyed in schedule data with the smart-phone of the designer and his superior. This scenario is not a strictly predetermined business practice protocol - it is a resourceful and efficient use of the existing devices and services. The workflow of most of the small design offices therefore revolves around the available digital equipment and software.

Currently, architectural design offices are playing the role of a hub in the data flow for a small project. The architect traditionally receives, processes and distributes information between the stakeholders, and therefore the vital data is stored in the hard drives of the designer's office. The designer receives and processes the 'title' from the owner, the Feature Survey Plan from the land surveyor, the result of the Soil Test, the Bush Fire Assessment and the Energy Efficiency Assessment. The designer collaborates with the structural engineer during the design procedure, and maintains their connection with the client and the builder. More importantly the designer submits the project to the authorities for Development Approval (Figure 49). Bigger files may be distributed via cloud services but generally speaking, the data transfer is managed by the designer. The designer and the engineer may occasionally use IFC files to exchange 3D data, but the vast majority of the digital communication is using the PDF file format via Internet (5.7.2).

The scheme of the data flow within the BIM environment shows a similar pattern; the bulk of the vital information of the future project is congregated in a mass storage device maintained by the architect's office. This arrangement is analogous with the traditional small business model, where most of the paper-drawings of the project were assembled by the architect for submissions.

The main difference between the current (Figure 49) and the BIM (Figure 48) data flow pattern is most likely governed by the extensive use of the parametric 3D objects within a federated model.

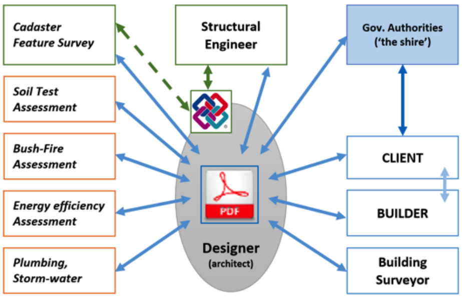


Figure 49 Present-day flow of a small project (Created by: F. Acs)

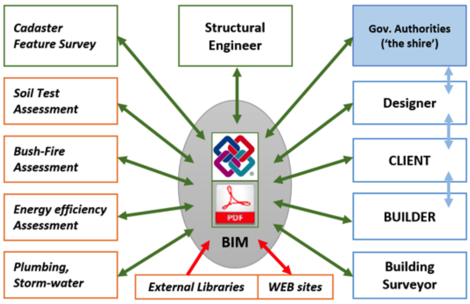


Figure 48 Data-flow of a small project within BIM environment using 'federated' model (Created by: F. Acs)

The project's database should be available for all stakeholders; therefore the BIM data of the project ought to be located in a 'cloud' server. The mass storage in the 'cloud' is mature technology, supplied by global software giants such as Microsoft, Apple, Google and Facebook. The local computer networks of the offices by this time routinely utilises the capabilities of the broadband Internet services. The hardware and the software are a given and integral part of the everyday business practice.

The questions yet to be answered are: who is supposed to keep running a particular BIM database, and how long should it exist? More importantly, who is liable for the integrity of the BIM data within the database?

5.10 **Return of investment – ROI**

The gradual transition from the CAD to the BIM environment has started in architectural and engineering offices. The annual software maintenance procedure almost automatically offers a BIM authoring upgrade within a reasonable price range. The designers are usually well informed and expecting the transition. The BIM environment can however noticeably redistribute the workload and the administration of changes in the workflow.

Within the BIM environment the building is visually constructed in a three-dimensional coordinate system. The floor levels, the 'storeys' and the building element attributes require adequate settings. Although the library elements and the intuitive GUIs are positively supporting the procedure, there is a noticeable productivity loss at the preliminary stage of the design. The efficiency drop can be considerable during the implementation of the BIM system in a land surveying office, where an unaccustomed architectural BIM authoring software is introduced in order to model the terrain (Figure 50).

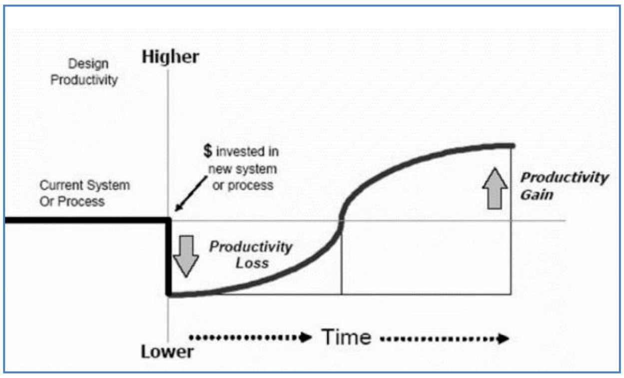


Figure 50 Productivity loss during BIM system implementation. (Autodesk-Revit 2007)

The BIM environment, however, utilises highly sophisticated, efficient and already existing communication methods, such as the Internet and mobile devices linked to mobile phone networks for collaboration. The BIM design, the hyperlinked documentation and cost estimating solutions are transparent, traceable and more flexible to variation than their predecessors were. The accuracy of the photorealistic images, capable of depicting the building inside-out at will, the 'artistic impression' presentation sketches are seldom used. All the characteristics mentioned above can help to improve the quality of the design and the construction, and consequently the value of the future buildings (Coates et al. 2010; Salih 2012).

A Feature Survey created by a land surveyor is the result of precise and accurate observations, rigorous computation and three-dimensional terrain modelling. The 3D component however customarily transferred into 2D vector drawings. In order to use the Feature Survey for architectural design purposes, the 3D model of the terrain has to be reconstructed in the architectural office (5.3). The 2D contour-lines probably provide sufficient information for the designer when the topography of the building site is smooth. A project on an uneven terrain however might require detailed 3D model.

In the following example, half a group of single storey units were erected for people with restricted mobility. The design focused on the houses and the project satisfied the highest standards for its purpose. However, the terrain was rugged and massive rocks were found during the construction under thin topsoil. Within the circumstances the site management did their best under pressure of a very limited budget and a deadline. The 'on the fly' re-designed ramps conformed to the building code, the unfriendly path with sharp turns however may raise an eyebrow (Figure 51).

In an ideal word of the BIM environment the architect would utilise a parametric Feature Survey 3D terrain model, received as an IFC file from the land surveyor (5.4). During the ideal design procedure the BIM authoring software 'ramp' library element module is employed in order to design the ramps between the buildings. The architect sets the parameters, such as *min/max slope, path with and length* of the 'ramp' library module and link it to the 'pathway-finder' module that is further linked to the terrain model. The entry and the exit points of the ramps are fixed and the terrain model plays the role of the 'attractor' (4.2.2). The parameters of the modules are optimised by the results of the 'cut-and-fill' module which uses 'intersection' Boolean operations (5.3). The results are automatically compared with the allocated budget and the price estimates of the contractors. Most likely the 'ramp' module will offer more than one result. The fine-tuning and the final decision is made by the designer.

Figure 51 The red lines indicate the path of the existing ramps (Created by: F. Acs)

The path finding procedure is very similar to the MCDA model from ESRI ArcGIS software, used for corridor analysis. The optimisation procedure corresponds to the Conditional Simulation and Monte Carlo Simulation. The ‘ramp’ module is in fact a modified ‘stair’ module, which is a standard module of an AEC BIM authoring software. Land surveyors traditionally designed rural roads and calculated ‘cut-an-fill’ excavations along an alignment. The CAD systems such as Liscad or CivilCAD possess the necessary design modules. The moment the land surveying software adopts the parametric technology, rigorous ‘cut-and-fill’ calculations and professional footpath design can be executed. The curriculum of a spatial science studies degree equips every undergraduate with the necessary information and knowledge in order to efficiently apply the ‘ramp’ simulation even for a small project.

The investment part of the ROI in this illustration indicates the extra time allocated for the 3D model and collaboration. The usufruct is gained by the end-user, the people who use the ramps every day. The benefit might be realised by the increased value of the property. The example above might suggest that no profit can be directly realised by using advanced BIM technology and careful design in case of small projects. The ‘federated’ terrain model is, however, a reusable product (5.7.1). Sooner or later it will be necessary to produce an ‘As-Built’ survey documentation or execute a ‘change detection’ survey for an insurance company. The documents for 3D cadastral submission will require a 3D terrain model extended with the underground services. The updated ‘As-Built’ model will be used to create Indoor Navigation model (Figure 52). The initial technological investments and time spent with collaboration might be considered as an opportunity cost which can potentially create future business opportunities.

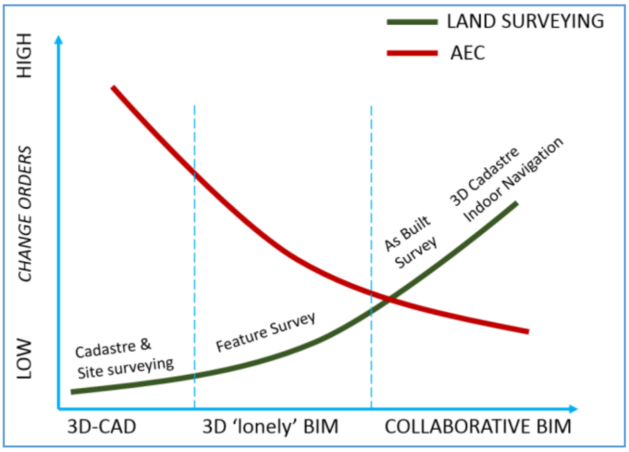


Figure 52 Possible AEC industry trends in change-orders. Modified graph of J.C.Cannistraro (Salih 2012)

6 Case Study 1: A Crossover (Small Residential Development)

Small projects such as a crossovers and a carports most likely do not require extensive involvement of a land surveyor. The undulating and zig-zagging streets of Hobart however often produce topography which can be challenging to visualise from 2D drawings even for the local city council officials. Employing the most recent technologies allow to build virtual 3D models which not only visualise the project but helps to find the solution as well.

6.1 The Site

The client is currently parking at a street corner and would like to establish a carport within the property line. The 'L' shape street corner is located on a hillside, the steep slopes are indicated with red arrow on Figure 53. According to the requirements of the city council the floor level of the carport should be slightly below the street level and the rainwater from the roof of the future building should be drained to the existing stormwater pipe.

