Title:	**Virtual Building and the Progression of Digital Technology**
Authors:	Stuart Bull, Ridley VDC Consultant, Ridley Hernan Jerez, VDC Technical Manager, Ridley
Subjects:	Façade Design IT/Computer Science/Software Property Ownership/Management
Keywords:	Building Management Environment Façade Virtual Reality
Publication Date:	2015
Original Publication:	Global Interchanges: Resurgence of the Skyscraper City
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Virtual Building and the Progression of Digital Technology

Stuart Bull
Ridley VDC Consultant / Regional DE leader Laing O'Rourke

Ridley & Co,
Sydney, Australia

BEng (Honours) Civ. Eng, MSc in Arch. Eng. Design,

MHKIBIM, BCA Singapore BIM Management Accredited

Stuart is the Director of Ridley Virtual Design & Construction. Prior to this, he was Regional BIM Coordinator at Arup, holding local and global responsibility to deliver BIM value-add services. He holds particular interests in BIM project strategy, BIM enabled supply chain integration, BIM in FM opportunities and post construction management BIM processes.

His notable recent experience includes the Atlantis II Development, Dubai, 30 St Mary's Axe London, the Pinnacle Tower, London, the Singha Corporate HQ, Bangkok and 8 Chifley Square Sydney.

Hernan Jerez
VDC Technical Manager

Ridley & Co,
Sydney, Australia

Bachelor of Architecture, Electronic Engineering Studies

Hernan is a technical specialist, qualified architect and highly skilled in the delivery of fully integrated and federated Virtual Building Models.

He is interested in developing holistic Building Models that integrate any information that can be translated and attached into a 3D virtual form such as Analysis, Sequencing, GIS, Building Services and Structure, to name a few.

His recent experience in tall buildings includes Atlantis II, Dubai, Union Sun retail, Chengdu, China, 160 Spencer Street, Melbourne and the Xuhui Binjiang Commerical Dev, China.

Abstract

Emerging digital technology is moving the industry closer to a holistic ideal of the 'virtual building', a fully defined integrated and operationally tested virtual prototype of the completed asset.

Historically the building and construction industry experiences low productivity compared the automotive and aeronautical industries, largely attributed to poor planning and communication. Building Information Modeling is a process that is used to resolve these problems by simulating geometrical spaces and expressing design and construction intent graphically.

Key indicators of increased productivity are reductions in the amount of rework, schedule compliance, and change orders due to documentation conflicts. This paper aims to explain and demonstrate the key opportunities to exploit large scale implementation of digital technology, processes and interoperability in a true collaborative environment that can aid the workflow and strategies of all parties in the delivery required from the earliest phases of tall building development in the design and construction.

Keywords: Virtual Building and the Progression of Digital Technology, Environment, Facades, Facility Management, Sim City, The Virtual Building

Introduction

Emerging technology is moving us closer to the development of the Virtual Building Model: a fully defined, integrated and operationally tested virtual prototype of the finished building.

Currently the AEC Industry has at reach, technology that allows for the setup of what is essentially a 3D Database enriched with information that can be developed, utilized, interrogated and supplemented, for the purpose of simulating any built project. This informed 3D model or Virtual Building (VBM) then becomes a central place for every one of the Project stakeholders to communicate, share and test possible scenarios before construction, building on the basis of hard facts and less on intuition..

Essentially this is a process of minimizing risk and maximizing potential by simulating and testing a hypothetical virtual building, allowing designers, builders and owners to avoid time consuming and costly trial and error approaches currently in practice in the building industry. Beyond the immediate risk mitigation benefits, the emerging process is becoming fundamental to the coordination and documentation processes and facilitating new design innovation.

This methodology is widely known as Building Information Modeling [BIM] but during this paper we will refer to Virtual Design and Construction [VDC] as the methodology to obtain a Virtual Building Model [VBM] which is the final product and embraces a wider scope of use and opportunities. Over the last 20+ years, BIM has reached some degree of maturity since the late 1980's when the more mainstream implementation of digital procedure in the AEC industry really took hold. Functionality.

A VBM will eventually enable designers to develop a fully tested building solution with confidence not just in the building's constructability but also in the long-term operational performance.

The Virtual Building Model

The "Virtual Building" is a digital 3D Model in which all design, construction, environmental performance and operational problems are visualized, solved and optimized using integrated computer simulation and coordination.

The VBM is intended to support project stakeholders throughout the lifecycle of a project in the following areas:

- Exploration, as a constantly evolving tool for exploring new directions in design and construction.
- Communication, enabling project teams to quickly and accurately communicate design forms, functions and behaviors to other team members and the broader collection of stakeholders.
- Integration, providing an environment where design and facility team members can share and coordinate project information quickly and efficiently.
- Optimization, facilitating analysis tools that are capable of geometric optimization, sustainability and costs that meet both short and long-term goals.

