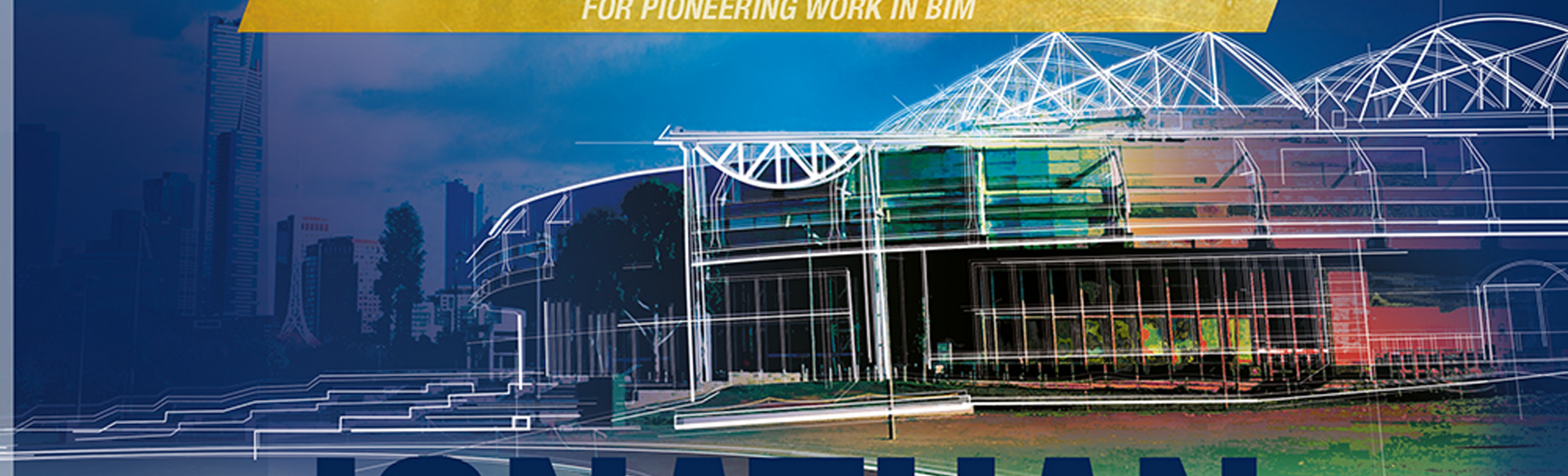
UNDERSTANDING BIM

THE PAST, PRESENT & FUTURE

BY THE RECIPIENT OF THE
2016 PRINCE PHILIP GOLD MEDAL
FOR PIONEERING WORK IN BIM



JONATHAN INGRAM

Understanding BIM

Understanding BIM presents the story of Building Information Modelling, an ever evolving and disruptive technology that has transformed the methodologies of the global construction industry. Written by the 2016 Prince Philip Gold Medal winner, Jonathan Ingram, it provides an in-depth understanding of BIM technologies, the business and organizational issues associated with its implementation, and the profound advantages its effective use can provide to a project team. Ingram, who pioneered the system heralding the BIM revolution, provides unrivalled access to case material and relevance to the current generation of BIM masters.

With hundreds of colour images and illustrations showing the breadth and power of BIM, the book covers:

- The history of BIM
- What BIM is in technical and practical terms
- How it changes the day to day working environment
- Why we need BIM and what problems it can solve
- Where BIM is headed, particularly with regards to AI, AR, VR and voice recognition
- International case studies from a range of disciplines including: architecture, construction management, and retail

Professionals and students in any field where the inter-disciplinary aspects of BIM are in operation will benefit from Ingram's insights. This book is an authoritative account of and reference on BIM for anyone wanting to understand its history, theory, application and potential future developments.

Known as the "Father of BIM", Jonathan Ingram designed and wrote the first Building Information Modelling systems. He has been honoured with the 2016 Prince Philip Gold Medal by the Royal Academy of Engineers for his "exceptional contribution to engineering" for "pioneering BIM". He taught the first courses in Object Modelling (BIM) at Harvard University, and was the winner of the 1990 British Computer Society Medal for Outstanding Innovation.

Understanding BIM

THE PAST, PRESENT AND FUTURE

Jonathan Ingram

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This book has been prepared from camera-ready copy provided by the author.

DEDICATION

To Harry, Alexander, and Maximilian, and, to Susana.