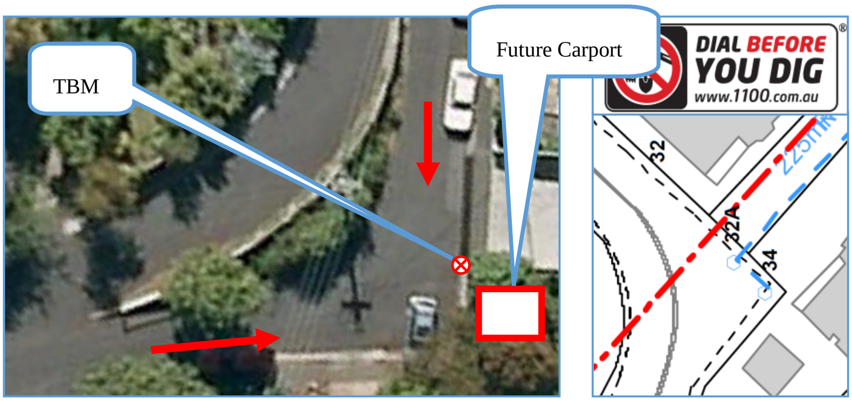


Figure 53 The site of the future cross-over and carport. The 'Dial-before-you-dig' map indicates the existing stormwater pipes (Source: TheLIST and 'Dial-Before-You-Dig)

The 'Dial-before-you-dig' map indicated that although the stormwater pit #34 grate is positioned in a lower level, then the #32A, the water inside the pipeline below the surface is flowing from #34 toward #32A. In order to be able to determine the flow of the rainwater and establish the required floor level (FL) of the future building a detailed land surveying plan was required.

6.2 Data Acquisition

As a first step a TBM was established. The height value and the Easting-Northing position of the TBM was determined with a CORS[36] corrected RTK[37] GPS equipment using nearby Survey Control Marks. In this case the TBM could have an arbitrary height value, but the GPS was available and the procedure took less than half an hour. Another half an hour was allocated to taking a series of photos of the site using Canon 600D DSLR[38] camera with a 35 mm lens. Also the distances between nominated control points and the dimensions of the existing stormwater pits were measured using Leica Disto-A5 (DISTO) digital distance measurement tool. The images were processed into a dense point-cloud later in the office using Agisoft PhotoScan photogrammetry software (http://www.agisoft.com/).

At that point of time it was not clear which points of the streetscape will be relevant, hence the whole area was recorded employing close range photogrammetry. The software semi automatically listed the Easting, Northing (MGA) and AHD values of the pre-selected points of the dense point-cloud (Figure 54). These points were used as survey observations in order to create the 3D model of the footpath and the driveway. Although the PhotoScan is able to export the data into LAS file format or 3D PDF as well, in this example the dense point cloud was used as a real-size, measurable 3D virtual model of the area of interest.

Figure 54 Screen capture images of the point-cloud scene created by PhotoScan software. The Easting, Northing and the AHD values of the nominated points are marked with 'blue flags' and listed on the screen. (Created by: F. Acs)

---

[36] Continuously Operating Reference Stations
[37] Real-time Kinematic
[38] Digital Single–Lens Reflex camera (https://store.canon.com.au/en/Our-Products/Digital-Cameras/EOS-Digital-SLR-Cameras/EOS-600D)

6.3 Terrain modelling and the Design Procedure

The survey observation data and an architectural BIM authoring software, ArchiCAD 19, were used to construct the 3D model of the existing terrain and design the carport and the crossover. The virtual model of the design and the terrain of future building was constructed simultaneously. Although a proper BIM model of the project was constructed, the 3D modelling was used only to demonstrate the flow-path of the rainwater for the planning department officials. The Development Application required traditional 2D drawings. While the design was presented in animated 3D PDF as well, only the screen-capture images of the 3D model were carefully interrogated by the authorities. The pictures were captured from several angles such as top-view, bird-eye view, and worm’s eye view. Although the surface topography was an important guideline, the 3D terrain model was set to be see-through in order to be able to assess the objects below the surface. The structure and the geometry of the carport is accurate, the properties of the building materials are indicative, the shadow casting is realistic (Figure 55). All the 2D components, sections, elevations and plans were derived directly from the 3D model and submitted in PDF file format.

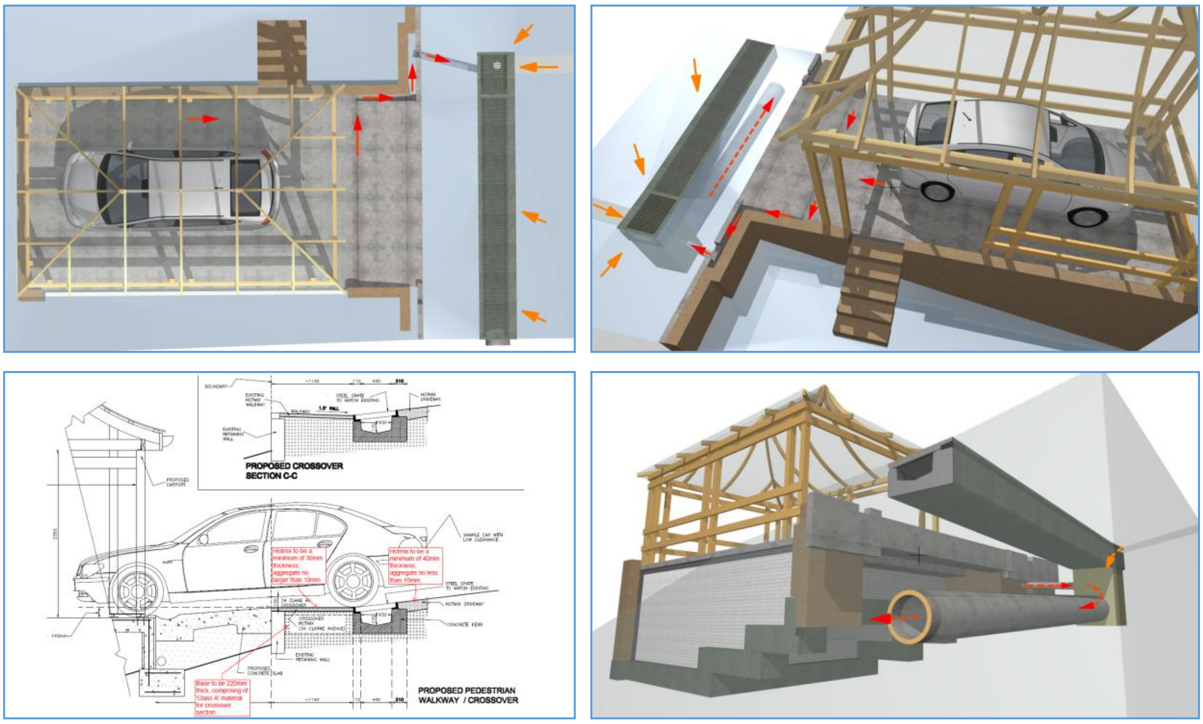


Figure 55 The 3D model of the design was used to demonstrate the rainwater flow directions. Only the 2D drawings were assessed for Development Application purposes by the city council. (Created by: F. Acs)

6.4 Design workflow

The design of a crossover and a carport seems to be a task for an architectural office. In an ideal world however the land surveying office should produce the 3D terrain model and the initial 3D design model of the crossover and the stormwater management. The 3D model of the design sent as an IFC file to the designer, where the footings, the walls and the roof structure is added to the package. The engineer corrects or approves the details of the structural elements. The improved package is finalised at the building surveyor's office where the design receives the final touch for submission. This was not the case during this project. All the survey, design and model crafting tasks were prepared, executed and presented by the same AEC professional, as is often the usual practice for a small project.

6.5 Data Presentation – Data Transfer

The modelling and the visualisation components of the BIM authoring software was used in this project. The 3D parametric design capabilities were mainly utilised to accelerate the terrain and building modelling, the software was essentially emulating a CAD software package. If data transfer occurred, it was done with the same computer. As it was indicated, the results were translated to PDF file format and submitted or distributed via Internet.

6.6 Summary

This case study described above demonstrates that when land surveying and the design procedure collaborate via 3D modelling then even a small project can be completed efficiently. Neither the site survey, nor the design procedure required more time than the traditional workflow practice would indicate. The 3D screen captures described the stormwater management clearly and helped to reduce the lengths of the Development Application approval procedure. These images were also successfully re-used during the budget negotiation with the builder.

7 Case Study 2 – Addition (Residential Development)

7.1 The Site / Data Acquisition

The area of interest is a 480 square metre lot within a residential zone of a township. The client's aim was to add an extension to the existing two level single dwelling family house. The sloping terrain and the setbacks allowed extending the house toward the backyard. The small parcel and the close proximity to other houses required a survey of the terrain, the existing building (exterior and interior), and the positions of the neighbouring buildings.

Two TBMs were established, one at the driveway, near the crossover, the other one at the end of the driveway with a clear line of sight from each other. The horizontal and the vertical positions of the TBMs were determined with a survey grade RTK GPS/GNSS. The street front TBM was used as a base station and the rover visited the nearby survey control marks (SPMs). The backyard TBM horizontal coordinates were used to establish the bearing from the street front TBM. A total station, positioned over the TBMs was used to survey the terrain and the position of the visually available building corners. Additional temporary TBMs were also established in order to achieve a closed loop around the existing buildings. A professional surveying software produced the contour lines, which were saved in DWG file format.

The building was measured with a DISTO and the data was recorded manually into a sketchbook. The walls of old buildings are not always parallel or perpendicular, therefore distances between structural walls were measured at frequent intervals. The distances of internal spaces and the visible corners were measured diagonally as well. The ceiling heights and distances between the terrain and the eaves were also measured with DISTO. A large numbers of photographs were taken using an off-shelf high resolution digital camera. The images are used as a visual notebook.

7.2 Terrain Modelling

An architectural BIM authoring software and the imported DWG contour lines were used to create the 3D terrain (5.3). The 3D model of the building was constructed in conjunction with the 3D terrain model using the same software and the same proprietary file format. During the modelling the local Cartesian coordinate system of the BIM software was used. It allows creation of the building parallel with the XYZ axes. The model of the building is organised according to floor levels or 'storeys' (1.5.4) within the software and temporarily registered only to the street front TBM. When the modelling was finished, the building objects were rotated to the direction defined by the two TBMs.

The terrain model was constructed within the AHD 'storey' (5.3) and also registered to the TBMs. Consequently the software local coordinate system will coincide with the MGA coordinates.

The model of the existing building and the 3D terrain together were considered the result of the site survey required by the architect. The site survey was exported into IFC2x3 file format and transferred as an e-mail attachment.

This project used the automatically generated IFC model settings, only two custom made properties, the projection (Pset_Projection[39]=MGA) and an arbitrary Weblink (Pset_Weblink=URL) were linked semi-automatically via 'IFC Scheme Setup' module. In ArchiCAD 19 software this module is used to add property or classification in general. It creates tags and blank bars for every nominated object. The individual objects, or object groups, such as the round-shape footing object properties in the example are managed via the 'Manage IFC Properties' module (Figure 56).