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Editor’s Note

I met Jonathan Ingram though the Autodesk Users Group International (AUGI) web-forum in 2015, while following a thread discussing the Origins of Revit. I was pleased to see that at least one other poster seemed to agree with me, that it was with SONATA, REfLEX and ProReflex, the last of which I had bought in 1997 from Parametric Technology Corporation (PTC) when Silicon Graphics Inc (SGI) released their O2 Irix 6.3 Workstation, the first BIM system available at a reasonable price, at least to sole practitioner Architects. It took a bit of effort to find him, having used a pseudonym for his post, but I wasn’t surprised when he replied to mine and turned out to be the building software writer of our time.

I studied at Cambridge University School of Architecture (CU SoA) 1970-75 and knew many at the Centre for Land Use and Built Form Studies (CLUBFS), but it is was only much later through the internet that I discovered what they were all really doing in detail. Of course, we all bought their books and some of us attended the CU Engineering Department summer course on Computing, learning Fortran, preparing me for Telex machines, essential to UAE professional life until the early 1980s, when the fax machine was invented. I had also plotted the setting out of Bury Bus and Railway Interchange while working my 2 years pre-qualification for the RIBA with Essex Goodman and Suggitt, Architects in Manchester UK, using our Structural Engineer Bingham Blades’ drafting system in 1977, prior to moving to the Middle East. I can’t imagine how much that table sized plotter must have cost at the time, but it must have been staggering by comparison with printing costs today.

CU SoA lectures and debate had convinced me that computers would eventually enable the whole building to be considered, including all its systems, perhaps even design and planning, where they had made a good start, not just lines and printing essential Drawings and Specifications required for daily professional practice. As anyone who has designed or built anything knows, it’s the building cost that causes all the problems, often resulting from poor Bills of Quantity especially, so why anyone would have marketed a computer system that couldn’t do it all is beyond me. I had considered the early systems and baulked at the price, so perhaps they were simply ahead of their time. A Whitechapel Computer Works MG-1 had a base price of around 10,000 pounds, half a Porsche 928S in 1984.

I have a chicken and egg theory about tools being accidental in their discovery, like using charcoal left over from cooking for cave painting, only to be developed once everyone has been convinced of their need, and hence the pencil thousands of years later. Does everyone remember adverts at the first computer shows c1980, suggesting that hundreds of thousands of dollars were required to make a computer drawing, compared with Michelangelo’s masterpieces using a pencil? It was only much later that I discovered he didn’t even have a pencil, but I expect that BIM only recently becoming widespread has nothing to do with its obvious benefits and desirability, but more to do with price, not the software but the computers on which to run it, and buildings if you don’t. When I bought my first system, the software cost about the same, but the work station itself was much more expensive; over the last 10 years, all that has changed, but the cost and value of building continues to go up.

There is also the issue of knowing what you want before being able to design a suitable tool, often itself depending on knowing what’s possible. I expect that the requirement for BIM was always there, but as the computers to process it were not, no-one knew they could have it, except of course, some of us lucky enough to have been at CU SoA when CAD was being invented.

It is an honour to be invited to edit Jonathan’s book, having seen his name in documents enclosed with my PTC ProReflex CD so many years ago: better still to have been able to contribute to some ideas that will improve BIM for all of us, outlined in Chapter 17 concerning the use of Apps and Plug-ins, allowing standard office software to read from the BIM direct. Who would ever have guessed ?

Don’t be in any doubt that without BIM, sole practitioner Architects are a thing of the past; everything will be designed and built by corporations, who can’t do without it either. As for Clients, it goes without saying; BIM has it all.

Peter Dew MA(Cantab) RIBA

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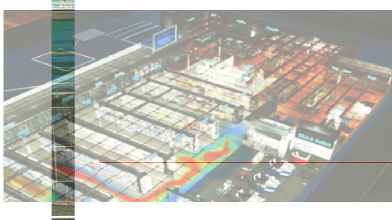

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Introduction

For most of my working life, I have saved things of interest into an old battered suitcase.

During the 1970s, my suitcase filled with 3D images, fonts, movies, and, in fact, anything graphical; there was no rhyme or reason, just items of interest.

During the 1980s, while writing SONATA, I continued throwing images, drawings, cuttings, documents and more movies into the suitcase. I found another case for the overflow.

While writing REfLEX in the 1990s, I threw even more of the same. By 1997 I was weary of writing systems and weary of throwing, so the suitcases were put away and forgotten.

Since then, I have watched, with interest, the up-take of building object modelling aka BIM. I had been somewhat surprised at the lack of clarity in the texts and by the lack of honesty about authorship and influence of these systems. In the end, the scale tipped, irritation overtook inertia, and I felt the time had come to retrieve the then 20kg of suitcases from storage and write this book. At the instigation of the Victoria and Albert Museum my battered suitcases found their RIBA Archive in South Kensington, London.

Over the years I have been often asked how I came to write such computer systems and how, decades on, I am still writing such systems.

As a young boy, I was raised in inland Australia, where by today's standards there was nothing to do; no TV and certainly no electronics. As a result I spent my time dismantling, designing and building, boats, planes, electric helicopters (powered from the mains), explosives, rockets, and war machines. My father had given me an account at the local hardware merchant. He stocked all the raw materials one could ever want; from sulphur and saltpetre to Uranium 237, from wood, nails, and glue, to electrical cable, motors, and magnets. I created many different projects and at one moment, I attempted to make nitroglycerin.

No one is more surprised than me, that I survived my childhood.

I went on to study Civil Engineering and, while studying, I was introduced to slide rules and computers. The former made me realize that there must be a better way and that the latter, was the better way (in spite of being fed with punch cards).

During this time, I designed a steel stadium, pipe networks, and other things that student engineers do. Everything was executed by hand using slide rule and pen and ink. When I graduated I worked as an engineer for a time, designing and setting out country roads. I used "chains" (a metal tape measure that needed to have temperature corrections applied), calculated by log tables and drawn by hand. Some of the resulting roads and small bridges still exist in remote parts of Victoria.

The pain of doing this by hand, believing there was a better way, led me to search for something. My first breakthroughs came when I worked as a scientist for the CSIRO, an Australian Government Research Organization. At the CSIRO, we had a very fancy range of computers, including the largest computer in the world at the time. These toys were an extension of my childhood, only more fun. I completed many different computer science projects: compilers, interpreters, databases, typesetting, and perhaps most importantly, a range of 3D systems. One of the more interesting projects was a hidden line movie of a street scene of buildings for planning approval for the Hobart courts. I still have the sprocketed 16mm film, possibly one of the first architectural movies generated for planning purposes. (To view this, download the UnderstandingBIM app from your app store). The tool set I developed was incorporated for the systems a few years later.

Some years later, I moved to England (via all the countries between) and there, knowing what I wanted to do, I found the perfect environment to hone my skills. I chose an architectural practice with heavy computer leanings, Gollins Melvin Ward Partnership. They were working with a 2½ D drafting system called RUCAPS (developed at Liverpool University) based on BDS concepts to which I added a separate stand-alone 3D modelling system.

The arrival of the first desktop workstations meant it was time to build what I had been formulating for some years; an accumulation of the systems from my days as a scientist and live architectural requirements. When GMW failed to see my vision I left, much to their annoyance. For my development I bought the first desktop machine available in the UK, a very expensive Whitechapel Computer Works MG-1.

Although I had a vision, it was only the beginning of several lonely years in my attic in Berkhamsted designing and building in what was to become the new CAD system (see Appendix 4 and 5). These are interesting in that they meet the criteria of a modern BIM system.

There were NO tools available to help; no libraries, no interfaces and almost no graphics capability. There was a Fortran compiler and a technique for setting pixels on or off on the monochrome screen. To do this, I had to set individual bits in memory to draw lines. I wanted the look of the new windows and pull-down menus, as recently developed by Rank Xerox. I had to write the overlaying windows system to manage the screen. Pull-down menus had to be done from first principles. The piece of code I was most proud of was a few lines of recursive code that managed the overlapping of all the different windows on the screen. It recursively divided each window so that only that part visible was drawn.

When the system was coming together, two years into the project, I was joined by Murray Pearson, an architectural draftsman. He was brilliant. We had only one machine between us. I would work on it from early till 6 pm, and he would do the night shift, often finishing at 3 am. He came up with lists of bugs and issues and I endeavoured to fix these in the day. Murray had considerable input into the final design of the system. Rashmi Mistry extended the team to three late in 1987. He helped hugely in sorting out the tangles.

The result of all this was SONATA.