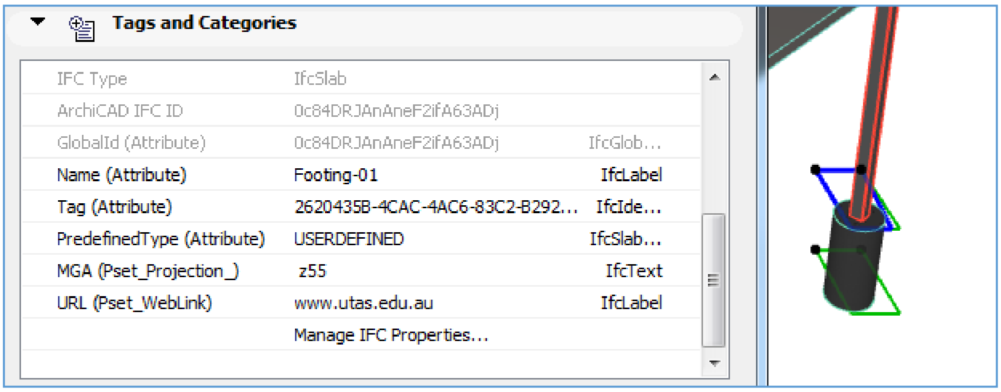


Figure 56 For demonstration purposes the URL tag points to ' www.utas.edu.au '. The green rectangle indicates the bounding box of the round shape concrete footing object (concrete pier). (Created by: F. Acs)

39 'Pset_' stands for the Property Set command

The blank spaces can be filled or modified with the values required by the project. The settings can be saved, exported, imported or edited in XML file format, therefore can be reused in similar projects.

For quality assurance purposes, the IFC model was interrogated first in 'BIMsight' model viewer. The 'BIMsight' allows to represent separately imported 2D and 3D CAD vector elements, e.g. contour lines from a traditional CAD drawing (DWG/DXF file format) and the IFC model superimposed. Consequently the terrain modelling and other vector elements can be assessed together with the 3D model (Figure 57).

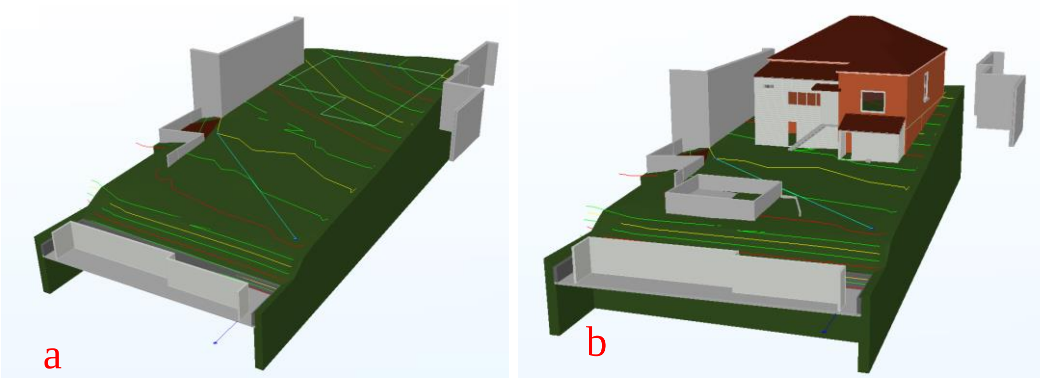


Figure 57 a.) IFC model of the terrain and the objects indicating the neighbouring buildings, the polylines (vectors, contour lines) are colour coded
b.) IFC model of the Site Plan in perspective projection (Created by: F. Acs)

Finally the IFC file was optimised by the SOLIBRI IFC Optimiser software[40]. The software vendor offers faster file opening and smaller file size after the optimisation and a loss less compressing process if the ZIP option is selected. The optimisation process was successfully tried on this project.

7.3 Building Envelope

To demonstrate the design of the future extension to the local government authorities, two models were required and presented: the model of the existing building and the model containing the extension. The town planners are accustomed to the presentation of the case in 3D. Previously free hand 3D sketches or manually drafted two point perspective technical

[40] http://www.solibri.com.au/products/solibri-ifc-optimizer

drawings were presented in order to be able to mark the problematic areas of the project. The appearance of CAD software accelerated the process; CAD generated perspective are required when the appearance of the future building or height values may affect the viewshed of the neighbour buildings.

In order to demonstrate the connection of the project with the current development regulations and city planning schemes, two BIM models were constructed: the existing and the proposed building. In order to satisfy the client, the interior spaces of the models were completed as well. Besides the architectural and structural elements, 3D kitchen and bathroom appliances, light fittings and furniture layouts are the integral part of the design. In this project both models were also equipped with a see-through Building Envelope object (Figure 58). The building elements in the ‘shadow’ are within the building envelope, and the elements outside are receiving ‘full ambient light’.

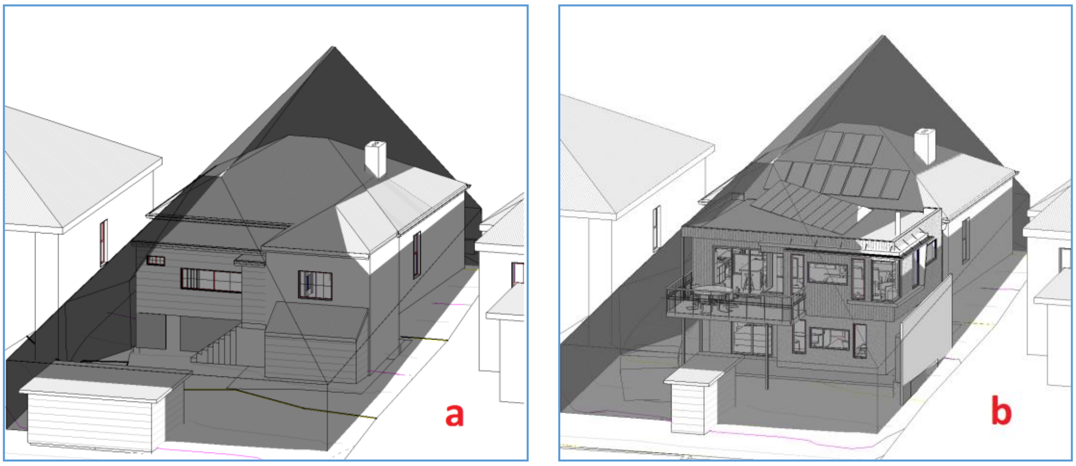


Figure 58 The IFC model of the project contains the 3D model of the buildings, the terrain, the Building Envelope objects and the contourline vectors
a.) The model of the existing building b.) The proposed future building
(Created by: MK – IDDS -2015)

This presentation tries to combine the advantages of the advanced high resolution visualisation and the 3D modelling capabilities of the BIM authoring software. During the design procedure the actual stage of the 3D model was used to evaluate ideas and solutions with the client and the future builder.

7.4 Deriving set-out data from IFC model

For this project among others the SOLIBRI model viewer on a small laptop was used as an experiment to check and derive set-out data using the BIM environment. Once the coordinated IFC model is opened in the viewer, the ‘Spin’ option of the model allows to freely orbit around the objects, and the mouse scroll can be used for zoom-in or out. When an object, such as the round shape footing is selected among others the exact MGA coordinates of the axis of the cylinder can be read as ‘Global X’ and ‘Global Y’ values (Figure 59). The ‘Global Top Elevation’ and the ‘Global Bottom Elevation’ values coincide with the AHD values of the object top and bottom plane, relevant to land surveyors. MGA coordinate and AHD values (XYZ) can be obtained from any point of the model manually, using the ‘Mark-up’ menu ‘Coordinate-Stamp’ tool. The ‘Component-Stamp’ marks the relevant information of the (building) material property values as text.

The ‘Top Elevation’ and the “Bottom Elevation’ values of the ‘Location’ menu are related to the lower finished floor level (LWR FFL) of the actual ‘storey’ which values are used customary for vertical navigation within the project by AEC industry professionals.

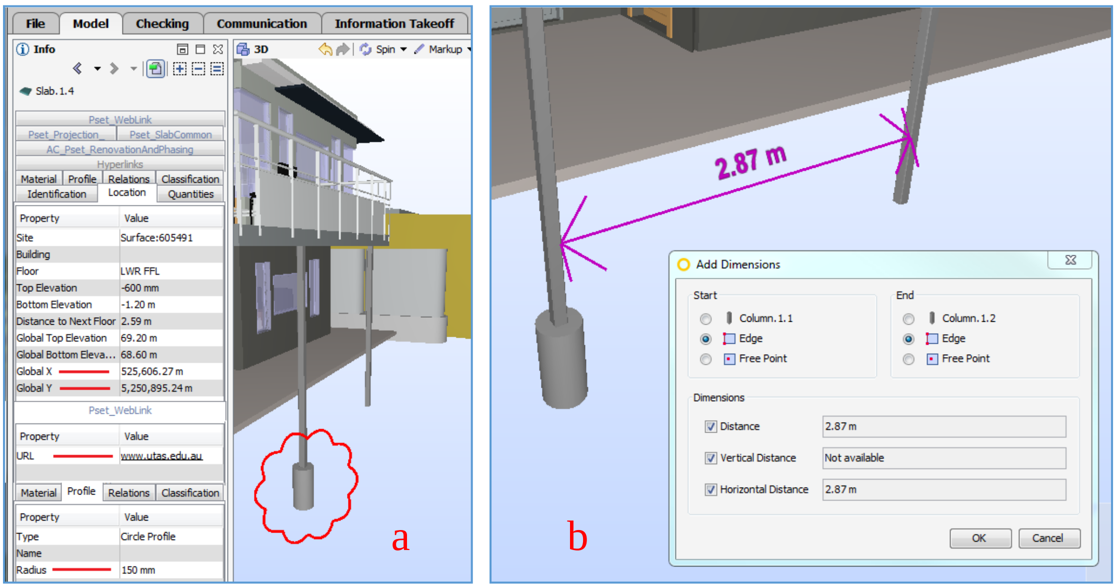


Figure 59 a.) The ‘Model’ info contains the attributes of the highlighted object. In this example the ‘Global X and Y’ (MGA coordinates), the attached URL address and the Radius value are marked with red line.
b.)The ‘Info’ bar ‘Dimension’ option allows to measure distances within the IFC model (Created by: F Acs)

Distances can be obtained manually with the use of mouse clicks. The 'Add Dimensions' pop-up menu radio buttons allow to choose the distance from the axis, from a plane ('Edge') or from a 'free Point'. The measured dimension stays on the model in 3D if the 'OK' is selected. The distance values are usually stored as a screen capture image for mobile communication purposes. The model, the screen captures and the annotations can be stored as a SOLIBRI model checker (SMC) file format, in order to save or record the actual state of the model and the marking.

For site measurement and setting out purposes the current version (June 2015) of SOLIBRI model viewer can be considered more user friendly if compared with BIMsight and DDS-CAD viewer software, which were also tested for this project. A user friendly model viewer can be a great advantage on construction site where the simplicity, the speed and the visual appearance might be important factors of the practical use.