I invested in a colour screen and went to the USA and showed it at a CAD conference (well actually a hotel room near the conference). The idea of having automated coordination of plan, elevation and 3D and the complex parametrics sparked interest in various companies. Autodesk expressed an interest and said they wanted it, and in October 1987 we went to Sausalito with high hopes and little cash. There we demonstrated the capabilities to senior members of Autodesk and started talking seriously. Halfway through the meeting the phone calls started. The bad news was that it was on Black Monday 1987 and we went home empty-handed. I do remember an employee's car in the Autodesk car park with license plate "AutoBad".

Despite my reservations, I was persuaded to sell SONATA to GMWC. It went on to be sold to the Canadian company Alias. Alias overstretched themselves and abandoned a number of projects including SONATA. There were distributors in 25 countries at one time.

Perhaps the first real user of SONATA in real projects was Mark Edwards, an architect and engineer. He built a team to fix the many bugs I managed to include. He is still putting teams together to fix my bugs.

In 1992 I decided to have another go. Technology had progressed leading to improvements in the concept, in particular the compilation of objects and merging with the system at runtime. This meant vast improvements in execution speed. Many graphical libraries were available simplifying the coding. I was in contact with some of the people who had worked on SONATA; Gerard Gartside joined me, and together, we built REfLEX Systems. Initially we worked in my house in Berkhamsted, but when we had 12 employees, my very patient ex-wife strongly encouraged us to move into an industrial unit up the road. Around that time I was appointed Professor of Engineering and Construction Management at the University of Reading, but was unable to take up the appointment because of the subsequent sale of REfLEX.

In 1996 I negotiated and sold REfLEX to Parametric Technology Corporation (PTC). Almost the whole company moved to the USA where we started work on ProReflex. There I was appointed Chief Technology Officer of PTC.

The founders of Revit, employees of PTC at this time, had been working on the mechanical CAD system Pro/ENGINEER. When they left PTC, they acquired a non-exclusive development rights ProReflex (REfLEX) including all code, documentation and access to the REfLEX developers. They went on to develop Revit; the overlap in functionality between Revit and REfLEX/ProReflex is huge. I still have Revit Version 1 from 2000 running on my desktop. Some of the errors between the two systems are similar and possibly identical (see the Understanding BIM app for developments). One of the claims on the Revit 1.0 box is "The first parametric building modeler"; there are at least two systems before Revit. The amount of accrued development over the years from software and usage must be in the thousands of man years if you go back to BDS, RUCAPS, SONATA and others. I find it hard to believe that the Revit developers arrived at this point without in-depth reference to ProReflex/REfLEX/SONATA, given the similarity in most of the functionality (except families).

I left PTC after several years to pursue my own interests. Over the following years, I founded startups, innovated, and patented in various fields, including sensors, electronics, renewable wave energy, pharmaceuticals, and tyre pressure measurement. I also taught postgraduate Architects at Harvard on Object Models in Architecture, I had a research project in AI with Prof Jean Jacques Slotine at MIT, I wrote a light opera (lyrics, libretto and music)(watch the billboards!), and several other projects. Somewhere in there, there was a book called "The Miracle Molecule". The molecule was miraculous as a cancer cure, but failed phase 3 trials with FDA due to a change in protocol.

It has been fascinating to watch the development of technology. When I started technology was a room full of punch card driven computers with the processing power found in a contemporary musical birthday card. Memory, speed and storage was measured in thousands and now everything is measured in billions.

More recently, I have returned to Information Modelling, applying the principles of BIM to Retail. This has been spiced up with these technologies of Augmented Reality, Artificial Intelligence, Virtual Reality, voice recognition, and language understanding, and, best of all, really fast machines and mobile computing.

The new app that comes with this book is an experiment in just this (see app store for UnderstandingBIM). The idea is to bring the book to life, with animations, models, videos, additional images, interviews, other media, and as yet untested, a direct social media link. Material can be added to the app even after this book is published.

In terms of man-machine interfaces and capabilities, Artificial Intelligence and Enhanced Reality take us to new realms. My belief is that one day soon, we will have systems that are cognisant, capable and coherent, aiding and assisting many aspects of human endeavour. I sincerely hope that my own efforts will inspire designers of the future.

Jonathan Ingram

London
2020

Addendum by Mark Edwards (CEO of 345 Holdings)

"My favourite story on that was being a naive architect just out of university I started using the first cut of SONATA on a live project (as you would) and I was working through the night on a deadline when I tried a Boolean operations on a curved wall and the whole project disappeared at 3am, I spent the next 5 hours panicking trying to recover as I had no idea what was happening.