7.5 **Summary**

Every object of the coordinated model, including the Building Envelope of this particular project was constructed with the REVIT BIM authoring software and was able to fulfil the requirements of the CDE. In spite of the fact that the 3D model was highly appreciated by the client, the future builder and the councillors, only the black and white screen capture images of the model, in perspective projection, were required for submission to the City Council. The images were used as aid for visual assessment, as a precise and accurate artistic impression. Most likely for an experienced town planner the images in conjunction with the 2D drawings might be sufficient evidence to support the building application. The IFC model however could be used for a rigorous and accurate analysis in order to determine the compliance of the design with the actual Building Code and City Planning rules. The BIM model of the project at this level of BIM readiness already contains a large amount of spatial information, terrain and building element details, including URL links. This information, as it was demonstrated, can be obtained manually from the IFC model with available free software. Therefore a design within the BIM environment by this time has the potential to supply the assessment procedure with swiftly achievable, accurate and traceable information even for a small project, without a detailed knowledge of the actual modelling procedure. Moreover the model, as it is, can be utilised to derive or check spatial information, such as horizontal and vertical coordinates of setout points, distances from existing building elements and additional attached information and metadata.

8 Case Study 3 – New Building (Residential Development)

8.1 The Site / Data Acquisition

The future building site is a triangular shaped cleared bushland parcel of land located on a steep hillside. Although the size of the parcel is relatively big compared to the surrounding lots, it offers only a limited area usable for a family house. The street connection and the services are located at the lowest part of the future building site. A steep unsealed driveway was cut from the crossover up to a small flat area which was designated for the future building. The neighbouring buildings are located more than 40 m away from the boundary lines.

Two TBMs were established, one near to the crossover, the other one close to the future building. The base station of the survey grade RTK GPS was established over the TBM located on the higher ground. Although the terrain was rugged, there were no obstacles preventing frequent observation of the natural surface and the street front. Almost every boundary peg was loose or inaccurately positioned back after the clearing of the higher vegetation. Further observations were executed with a Total Station in order to achieve more precise horizontal and vertical coordinate values for the TBMs, using several intact neighbour boundary pegs on the other side of the road. The loose boundary pegs were marked with signs indicating the need for a future Identification Survey. Land surveying software was used to process the observations and produce a (CAD) site survey drawing (Figure 60).

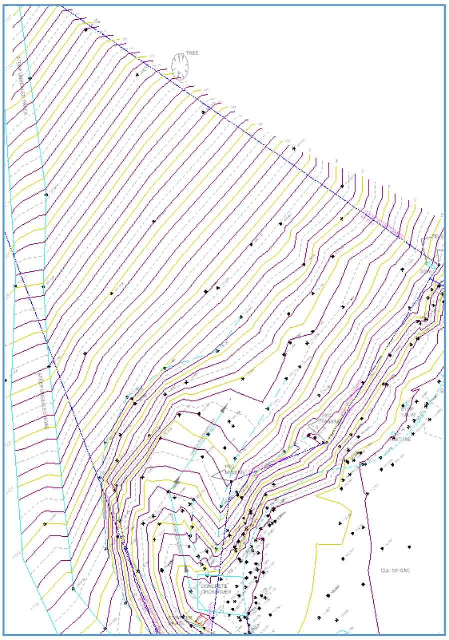


Figure 60 Screen capture image of the CAD Site Survey drawing (Drafted by: F. Acs)

8.2 Terrain Modelling

Architectural BIM authoring software and the imported contour lines (DWG file format) were used to create the 3D terrain (5.3). Although the terrain model was available from the start of the project, the architectural design process used non-parametric CAD software to produce the drawings. The BIM model of the future building was constructed later, in order to check the relationship between the design and the terrain in 3D. The model of the building and the terrain were merged at the last phase of the design.

The parametric terrain object contained the 3D model and the contour lines at 0.5 m intervals. The model was created using the registered 3D contourlines, consequently the local coordinates of the virtual model and the space above or under the terrain surface coincide with MGA z55 and AHD values. Several objects, such as the TBMs, the temporary boundary pegs, existing track, the concrete slab of the future building, and the proposed driveway object were added in order to create a BIM composite model of the future building site (*Figure 61*).

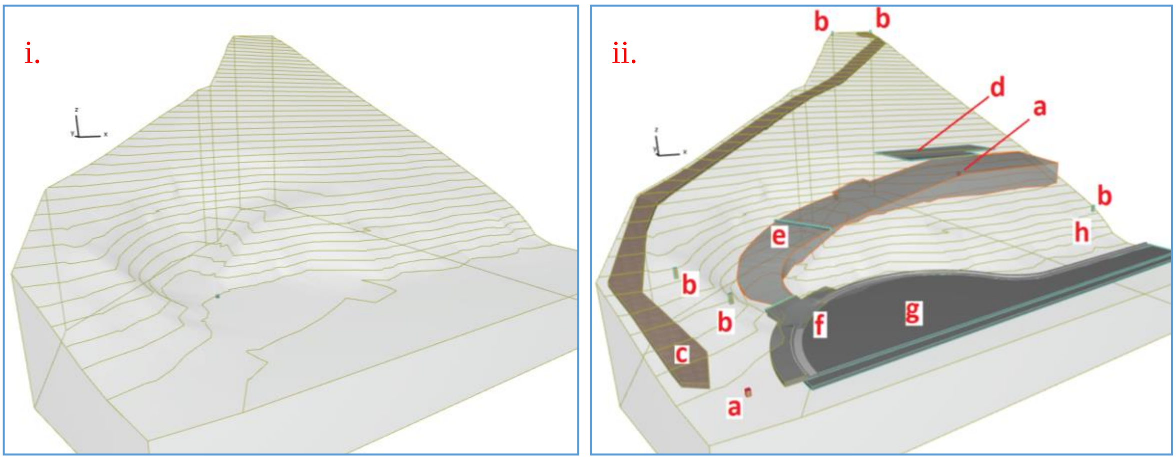


Figure 61 i.) The 3D model of the terrain ii.) The BIM model of the future building site a.- TBMs b.- 'temporary boundary pegs c.- unsealed track d.- the floor (concrete slab) of the future garage e.- the proposed driveway with st/w drainage grates f.- existing crossover g.- existing cul-de-sac (Created by: F. Acs)

The BIM site survey model (*Figure 61*) was visually assessed and digitally interrogated by the building designer using DDS and SOLIBRI model viewers (7.4). These viewers possess slightly different capabilities therefore in this project both software were utilised.

In spite of the see-through terrain model and the oversized, colour coded peg objects the architect had difficulties locating the TBMs, the boundary pegs, the services and detecting the boundary lines. In addition to this it was noted that the upper level TBM will be destroyed when the bobcat cuts the driveway path into the hillside.

There was no BIM Setout Plan required for this project. At this stage of the BIM model development however all required spatial information had already been present in the model and could already be obtained manually as previous described (7.4). A feasible solution might be the use of parametric peg objects to mark boundary corners, TBMs and setout points. The experiments with oversized or ‘signal emitting’[41] pegs within this project did not produce any satisfactory results. A feasible option is to use prefabricated peg objects as customisable library elements which closely resemble the pegs used for real life setting outs. In order to detect and mark these small elements, such as pegs, survey points such as ‘nails’ etc. the use of a customised Clash Detection module seems to be a practical option. The ‘machine reading’ and automatic marking capabilities of the BIM environment may result in accurate and precise detection of all designated objects regardless of the size of the project. The use of a Clash Detection module does not require the introduction of a new tool. As an experiment the pegs were exported as IFC files and re-imported as pseudo third party objects. The IFC file format helps to maintain the spatial integrity and the spatial relationship between the ‘pegs’. It also seems to be easier to trigger a clash detection procedure using imported objects into an existing model, in this case the terrain model. The initial experiments with automatic ‘Peg Detection’ method reinforced this prediction.

Next, the BIM model of the future building was merged into the BIM site plan in order to visualise the possible cut-and-fill options, stormwater drainages and the details of the necessary retaining walls (Figure 62).

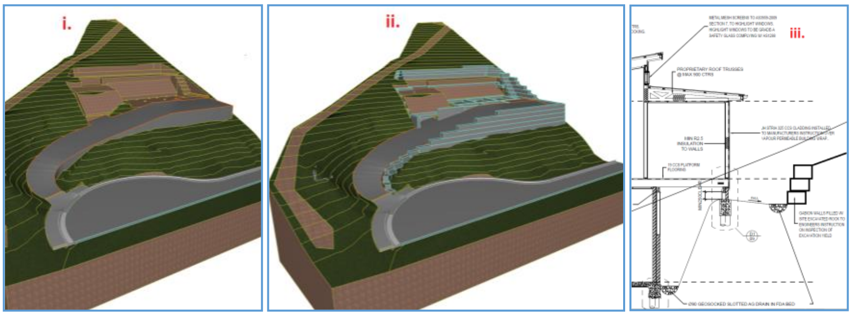


Figure 62 i.) Visualised BIM model of a cut-and-fill option ii.) BIM model of the footings and the retaining walls (Created by: F. Acs) iii.) 2D Section and details of the upper level Gabion retaining walls and the building (Designed and drafted by: DWDD)

41 Visual signals such as blinking light or ‘Gravity’ signals for snapping the mouse tip

The visualised contour lines on the model were used as a visual scale and navigation tool on the 3D surface. All the required coordinate and height values, 3D distances, and slope angles were manually derived and used as numeric input data for calculations in an Excel spreadsheet. The use of a (3D Boolean) ‘intersection’ operation could produce semi-automatic volume calculations, however the method in this particular project did not offer obvious advantages, and was therefore abandoned.

Designing and building of the model of the driveway in 3D was a labour intensive procedure with frequent use of traditional CAD methods. This task could have been executed within minutes with a designated BIM module for road alignment and design. Employing the Rhino-Grasshopper-BIM authoring software and custom built re-usable scripts (1.5.8), if available, could have offered a more efficient alternative. A preferred solution however would be a professional land surveying BIM module for all the design tasks requiring cut-and-fill processes.

8.3 **Building Zone-Stamps for Indoor Navigation**

Zone-stamps are generated semi-automatically by the BIM authoring software. As was indicated previously, zone-stamps are used as metadata storage containers as well as basic elements for internal navigation within a project (5.8). A series of zone-stamps can be used to describe the geometry of the ‘empty’ spaces surrounded by architectural and structural elements, and therefore can be considered to be the ‘skeleton’ of a project. Moreover the zone-stamps are coordinated 3D parametric objects equipped with attributes, attachments, hyperlinked documents and direct links with the Internet via hyperlinked URLs. Most importantly the zone-stamps, as schematic descriptions of projects, usually generate very small file sizes while containing vital information about a project.

The colour coded zone-stamps, describing the ‘empty’ spaces or rooms within this project, were extracted and visualised in perspective projection (Figure 63). Traditionally all the zone-stamps have ID numbers. The first digit(s) usually indicate the vertical location, the ‘storey’ number, followed by the ‘room’ number. Theoretically a large amount of freely customisable attributes can be attached to the ID number. For a family house, such as in this project the architects usually attach a name, a zone category, a function name, the description of the floor finish and the floor finish area value (Figure 63 and Table 4).

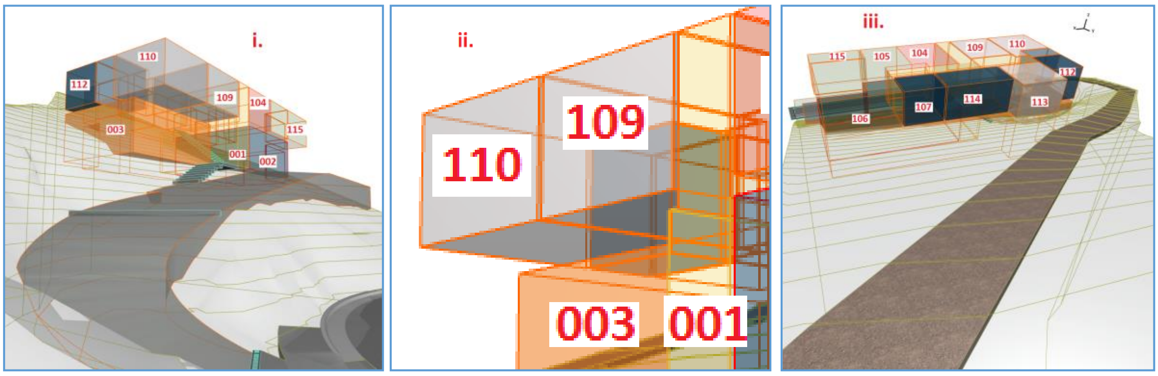


Figure 63 Zone-stamps of the future building. Refer to Table 4 for ID numbers
i.) View from the South ii.) Detail from East iii.) View from the North.
(Created by: F. Acs)

Table 4 Zone Stamp simplified architectural attribute table. This can be considered as a relational database which can be extended with additional data including spatial location values.

ID	Function Name	Zone Category 01=Residential, 02=Void ,	Floor Finish	Finished Area (m²)		ID	Function Name	Zone Category	Floor Finish	Finished Area (m²)
001	Entry	01	Timber	9.18		107	Laundry	01	Ceramic	6.94
002	Garage	01	Concrete	59.76		108	Corridor	01	Carpet	7.82
003	Void	02	Gravel	73.43		109	Bedroom 2	01	Carpet	14.71
101	Stairs	01	Timber	6.04		110	Bedroom 1	01	Carpet	14.54
102	Corridor	01	Timber	7.93		111	WIR (Bed-1)	01	Carpet	3.60
103	Storage	01	Timber	1.94		112	ENS (Bed-1)	01	Ceramic	6.80
104	Kitchen	01	Timber	16.04		113	Bedroom 3	01	Carpet	11.52
105	Meal	01	Timber	32.16		114	Bathroom	01	Ceramic	11.76
106	Lounge	01	Timber	12.97						

The 2D version of the zone-stamps structure, similar to the one described above, is widely used by architects to compose a bill of quantities. The data is semi automatically derived by the software. This feature can be utilised for the three-dimensional object zone-stamps as well. For indoor navigation the spatial components of the zone-stamp objects are the area of interest. Additional zone stamps were also added. The window and the door objects (including the garage door) are colour coded (Figure 64). A possible indoor navigation algorithm therefore could locate the available cross section areas for doors, internal corridors and stairs in order to calculate the possible routes of pedestrian traffic within this building. Certain values (parameters) and the spatial location are allocated to each room or zone-stamp. These values are also related to the vertical position of the room.

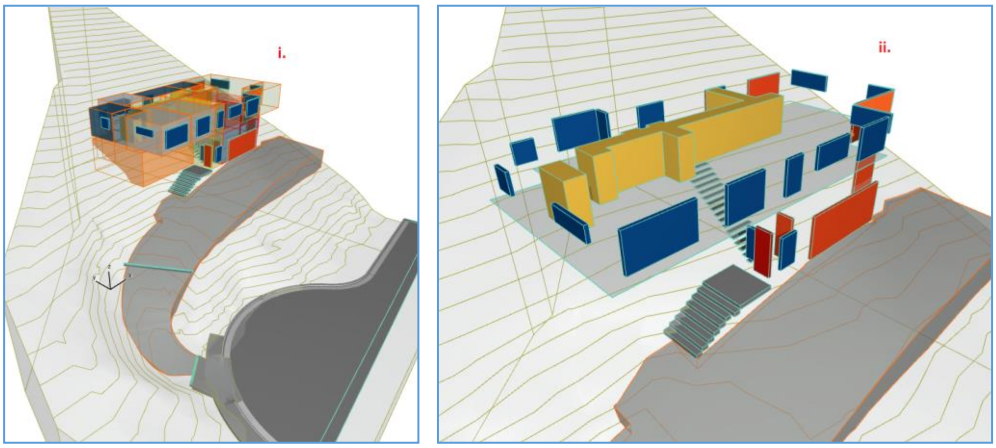


Figure 64 Additional zone-stamps for indoor navigation purposes. The windows are indicated with blue objects, the door with red. The entry door is dark red. i.) All zone-stamps are activated ii.) Some zone-stamps are hidden in order to be able to see the internal horizontal pedestrian corridor marked with yellow. The stairs are indicated with grey. (Created by: F. Acs)

The flow of traffic, in case of an emergency, might be evaluated in a manner that is similar to GIS watershed calculations (Zlatanova et al. 2015). The window objects and their vertical distances from the ground internally and externally also factor into an emergency scenario. All stamp-zone objects could be equipped with a special 'location' attribute, based upon the 'as-built' surveying observation data, conducted by land surveyor professionals. Therefore the coordinated objects (zone-stamps) are directly linked to the building local coordinate system[42] and with their accurate 'location-stamps' to the MGA as well. Future indoor navigation systems therefore may establish links, via BIM, to:

- GPS/GNSS navigation systems,
- Cadastre and spatial databases such as 'TheLIST, and the

42 Stored in archives or architectural databases

- online maps and geodatabases.

8.4 Zone-stamps for 3D Cadastre

As an experiment a schematic BIM model of the project was constructed for a possible 3D Cadastre system (5.8.4). The model is similar to the indoor version of BIM; it contains the same or similar objects. A custom made 'building-shell' zone stamp replaced the indoor-navigation zone-stamps (Figure 65).

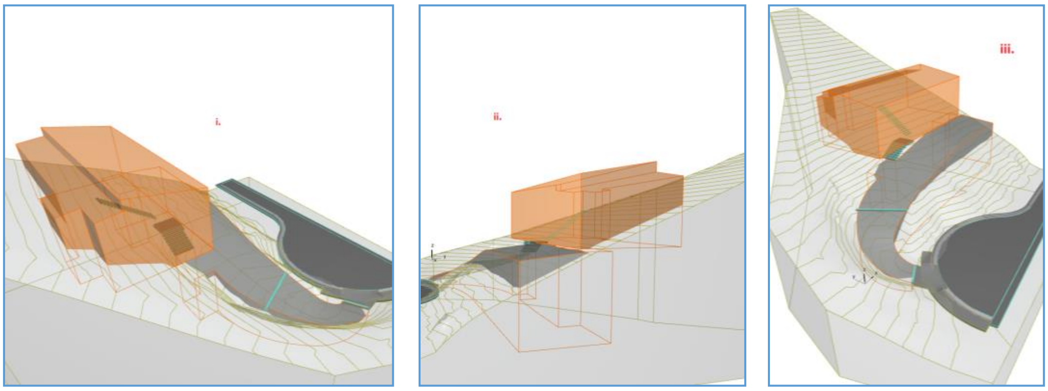


Figure 65 The composite model of the project prepared for a 3D Cadastre and it consist the terrain object, the Building object, and the Driveway object. The crossover and the cul-de-sac objects are additional elements for visualisation purposes. i.) View from South-West ii.) View from North iii.) View from South-East (Created by: F. Acs)

The characteristics of the BIM model above might be a valuable element for a possible 3D Cadastre. The schematic objects such as the zone-stamps and the simplified objects possess the ability to contain:

- the necessary spatial information and geometry
- the information and the documents required for a 3D Cadastre registration system
- the link to a map projection which is associated with a nationwide cadastral framework system such as MGA

The schematic model may require significantly less digital storage space.

8.4.1 Obtaining spatial information and geometry

The experimental model is intended to represent the geometry of the property. In this example it consists of the terrain model, the boundary peg objects, the driveway, and the outside shell of the building. The unsealed track was not registered as an easement and was therefore removed. (Figure 65). The terrain model was not modified or customised; it represents the surface of the parcel at the time of the surveying. The East end of the terrain model,, the section of the cul-de-sac, the crossover and the designed driveway - including the stormwater grate objects - are used as additional elements. The shell of the building is a modified zone-stamp, which exactly follows the outside surface of the building except for the eaves. At this stage of the experiment, only significant overhangs or unusual eaves[43] are represented within the schematic building object (*Figure 66*).

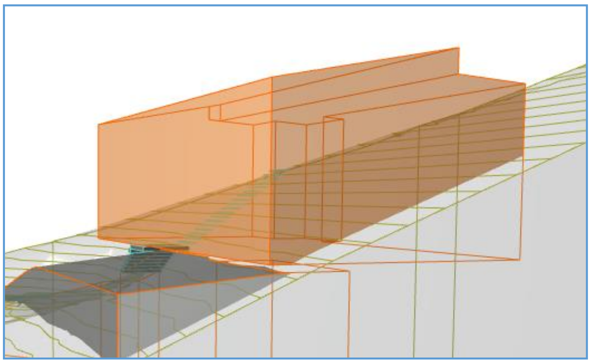


Figure 66 The custom made 'building shell' zone-stamp prepared for 3D Cadastre. (Created by: F. Acs)

The presence of the outdoor and the interior stairs, indicating the entry point to the building, are optional. The boundary peg objects are visually undetectable. The efficient visual representation of the 3D boundary lines or planes is yet to be solved. The use of colour coded surfaces or wrapped aerial photographs in conjunction with 3D polyline edges along the boundary might offer a feasible solution. The ArchiCAD 19 software allows for creation of 2D or 3D polylines in the form of a parametric object. The 2D drawing of the parcel; the boundary lines and the 2D contourlines were stored at the AHD 'storey' (5.3 and Figure 67).

43 The typical eave's overhangs are 150, 350, 450 and 600mm (Empirical data)

The annotations were attached as attributes. This experimental BIM model was saved in its native and in IFC3x2 file format. Both file format contains the same elements, therefore the 2D information (AHD storey) such as 2D contour lines and the boundary polygon are part of the model in the IFC file format as well (Figure 67). When the IFC file format model is interrogated in BIM-viewer software, the spatial information or the values of the 3D measurements can be obtained with the use of mouse click activated pop-up menus (7.4). Among other the coordinate stamp might be a useful tool for land surveyors as a setting-out utility tool.