When my boss came in he saw I looked exhausted and said ok, let's call Jonathan.

You came in and asked what I'd done, to which I replied 'what I've done, it's this bloody software '.

You said can you tell me exactly what you did in which order, which I did and you said aha that's a 'bug'...! What's a 'bug' I replied and you explained to which I innocently asked why you'd put that in there then.

You then asked what else I'd like in the system and I rattled off 5 ideas and you said 'I can have 4 of those by next week but the 5th will take longer' and that's exactly what started my career because when you delivered the new functionality I realised what was possible with the right minds and being able to talk each other's language and I've been doing it ever since...!"

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Why Do We Need BIM? 1

An intelligent, computer-based model of a structure must help in its conception, design, construction and management. This process, now known as Building Information Modelling or BIM, has become the mainstay of modern building and infrastructure design, construction, and management. It forms the basis of a complete new digital approach across the Construction Industry, from town planning through structural analysis, to highway and tunnel design through ships. This book takes us through the journey of this revolution, how it was achieved, how it is used and where it is going.

This first chapter details the traditional drawing-based approach to building design, how this tends towards fragmenting the design process. It shows how BIM is necessary to solve this and other problems.

DRAWING BASED CONSTRUCTION

Building construction is one of the most information intensive industries. Buildings (and infrastructure) are complex and the projects behind their construction are equally complicated and ever-changing, invariably generating huge volumes of information which must be accessible to large numbers of diverse companies and individuals. Many of these are united for the first time by the project itself. Traditionally drawings have been used to represent the basis of the building. It is difficult to imagine some of the buildings of antiquity being built without some form of drawings.

The earliest surviving “construction drawing”, a stone wall etched with the profiles of columns and mouldings, was found in the Temple of Apollo at Didyma constructed just before the time of Christ. Since then and probably before then, buildings, roads, harbours and mausoleums have been built using designs set out on paper, papyrus or in the case of Didyma, stone.

The very human skill of drawing has a history dating back tens of thousands of years, certainly before writing and possibly before language. It is one of the more important intellectual skills that our species has developed. The ability to capture an abstract representation of the physical world in a form that enables it to be communicated with others is a remarkable gift.

Drawing is a primary form of communication, where artists convey views of the world they see, but the meaning and intent of many drawings can be diverse and potentially unclear. In some cases, the viewer must spend time learning how artists approach their subjects, the techniques and conventions used to represent them. The viewer must make an effort to learn the explicit language of the artist.

These and many other issues around meaning or communications, come to bear, in one way or another, at the more mundane level of technical drawing. For us, a drawing is a two dimensional (2D) depiction of a physical object, typically created using lines or shading to represent the visible edges of the object. It is usually seen from a given view point, perhaps shaded or hatched to illustrate materials and 3D form.

Lines may form simple shapes such as polygons, ellipses and other conic sections. Such lines may readily be traced out using tools like templates. Alternatively, they may take the form of more complex shapes that can only be drawn freehand, or using a device like a spline tool, or by plotting, point-by-point, the path of a mathematical function. Such lines can be very difficult to generate precisely in the first place and difficult, if not impossible, to subsequently reproduce accurately.

To fully represent a simple three-dimensional object, it is usually necessary to develop separate views of the object in question. A single 3D drawing will certainly show the essence but to accurately show the complete object different views of the object must be formed. Each view in turn may contain a symbolic representation of the actual geometry. It might also contain other detail in order to show all facets of a complex object. Each of these views comprises its own array of lines of different types, including parts of lines where one edge of the object passes from one view to another. In many circumstances it is usual to apply additional drawing conventions such as colours, line-styles, hatching and shading to add realism or technical detail to drawings.

This is the sort of process that is involved in drawing a single, simple object. However, buildings usually involve a large number of highly complex objects connected in different ways. To show the whole structure uniquely requires many drawings, and even then aspects of the design may be hidden. This is greatly complicated by the need to accommodate different views for each of the many disciplines involved. Ensuring all of these drawings are correct within themselves and consistent with each other as the work evolves through various designs and development processes and iterations is a major task.

A drawing is a store of information, where the data are individual lines and text, each of whose attributes include its point of origin, its path and length. There is only so much information that can be gleaned from lines on a 2D page. Somewhat stating the obvious, our world is very much 3D but also varies in time.

Construction drawings, no matter how detailed you get, you can only say approximately what you mean or intend. We depend on the person at the other end of the conversation to complete the picture and read the drawing correctly, to understand it fully and use it intelligently in his or her particular situation. And no matter how much effort you put into it, your drawing will never be unambiguously clear, complete, correct, internally consistent and coordinated with other people's related documentation. With drawings, certainly large numbers of drawings, this is simply not possible.

As a result, huge numbers of people across the construction industry have spent inordinate amounts of time checking information, guessing the true intent, sometimes getting it wrong, correcting things, making mistakes, cutting stuff out… all because the only way we could design buildings was with drawings; drawings that are potentially untrustworthy, at odds with other drawings, unintelligent, in-computable information, at least some of the time.

When you have done this every day of your working life, or worked with other people who do so, it can be difficult to stand back and appreciate just how complex and inherently problematic the process is in real terms. Transferring the process to a computer, using a computer-aided drafting (CAD) system, might appear to simplify things, and it does to the extent that the machine can be programmed to store all of the necessary information about each of the individual lines. The computer can ensure that lines that are supposed to intersect at a particular point do so, that lines that are supposed to be parallel remain parallel, and so on. Producing drawings on a 2D CAD system or even derived from a 3D CAD does not, however, guarantee that the drawings will be consistent.

A set of drawings produced on any CAD system looks convincing. They are drawn perfectly (compared to manually produced drawings), parts are replicated precisely and the patterns and text look printed. However, the real issues are hidden. If the drawings are produced in a conventional CAD system as separate plans and elevations, then the chances of them being perfectly coordinated, matching each other exactly when detailing the same items in the building, are minimal; the bigger and more complex the building, the greater the risk of error. The larger the number of documents produced, the greater the likelihood of error, and, the lack of coordination between the drawings and the ambiguities.

Related problems derive from the fact that CAD operators produce large numbers of drawings – just because they can. Designers, swamped with stacks of convincing looking drawings, become over-confident, often neglecting to check details, particularly at interfaces between different elements and disciplines. When teams come under schedule or production pressure and have to recruit additional staff, the newcomers usually have to get up to speed very rapidly, potentially compromising existing quality and technical standards – all without seeming to do so.

Compounding the possibility for error, information brought together to complete the design of a building usually comes from diverse sources. Professionals from different disciplines each contribute in varying ways to aspects of the design at different times. The architect provides the overall concept in terms of base drawings, possibly a 3D sketch; various engineers contribute their specialist knowledge; construction managers, town planners, lighting specialists and the client or end-user all contribute and comment. Coordination of all this input is problematic. There are bound to be conflicts between the various types of information, even about what is intended, because there is no unifying single reference point. Even within single organisations, information is often fragmented.

Finding a common base where this diverse information can be stored and compared is also problematic. The diverse professionals tend to store data in formats specific to them, making comparison difficult if not impossible.

Traditional CAD programs do not assist in this coordination either. The needs of the different disciplines are diverse, requiring information in different formats and outputting very specific data, usually in highly specified formats. For example, designing steelwork or laying out building services are specialist applications, almost always with their own databases and at best generating sets of 2D drawings that represent something in 3D. Visualizing and coordinating this information is again fraught with pitfalls; the framework is often fluid, making true comparisons impossible.

Buildability of the structure is an additional factor that is not addressed with these types of representations. Can the steelwork be assembled; can the lift be brought on site and put in place? Buildability must be addressed at an early stage, otherwise different contributions from different disciplines may result in an assembly process that does not work in practice.

The structural engineer changing beam size, services engineers changing ductwork size and position, perhaps even a simple change of room layout can all lead to potential clashes of two or more objects trying to occupy the same space at the same time. Discovering and resolving these problems on site is an expensive and unsatisfactory solution.

These various issues of coordination, design, buildability and sharing information across disciplines were not easily solved by conventional drawings, nor by traditional CAD systems.

The information needed by the different disciplines is directly related to what they need to do. Much of the information is not graphical, but rather lists of items, costs, delivery schedules, stresses and strains, amongst other things.