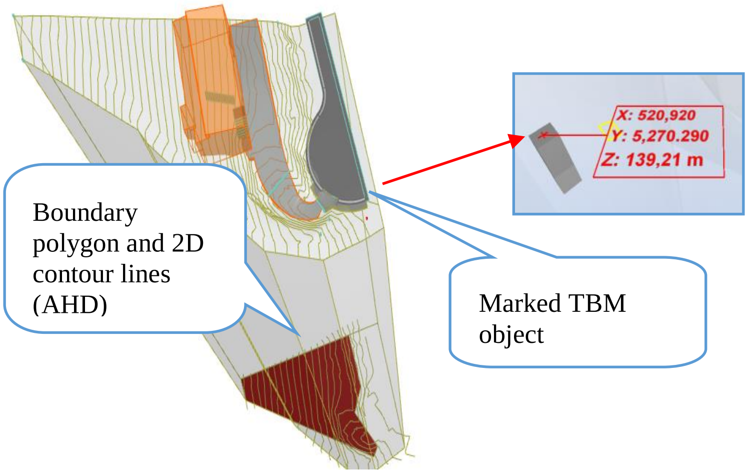


Figure 67 Bird-eye-view of 2D and 3D objects in the same model (Created by: F. Acs)

Most of the free BIM viewer software are user friendly and intuitive. Obtaining information is a straightforward procedure. The use of a free BIM viewer for ‘reading’ 3D drawings, and the use of the free PDF viewer for the ‘reading’ of 2D line drawings are similar procedures. The zoom-in, zoom-out, orbit capabilities and the advantages of the hyperlinked documents are acknowledged (Figure 68). The free BIM viewers in conjunction with a spatial database such as TheLIST might have further potential to offer, and the ability to support 3D Cadastral information.

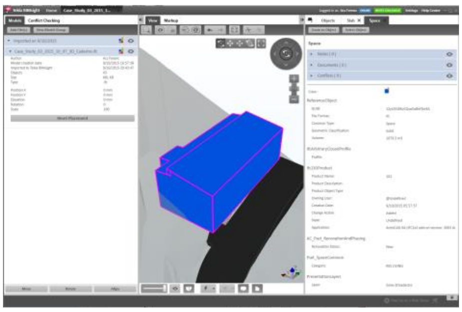


Figure 68 Obtaining information using BIMsight viewer. (Screen capture image)

8.4.2 Attached documents / Link to map projection

As it was indicated in various chapters above, a coordinated BIM model is composed of prefabricated (library) and custom made parametric objects. The following characteristics of the BIM environment should also be recalled:

- The BIM environment allows us to form a schematic and simplified BIM model which may contain the required spatial information and the geometry of a property.
- The BIM possesses the ability to store attributes, attachments and direct links (via URL) within the model. Consequently a purpose built and customised BIM model may support a technical solution which is suitable to incorporate the information and the documents required by a 3D cadastre.
- The objects within the model are organised within the local coordinate system of BIM authoring software. With the help of TBMs provided by a land surveyor, the model can be registered to a spatial position, where the local coordinates of the BIM software coincide with the coordinates of the designated map projection. Consequently, in this project the horizontal coordinates of the objects are directly linked to MGA, and the vertical coordinates to AHD.
- The files are stored or distributed in the virtual space with the help of the existing digital networks, utilising the CDE and the neutral IFC file format.

8.4.3 File sizes

This project in its native format contains the full Development Application BIM model, the architectural elements including the 3D bathroom, restroom, doors and windows as add-on library elements. The project also contains the structural BIM model and the required line drawings with annotations in 2D. The custom built Indoor Navigation and 3D Cadastre objects are also stored within this file on a layer setting allocated to this purpose. The terrain model alone has several copies. There is an ‘archived’ 3D terrain model stored on a ‘frozen’ layer (Figure 67), a terrain model with the embedded (subtraction) track and the driveway.

Finally there are customised terrain objects for cut-and-fill purposes (subtraction and intersection).

The exported BIM IFC files contain the following elements:

Table 5 The file sizes of the example project.

Model type	**Objects**	**Uncompressed File Format**	**File Size (KB)**
BIM (Complete documentation)	3D Architectural and Structural 3D Terrain , track, driveway, crossover and cul-de-sac 3D cut-and-fill and retaining walls 3D Indoor Navigation zone stamps 3D building shell and 2D parcel, contourlines 2D line drawings and annotations	PLN (A BIM authoring software native format)	22,350
BIM (Project)	3D Architectural and Structural 3D Terrain , track, driveway crossover and cul-de-sac 3D cut-and-fill and retaining walls 2D line drawings and annotations, 2D parcel and contourlines	IFC2x3	2,650
Indoor Navigation (Schematic)	3D Terrain , track, driveway, crossover and cul-de-sac 3D Indoor Navigation zone stamps	IFC2x3	836
3D Cadastre (Schematic)	3D Terrain , track, driveway, crossover and cul-de-sac 3D building shell and 2D parcel, contourlines 2D parcel and contourlines	IFC2x3	682

Elements of the architectural and the structural BIM model of the project were used for the experimental Indoor and 3D cadastre models. The construction of the customised Indoor Navigation and 3D Cadastre objects and their attributes required several trial-and-error processes. Once the settings were prepared and tested, the creation of the indoor navigation zone-stamps could be automatized. The building-shell object however required more consideration and manual involvement. The Indoor-Navigation model and the Cadastre models were individually saved and translated to IFC file format. The file sizes can be further reduced by employing BIM model checker and IFC optimiser software.

When applicable or required, all objects and the terrain model of the project should be updated with spatial information derived from the current As-built survey conducted by land surveying professionals.

8.5 Conclusion

Professional land surveying software is more than capable of processing field observations into a proper TIN surface and supporting designers with precise 2D technical drawings. Collaboration with designers via CDE requires however the use of a BIM authoring software in order to create parametric terrain objects or a federated BIM model equipped with the necessary attachments, attributes and stored in a BIM compatible file format. Until an applicable land surveying software hits the market, as a second best option, an architectural BIM authoring software has to be employed (5.3).

BIM software such as ArchiCAD or REVIT are based upon mature, object oriented (proprietary) software technology. Both products provide an intuitive modelling workspace, pop-up menus and the object-setting interfaces. The 3D navigation in the virtual space is very similar to the 'First-person Shooter Engine'[44] (FPS) (Mitchell & Lowe 2010), the visualisation technology resembles the Photoshop, comprehensive tutorials are available on YouTube. Consequently an average spatial-science undergraduate is capable of starting BIM modelling with these software almost immediately.

As was demonstrated in this work, a BIM environment allows production of a 3D terrain (5.3) and BIM Feature Survey Plan (5.4). The use of a BIM module also permits creation of land surveying documentation which can be part of a traceable and transparent Federated Model (5.7.1) of the project. Consequently the land surveyors' office will be able to collaborate directly, with all the stakeholders. The use of the zoning tools, such as the Building Envelope (5.8.1 and 5.8.2), the IFC file format, and the utilisation of a free BIM viewer (7.4) may open further opportunities and a more useful BIM surveyor model. It is beyond the scope of this project to indicate the implications of a possible 3D Cadastre system, however the experiments with coordinated BIM objects as useable tools for a future system of that kind seem to suggest its feasibility.

[44] Such as EON Zermatt and ArchiCAD in 2006 (http://www.tdt3d.com/64_617_0.html)

9 Summary

Impacts and Opportunities for Land surveying and the Cadastre

The latest developments of the AEC industry and the increasing use of CDE and BIM are driven by architects and engineers. The topography of a building site and spatial data however are vital to support the design, the construction and the maintenance processes throughout the entire life-cycle of a project. The land surveying profession, while maintaining the integrity of the spatial data within the BIM, may considerably enhance the value of the collaborative efforts between the stakeholders of the project (AIA 2013).

BIM environments do not influence the field work methods, the survey calculations, the data validation and adjustment procedures. The current survey practise, equipment and the applied sophisticated technologies are capable of producing precise, accurate and suitable spatial data for BIM, seamlessly.

While the digital 3D space is a natural environment for the land surveying professionals, the construction of BIM objects may impact or alter typical workflows in the office (5.4). The highly qualified and well equipped land surveying professional however may find that the BIM environment offers a wide range of opportunities for an increased participation in the AEC industry (Figure 69). Currently almost every finished construction requires an As-built survey for the record. The precisely manufactured building elements require accurate and professional setout processes. The operators/owners may need regular survey update processes generated by the increasing importance of FM. The AEC industry and a possible Indoor Navigation (5.8) presumably will increasingly rely on the knowledge and expertise of the land surveying professionals in order to maintain the spatial integrity of the BIM. The preparation and execution of a future 3D Cadastre system undoubtedly will bring the spatial profession into a new level of expansion.

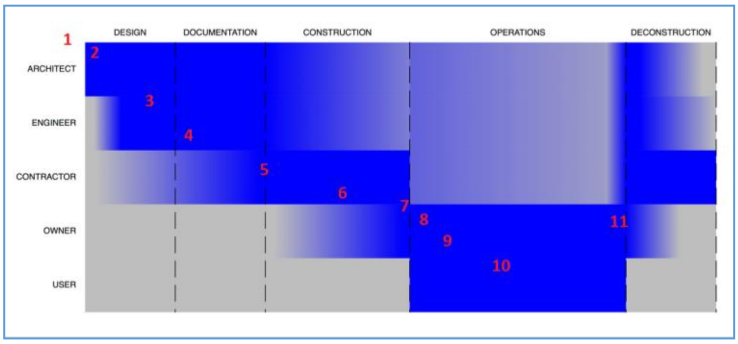


Figure 69 Participation of the land surveying profession within the AEC industry
1.) Boundary Survey 2.) Feature Survey, Building Envelope, Underground Services
3.) Site Survey Terrain Model 4.) Federated model, Cut-and-Fill, Driveway / roads
5.) Setting-out, Construction Survey 6.) Construction monitoring 7.) As-built Survey
8.) 3D Cadastre 9.) Indoor Navigation 10.) Re-survey or update for FM
11.) Re-survey (As-Built update) (Source: Shoegnome Modified by F. Acs)

The latest technological advances, such as networked computers and the development of telecommunication and navigation systems create unprecedented opportunities for the AEC industry. For the first time in human history the current level of coordinated 3D modelling and potential for collaboration between professionals, already permits an almost complete artistic freedom in design without compromising high precision engineering and construction. It is now for the land surveying profession, while defining and maintaining the spatial components of ingenious designs, to place the projects at their destination; down to earth.

10 Glossary

2D	Two-dimensional
3D	Three-dimensional
2D/3D/4D…	Descriptions of BIM implementation with increasing 'richness' of associated information

A

AAD	Algorithm Aided Design (http://www.grasshopper3d.com/page/tutorials-1 http://www.arturotedeschi.com/wordpress/?page_id=6691)
ABA	Architectural Barriers Act (US) – (http://www.access-board.gov/the-board/laws/architectural-barriers-act-aba)
ADA	Americans with Disabilities Act (US)
ADAAG	Accessibility Guidelines (ADAAG) (US)
ADSL-2	Asymmetric Digital Subscriber Line (Standard for high speed broadband Internet)
AEC	Architecture, Engineering, Construction (AE / AECFM)
AECOO	Architecture, Engineering, Construction and Owner Operator (AECO)
AHD	Australian Height Datum (http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/geodetic-datums/australian-height-datum-ahd)
ArchiCAD	Architectural BIM authoring software (http://graphisoft.com.au/)
Autodesk	Software vendor (http://www.autodesk.com.au/)

B

BCA	Building Code of Australia (http://www.abcb.gov.au/about-the-national-construction-code/the-building-code-of-australia.aspx)
B-Rep	Boundary Representation (http://www.buildingsmart-tech.org/ifc/IFC4/final/html/schema/templates/body-brep-geometry.htm)

BCF BIM Collaboration Format (http://www.buildingsmart-tech.org/specifications/bcf-releases)

BI Business Intelligence

BIM Building Information Model (Modelling/Management)

BIMsight Free BIM-viewer software (TEKLA / Trimble) (http://www.teklabimsight.com/)

BIMx BIM presentation application (http://www.graphisoft.com/bimx/)

BrIM Bridge Information Modelling

BISDM Building Interior Spatial Data Model

BMS Building Management System (FM)

bsDD buildingSMART Data Dictionary ?

C

CAD Computer Aided Design

CAM Computer Aided Manufacturing

CAE Computer Aided Engineering

CDE Common Data Environment (British Standard PAS1192-2) (http://www.bimtaskgroup.org/pas11922-overview/)

CIM City Information Modelling

CityEngine is to supply 3D contents from GIS data and also generate scenes and 3D models.

CityGML is an XML-based format for the storage and exchange of 3D urban models. It extends Geography Markup Language 3 (GML3)

CIOB Chartered Institute of Building (UK) (www.ciob.org/)

Clash Detection A process to identify conflicts and issues

Cloud Resource or database remote from a user's computer

CNC Computer Numerical Control ; The design, produced by CAD converted into sequence of alphanumerical codes in order to control a (milling) machine

Computational Design the extensive use of computers and mathematical approach in order to create design objects in 3D

CSG Constructive Solid Geometry

D

DDS BIM authoring software (NEMETSCHEK) (http://www.dds-cad.net/)

DDS-CAD Viewer Free BIM-viewer software (http://www.dds-cad.net/downloads/dds-cad-viewer/)

DMU Digital Mock-ups

Dropbox Data storage and transfer service (www.dropbox.com/)

DSM Digital Surface Model

DTM Digital Terrain Model

DURAARK Durable Architectural Knowledge (http://duraark.eu/)

DWG “drawing” (Autodesk) file format

DXF “data exchange format” (Autodesk) file format

E

F

Facebook Social (multimedia) social network application (www.faceboo.com/)

FF&E Furniture, Fixtures & Equipment

FL Floor Level

FM Facility Management

FME Feature Manipulation Engine (software) http://www.safe.com/fme/

Free BIM-viewer Free software application to visualise and interrogate BIM models

G

gbXML File format, used to exchange building data from modelling software to analysis software and back

GIS Geographic Information System

Google-Drive Free online data storage service (https://www.google.com.au/drive/)

GLODON Chinese AEC IT software developer (https://www.linkedin.com/company/glodon-software-co-ltd)

Google Earth Virtual Globe (https://www.google.com/earth/)

GPS Global Positioning System

GraphiSoft BIM authoring software developer

GSA U.S. General Services Administration (http://www.gsa.gov/portal/content/105075)

GUI Graphical User Interface

GUID Globally Unique Identifier

H

HVAC Heating, Ventilating, Air-conditioning

I

IFC Industry Foundation Classes, openBIM file format (http://www.buildingsmart-tech.org/specifications/ifc-view-definition)

IFC2x3 IFC file format (Feb. 2006)

IFC4 IFC file format (Mar. 2013)

ITC4EE ITC for Energy Efficiency

IKEA Multinational group of companies that designs and sells ready-to-assemble furniture

ITC Information and Communication Technology

J

K

L

LADM Land Administration Domain Model (http://www.iso.org/iso/catalogue_detail.htm%3Fcsnumber%3D51206)

LAN Local Area Network

Liscad Professional land surveying software (http://www.listech.com/liscad/)

Listech Software development company (https://www.listech.com/profile.aspx)

Listech Neo Geospatial software (https://www.listech.com/neo/default.aspx)

LOD Level of Development, Level of Detail

LOI Level of Information

M

MEPF Mechanical, Electric, Plumbing, Fire

Mercator projection A cylindrical map projection presented by G. Mercator in 1569 (http://www.britannica.com/science/Mercator-projection)

MGA z55 Map Grid of Australia zone 55

MIT Massachusetts Institute of technology (http://web.mit.edu/)

MPS Model Progression Specification

Monte Carlo Simulation Monte Carlo methods used in optimisation problems to solve any problem having a probabilistic interpretation

N

NEMETSCHEK Software developer company. (http://www.nemetschek.com/)

NIBS National Institute of Building Sciences (US) (http://www.nibs.org/)

O

O7M Operations and Maintenance (FM)

OneDrive Free online data storage service (https://onedrive.live.com/about/en-au/)

OGC Open Geospatial Consortium (http://www.opengeospatial.org/)

P

Pandora's Box a process that once begun generates almost endless chain of events

PDF File format (Portable Document Format)

PRC

Q

R

REVIT BIM authoring software (http://www.autodesk.com/products/revit-family/overview)

RDS Room Data Sheet (FM)

RFID Radio-Frequency Identification

RIBA Royal Institute of British Architects (https://www.architecture.com/riba/home.aspx)

RM Rapid Manufacturing

ROI Ratio of return to Investment

RRR Rights, Restriction, Responsibilities

S

SDI Spatial Data Infrastructure

Skype Online multimedia (social media) application (http://www.skype.com/en/)

SlimBIM BIM modelling service (http://www.slimbim.com/en/)

SlimBIM2go Simplify Leverage Integrate Mobile BIM (http://www.slimbim2go.com/)

Solibri BIM authoring software (http://www.solibri.com.au/)

Solibri Model Viewer Free BIM-viewer software (http://www.solibri.com.au/products/solibri-model-viewer)

SPM Standard Permanent Mark

Street View (https://www.google.com/maps/streetview/)

StruSoft Finite Element Method (FEM) software (www.strusoft.com/)

T

TBM Temporary Bench Mark

TEKLA BIM authoring software (http://www.tekla.com/)

Tetrahedron A solid object having four plane triangular faces; triangular pyramid

Part of Trimble Navigation (www.trimble.com)

TEKLA BIMsight Free BIM Viewer (http://www.teklabimsight.com/)

TEN Tetrahedron Network

TIN Triangular Irregular Network (3D TIN)

U

URL Uniform Resource Locator (Protocol identifier)

V

VEC "vector"; File format

VD&DVirtual Design and Construction

VICO Software developer (Trimble) (http://www.vicosoftware.com/)

VR Virtual Reality

W

X

XML Xtensible Markup Language

Y

YouTube video sharing website (www.youtube.com)

Z

11 Bibliography

Agar, C, Burt, N, Cumming, I, Hainsworth, J, Howie, K, Maple, T, Mccormack, C, Sutherland, D & Katsalidis, F 2014, ‘BIM in Practice - BIM What is it ?’, *AIA on-line*, accessed from <http://wp.architecture.com.au/bim/wp-content/uploads/sites/40/2014/07/BIM-What-is-it.pdf>.

AIA 2013, ‘BIM Outreach O9 - Surveying for BIM v1’, *AIA on-line*, accessed from <https://revitall.files.wordpress.com/2014/06/o9-bim-for-surveying-aia-ca.pdf>.

Aien, A, Kalantari, M, Rajabifard, A & Williamson, I 2011, ‘Advanced Principles of 3D Cadastral Data Modelling’, *2nd International Workshop on 3D Cadastres, 2011,*, no. November, pp. 377–396, accessed from <http://3dcadastres2011.nl/documents/022_presentation.pdf>.

Aien, A, Kalantari, M, Rajabifard, A, Williamson, I & Bennett, R 2013, ‘Utilising data modelling to understand the structure of 3D cadastres’, *Journal of Spatial Science*, vol. 58, no. 2, pp. 215–234, accessed from <http://www.tandfonline.com/doi/abs/10.1080/14498596.2013.801330>.

Arnold, BJ 2002, ‘High hopes for hi-tech’, *BBC News World Service*, accessed from <http://news.bbc.co.uk/2/hi/business/2522537.stm>.

Autodesk-Revit 2007, ‘BIM’s Return on Investment’, *Architecture*, pp. 1–5, accessed from <http://static.ziftsolutions.com/files/8a7c9fef2693aa1e0126d282571c02c7>.

Bazjanac, V & Crawley, DB 1997, ‘The Implementation of Industry Foundation Classes in Simulation Tools for the Building Industry’, *Proceedings of Building Simulation ’97*, no. July 1994, pp. 203–210, accessed from <http://www.inive.org/members_area/medias/pdf/Inive/IBPSA/UFSC585.pdf>.

Bergin, M 2011, ‘History of BIM’, *Architecture Research Lab online*, accessed from <http://www.architectureresearchlab.com/arl/2011/08/21/bim-history/>.

BIM Forum 2015, ‘Level of Development Specification for Building Information Models v2015 draft’, *bimforum.org*, no. April, pp. 0–124, accessed from <http://bimforum.org/wp-content/uploads/2015/04/Files.zip>.

Breunig, M, Al-doori, M, Butwilowski, E, Kuper, PV, Benner, J & Haefele, K 2014, ‘Proceedings of the 9th 3DGeoInfo Conference’, in *3DGeoInfo Conference*, accessed from <http://archive-ouverte.unige.ch/unige:45315/ATTACHMENT01>.

CIOB-online 2015, ‘Common Data Environment (UK)’, *Chartered Iinstitute of Building (UK)*, no. July, accessed from <http://www.designingbuildings.co.uk/wiki/Common_data_environment_CDE>.

Clark, K 2008, ‘A new physics superstar’, *US News and Word Report*, no. January, accessed from <http://www.usnews.com/education/online-education/articles/2008/01/10/a-new-physics-superstar>.

Coates, P, Arayici, Y, Koskela, K, Kagioglou, M, Usher, C & O’Reilly, K 2010, ‘The key performance indicators of the BIM implementation process’, *Practice*, accessed from <http://usir.salford.ac.uk/9551/6/ID_15_camera_ready.doc>.

Crane, N 2003, ‘Mercator : the man who mapped the planet’, *Oriion Books*, vol. 3, accessed from <http://www.amazon.com/Mercator-The-Man-Mapped-Planet/dp/075381692X>.

Czmoch, I & Pękala, A 2014, ‘Traditional Design versus BIM Based Design’, *Procedia Engineering*, vol. 91, no. TFoCE, pp. 210–215, accessed from <http://linkinghub.elsevier.com/retrieve/pii/S1877705814030665>.