This non-graphical data was usually input in a form suitable for the particular systems being used to specify that aspect of the building. Some of this information is required by several

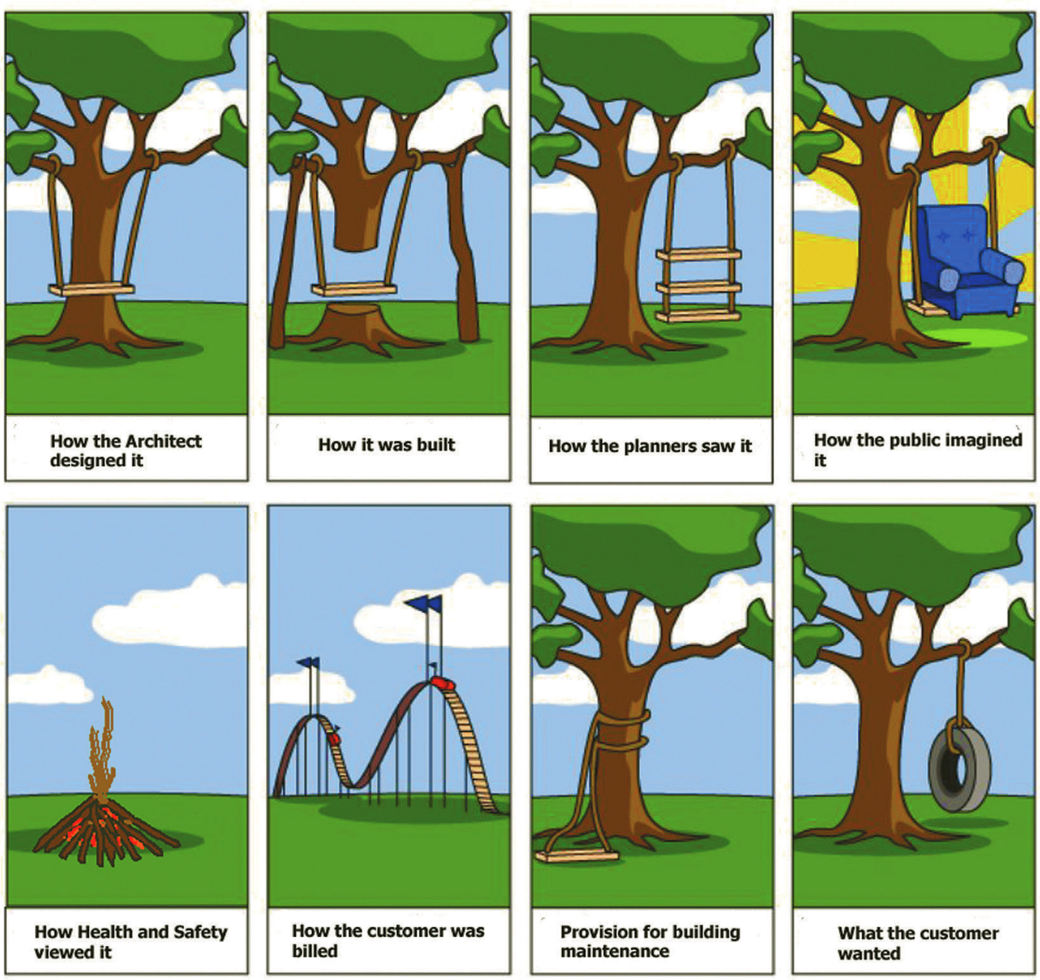

Figure 1. *The problems of building a swing*

disciplines. Sharing the information had to be done explicitly, outside the drawings. This was, of course, problematic and led to further lack of coordination and consistency.

Some stakeholders in a project require a 3D view of the structure. For instance the town planner or Joe Citizen needs this type of view. Coordinating the 3D model with the different 2D views of the structure has always been problematic. Some early CAD systems have allowed the projection of 3D onto a 2D drawing and then allow annotation of that drawing model. This solves the coordination problem temporarily but as soon as there are changes, and there will be, the 2D drawings are out of date. This was later referred to as 3D+2D as 3D projections cannot be used direct as 2D drawings because many of the symbols used are symbolic, needing particular representation.

Another issue comes from the level of detail required at the different stages of design. The town planner does not want to see reinforcement detail and a massing diagram is insufficient for the facilities manager. Similarly as the design develops the level of detail and its accuracy increase.

Construction managers also need to see the structure in a temporal sense; how the building will look at different stages of construction. Overall planning, coordination and control of a building project from start to handover requires time-based information. The problem of what and when items need to be ordered, delivered, constructed and maintained is very different from the straight analysis.

This information needs to be related to each of the sets of drawings and models coming from the development team, where integrating the construction sequence into the design brings significant benefits. The allocation of jobs and the sequence in which particular construction tasks are to be initiated becomes of paramount importance when building any structure. 3D drawings do not really tackle this 'temporal' or programming problem, traditionally tackled by a range of project planning software systems, which needs to be integrated into the overall design of the building.