Dana, JD 1854, *A System of Mineralogy* Fourth Edi., George P. Putham & Co., New York, accessed from

<http://books.googleusercontent.com/books/content?req=AKW5QadGg0JcYQEz8ZEoYN59D0-dY5umt7ZzlPWkQijd0PuEfG3vfRdcRvBjJqRFYt2H7cFkX5RNmFVCoxeXwnq-yxltpnpVOwWRXw4rJ2wB2UB1AYE6bge_hUIRpKERl0ViahB0lGQeCOknZ2amsq7bQTCWJibZF0TjyHHatYqJgN9GsC2-f0l2UFXWAlgy_lDjwmExLo>.

Davis, D 2013a, ‘The Challenges of Parametric Modelling (Chapter 2)’, *danieldavis-online*, pp. 1–42, accessed from <http://www.danieldavis.com/thesis-ch2/#2>.

Davis, D 2013b, ‘Modelled on Software Engineering : Flexible Parametric Models in the Practice of Architecture’, , no. February, accessed from <http://www.danieldavis.com/papers/danieldavis_thesis.pdf>.

Dulux-online 2015, ‘Dulux BIM solutions’, accessed from <http://www.dulux.com.au/specifier/colour/bim>.

Duncan, EE & Abdul Rahman, A 2015, ‘3D GIS for mine development – integrated concepts’, *International Journal of Mining, Reclamation and Environment*, vol. 29, no. 1, pp. 3–18, accessed from <http://www.tandfonline.com/doi/abs/10.1080/17480930.2013.828443>.

Eastman, C & Henrion, M 1977, ‘GLIDE: a Language for Design Information Systems’, *ACM Computer Graphics*, vol. 11, pp. 24–33, accessed from <http://design.osu.edu/carlson/history/PDFs/eastmanGLIDE.pdf>.

El-Mekawy, M & Östman, A 2010, ‘Semantic Mapping: an Ontology Engineering Method for Integrating Building Models in IFC and CITYGML’, in *Proceedings of the 3rd ISDE Digital Earth Summit*,pp. 1–11, accessed from <http://news.digitalearth-isde.org/Bulgaria/pdf/32_El-Mekawy_Sweden_paper.pdf>.

GSA-US 2007, ‘GSA BIM Guide 01 – Overview’, *The National 3D-4D BIM Program*, p. 41, accessed from <http://www.gsa.gov/graphics/pbs/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf>.

GSA-US 2009, ‘GSA BIM 04 - Guide for 4D Phasing v1’, *The National 3D-4D BIM Program*, accessed from <http://www.gsa.gov/portal/mediaId/226795/fileName/BIM_Guide_Series_04_v1.action>.

Hodgson, T 2008, ‘Digital Design - the potential of Computer Aided Designing in design learning environments’, *Design and Technology Education: An International Journal*, vol. 11, no. 1, pp. 10–17, accessed from <http://ojs.lboro.ac.uk/ojs/index.php/DATE/article/download/108/88>.

Holloway, BJ 2012, ‘Solar House 2 . 0 The Endesa Pavilion’, *gizmag*, no. May, accessed from <http://www.gizmag.com/endesa-pavilion-solar-house-20/22627/>.

ISA_Project_Team 2008, *What is Building Information Modeling (BIM)?*,.

Isikdag, U, Horhammer, M, Zlatanova, S, Isikdag, U, Horhammer, M & Zlatanova, S 2014, ‘Semantically Rich 3D Building and Cadastral Models for Valuation’, in *4th International Workshop for 3D Cadastres*,pp. 35–54, accessed from <http://mycoordinates.org/semantically-rich-3d-building-and-cadastral-models-for-valuation/>.

Kamardeen, I 2010, ‘8D BIM modelling tool for accident prevention through design’, *26th Annual ARCOM Conference*, no. September, pp. 281–289.

Keay, J 2001, ‘The Great Arc’, *HarperCollins*, p. 182, accessed from <https://books.google.com.au/books?id=vtfdC7CH4_0C&dq=The+Great+Arc+by+John+Keay&hl=en&sa=X&ei=ypeQVfG8KYPNmwXc2IDYDQ&ved=0CB0Q6AEwAA>.

Kotnik, T 2006, ‘Algorithmic Architecture Introduction to the MAS Colloquia 2006 / 07’, *Caad*, p. 16, accessed from <http://wiki.arch.ethz.ch/asterix/pub/MAS0607/MasColloquia/Lecture01.pdf>.

Kurrer, K-E 2012, ‘The History of the Theory of Structures: From Arch Analysis to Computational Mechanics (Google eBook)’, , p. 848, accessed from <http://au.wiley.com/WileyCDA/WileyTitle/productCd-3433018383.html>.

Lehmer, J 2013, ‘Evolution of the Roman Dome’, accessed from <https://engineeringrome.wikispaces.com/Evolution+of+the+Roman+Dome>.

Liebich, T, Adachi, Y, Forester, J, Hyvarinen, J, Karstila, K, Reed, K, Richter, S & Wix, J 2007, ‘Industry Foundation Classes IFC2x3’, *buildingSMART*, p. 2007, accessed from <http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/>.

Lymath, A 2014, ‘The 20 key BIM terms (UK)’, *NBS online*, vol. 2, no. December, accessed from <http://www.thenbs.com/topics/bim/articles/the-20-key-bim-terms-you-need-to-know.asp>.

McNell, D, Allison, H, Black, W, Cukrow, M & Harrison, K 2009, ‘Building Information Modelling’, *InfoComm International*, vol. Vol.1, p. pp 225–231, accessed from <http://www.infocomm.org/cps/rde/xchg/infocomm/hs.xsl/33591.htm>.

Mills, F & Payne, T 2015, ‘SHARE + INSPIRE (theB1M)’, *theB1M*, accessed from <http://www.theb1m.com/pdfs/The-B1M-Media-Information-2015.pdf>.

Mitchell, J & Lowe, R 2010, ‘Simulation of Clinical Work Environments using BIM and Computer Gaming Technology’, *Asia Pacifin Journal of Heath Management*, pp. 31–39, accessed from <http://www.achsm.org.au/DownloadDocument.ashx?DocumentID=219>.

Model-Support-Group 2015a, ‘buildingSMART PA-1 Parametric Documentation’, accessed from <http://www.buildingsmart-tech.org/future/old/ifc-future-extensions/project-proposals/pa-1-parametric/pa-1-parametric-documentation>.

Model-Support-Group 2015b, ‘Participants of the official buildingSMART IFC2x3’, *buildingSMART*, p. 2, accessed from <http://www.buildingsmart-tech.org/certification/ifc-certification-2.0/ifc2x3-cv-v2.0-certification/participants>.

Mordue, S 1994, ‘IFC – it is simply misunderstood ?’, *NBS online*, p. 1997, accessed from <http://www.thenbs.com/topics/bim/articles/ifc-is-it-simply-misunderstood.asp>.

Mortari, F, Zlatanova, S, Liu. Liu & Clementini, E 2012, ‘IGNM: A Novel Approach for Deriving Connectivity Graphs for Indoor Navigation’, *GDMC Delft University of Technology*, accessed from <http://www.gdmc.nl/publications/2014/Improved_Geometric_Network_Model.pdf>.

Natspec 2011, ‘NATSPEC National BIM Guide v1.0’, *Natspec-NBG-online*, no. 10 December 2013, accessed from <https://vdcscorecard.stanford.edu/sites/default/files/NATSPEC_National_BIM_Guide_v1.0.pdf>.

Noer, M 2012, ‘One man, one computer, 10 million students’, *Forbes*, no. November, pp. 1–8, accessed from <http://www.prisim.com/wp-content/uploads/2013/12/One-Man-One-Computer-10-Million-Students-How-Khan-Academy-Is-Reinventing-Education-Forbes.pdf>.

O’Donnell, JT, Maile, T, Rose, C, Mrazović, N, Morrissey, E, Regnier, C, Parrish, K & Bazjanac, V 2013, ‘Transforming BIM to BEM: Generation of Building Geometry for the NASA Ames Sustainability Base BIM’, *Bim*, no. January, p. 26, accessed from <http://buildings.lbl.gov/sites/all/files/LBNL-6033E.pdf>.

Paulson Jr., BC 1976, ‘Designing to Reduce Construction Costs’, *Journal of the Construction Division*, vol. 102, no. 4, pp. 587–592, accessed from <http://cedb.asce.org/cgi/WWWdisplay.cgi?7078>.

Quirk, V 2014, ‘A Brief History of BIM’, *ArchDaily*, no. May, pp. 1–10, accessed from <http://www.archdaily.com/?p=302490>.

Ryan, J 2014, ‘BIM and the UK Construction Industry’, *JJRYAN Technical Report TR-1405A*, vol. 2012, no. 04/30, accessed from <http://www.jjryan.com.au/publications/TR-1405A.pdf>.

Salih, S 2012, ‘The Impact of BIM/VDC on ROI’, *Department of Real Estate and Construction Management*, vol. Master of, no. 177, accessed from <https://www.kth.se/polopoly_fs/1.340468!/Menu/general/column-content/attachment/Thesis_Salih_SEN_final.pdf>.

Sebastian, R 2010, ‘BIM - by Sebastian’, *TNO*, accessed from <http://www.pantura-project.eu/Downloads/Building Information Modelling_Pantura background paper.pdf>.

Stoter, JE 2004, ‘3D Cadastre’, *Netherlands Geodetic Comission*, no. September, accessed from <http://www.itc.nl/library/Papers_2004/phd/stoter.pdf>.

Sutherland, IE 1963, ‘Sketchpad, A Man-Machine Graphical Communication System’, *designwoldonline.com*, accessed from <http://images.designworldonline.com.s3.amazonaws.com/CADhistory/Sketchpad_A_Man-Machine_Graphical_Communication_System_Jan63.pdf>.

Sutherland, IE 2012, ‘Looking Back: The TX-2 Computer and Sketchpad’, *Lincoln Laboratory Journal*, vol. 19, no. 1, pp. 82–84.

TAS-Dept-of-Health-and-Human_Services 2014, ‘Strategic Implementation of BIM’, *Dept of Health and Human Services (TAS)*, no. December 2014, p. 1, accessed from <http://bim.natspec.org/index.php/component/content/article/11-bim-documents/113-dept-of-health-and-human-services-tas-strategic-implementation-of-bim>.

Tennety, C 2007, ‘Machining Feature Recognition Using 2D Data of Extruded Operations in Solid Models A’, *etd.ohiolink.edu*, no. June, accessed from <https://etd.ohiolink.edu/rws_etd/document/get/ohiou1181406949/inline>.

VICO 2014, ‘5D BIM’, *VICO on-line*, pp. 4–5, accessed from <http://www.vicosoftware.com/what-is-5D-BIM/tabid/88207/Default.aspx>.

Zlatanova, S, Xiong, Q, Zhu, Q.Du, Z, Zhang, Y & Zeng, L 2015, ‘Multi-Level Indoor Path Planning Method’, *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XL-4/W5, no. May, pp. 19–23, accessed from <http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-4-W5/19/2015/>.

12 Table of Figures