Another issue faced by the different stakeholders contributing to the design of buildings was that they were often dispersed throughout different offices and locations, possibly around the world. Being able to interact with other professionals while designing (and constructing) a building is important to achieve the most effective design, but may not always be easily managed. Simply sending a set of drawings does not quite work, and is anything but conducive to collaboration.

The Construction Industry has struggled with these problems in building since the splitting of the different design aspects of a building. Formerly solved by the Master Builder, the on-site expert of ancient times, these issues have become more and more predominant with the increasing complexity of buildings, specialist technologies and complexities of the sub disciplines.

Figure 2. *Drawing Coordination was problematic*

VIRTUAL BUILDING MODEL

Building Information Modelling (BIM) proposes to solve all of these problems. It does so by building a virtual or computer based prototype of the structure using a technology that enforces coordination, encourages sharing and allows and in some many ways enforces design consistency.

Such a system needed to be an object based information model, representing the building in all its particularities. All information had to come from that single model. The different disciplines involved needed to be able to work concurrently to build their parts of that model across all 2D, 3D and other views. An internal understanding of connectivity and to some extent, function must be inherent, together with automatic detailing and design of the different parts.

Consistent databases cannot have duplicate information representing the same thing, if one is changed that consistency will be lost. All information must be defined once, and referred to at other points where that is information is needed. Whether inside or outside the model, all information should be defined once. When information is changed then all downstream related information must be updated.

BIM – CONSTRUCTION WITH (EFFECTIVELY) PERFECT INFORMATION

In general, design information generated using an object or information model-based process is inherently superior to comparable information generated using drawing processes[1]. In BIM, this is particularly true. Moving from CAD to BIM is not simply a matter of upgrading from one CAD system to a better one. In moving from CAD to BIM, we are introducing a truly fundamental change, a complete change in the nature and quality of information we work with and radically transforming how the entire construction industry works. It also introduces, necessarily, a change in work practices.

Put simply, but certainly not exhaustively, BIM involves the creation of a virtual 3D building model using not lines on sheets of paper or computer screens, but complex, fully specified, intelligent parametric objects, in a digital, multi-dimensional environment. These objects or components can be as detailed and as accurate as needed. They appear to behave just like building components in the real world. Doors, windows, walls, beams, pumps, luminaires, etc., all display properties in the modelling system which correspond exactly with those of their counterparts in the real world. Individual models, or parts of models created in this way, are inherently accurate and complete. They can contain extremely high quality information, rich with embodied intelligence and other forms of programmed behaviour.

What would happen if, instead of drawings, the information used in construction were fully trustworthy – needing no checking – and was readily computable, as the BIM vision promises? What would happen if the operation of the construction industry was based on the use of effectively perfect information? A few things come to mind.

One significant problem with our dependence on drawings, is their use as the basis for the procurement of traditional construction contracts. A minority of clients already procure in more progressive ways, such as framework agreements or alliances, with bidders evaluated on, say, 'best value' rather than lowest price, but most do not.

Effective competition in any market requires that the customer can specify their requirements accurately and in such a manner that competing suppliers' proposals can be compared and evaluated transparently, on a true, accurate, like-for-like basis. This is almost impossible to achieve using drawing-based documentation, where the scope of work can often be interpreted to mean almost anything a bidder can plausibly claim it means – which means that there is no definitive scope of work under the contract, certainly not one that can be challenged.

This in turn means that it is impossible to eliminate predatory bidders from the contracting process, as all bidders for a given contract know that one of their competitors may adopt a "bid low / claim high" strategy. They must all therefore bid as low as they dare, and hope to make their profit on re-interpreted work, claims and other extras. This behaviour eliminates the possibility of real competition for the operational components of traditionally procured construction contracts. Competition among contractors today is mainly about the marketing and estimating skills, the commercial nerve required to win work, and the claims management skills required to make money from projects won at cost or less. Skills in construction operations may give project teams a sense of pride and achievement, but are largely irrelevant to the survival of the firms they work for.

So contractors have no imperative to innovate, and avoid innovation risk and investing in improved production methods. Instead they sub-contract, and sub-sub-contract, right down the supply chain to the point where subsistence level, labour-only subcontractors, working in gang size firms, perform the bulk of the

1 "The Impact of Building Information Modelling: Transforming Construction", Ray Crotty, Routledge, 2011