Comparisons must be drawn from parallel industries in the use of digital technology, that being aeronautical (See Figure 1) and automotive. Both have long used fully integrated, collaborative and complex 3D models to develop the virtual then physical prototype, with the Boeing 777 becoming the first ever fully engineered and delivered virtual prototype over 20 years ago.

Why Virtual Building Models?

Through representation in 3D, the building can be far more easily understood by all project stakeholders. The VBM can produce almost limitless permutations of sections, plans, elevations and isometric views in any direction. More importantly, as the drawings are a reflection of the model, and therefore are fully co-ordinated with one-another and will only present consistent information. As a communication tool, the 3D modeling approach is thus far superior and is already showing results in producing a better product with less rework. And in various countries is becoming a mandate for delivery of government procured project, such as in the UK where level 2 BIM implementation will be mandatory form 2017

It's all about Process: The Virtual Design & Construction Processes

A key distinction between the traditional 2D documentation and the VBM is that the 3D Model is not composed by loose surfaces anymore but by objects that are enriched with data, as if each object becomes a spreadsheet of variables and crucial inputs.

As building systems complexity increases, it has become necessary to preview the building in order to rehearse its design and installation so to avoid costly errors on site. That not only requires the understanding of what a Virtual Building is but also understands the intricate organizational participation structure during different stages of the projects, swapping and inheriting responsibilities. Hence, the Virtual Design & Construction process is fundamentally the combination of both pure technology and the establishment of human workflows that will align the interest of the Project and transfer the responsibilities to the relevant actors. It offers the potential to vertically integrate the entire construction supply chain, as well as horizontally integrate the design teams.

The process of the VBM development must be workflow driven, contractually robust and clearly state the aims and objectives of use. Without these basic ingredients clearly identified misinterpretation of the model use will confuse the ongoing development and sharing of the risk attached with a digital geometric handover.

Figure 1. Virtually projected turbine. Reproduced from Eon Reality Inc (Source: Eon Reality Inc)

Figure 2. Sydney Adventist Hospital Services Modelling (Source: Ridley / Buildcorp)

The next step beyond virtual construction is to introduce a common model approach from the outset of the project. A common model is where a 3D model is shared centrally with all members of the design team. A shared central model requires agreed protocols regarding who can alter what and how and when it is updated. The model will need to be hosted on a central server located at either the client's office, at any member of the design team's office, or by a specialist modeling firm appointed to the project.

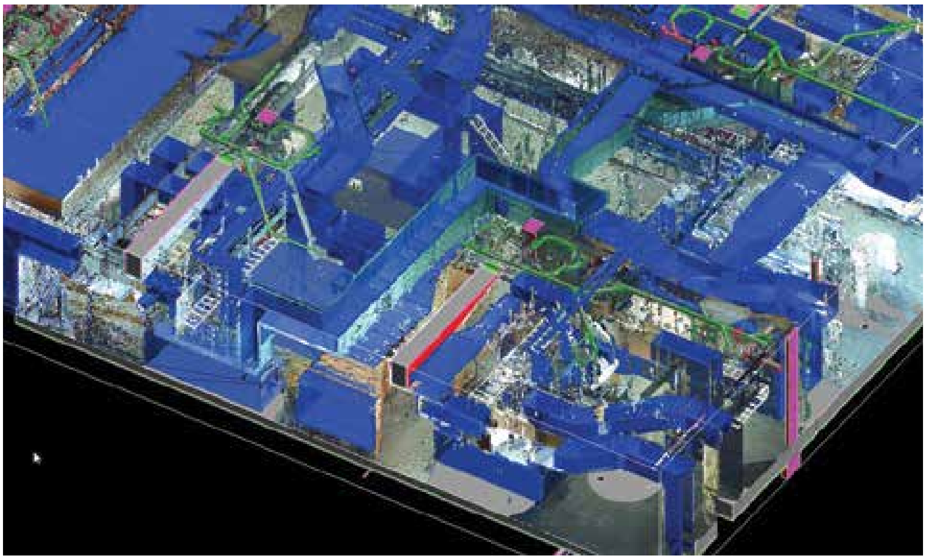

Figure 3. Sydney Adventist Hospital Services Modeling (Source: Ridley / Buildcorp)

Benefits of the Virtual Building Model

Some of the main benefits that the establishment of a VBM could bring into a Project will be described in the following pages.

Optimization

One of the main virtues of the VBM is the ability to assess and sort options to find an optimal set of solutions by computing different iterations. The process provides a support to design intuition rather than replacing it. Optimization routines used will vary depending on the problem to be solved, graphical scripting interfaces such as Grasshopper, Dynamo, Generative Components and CATIA allows the evaluation of various set of parameters that satisfied specific conditions.

This process is also known as "Form Finding" which allows the designer to see the results of an optimal concept by relying in a computational solution to that problem. Once a computational solution set has been built, alternate designs can be explored by varying the parameters. Algorithmic use of iterative decision making in the development of a BIM is fast becoming the most useful

Figure 4. Royal Atlantis Resort (Source: KPF)

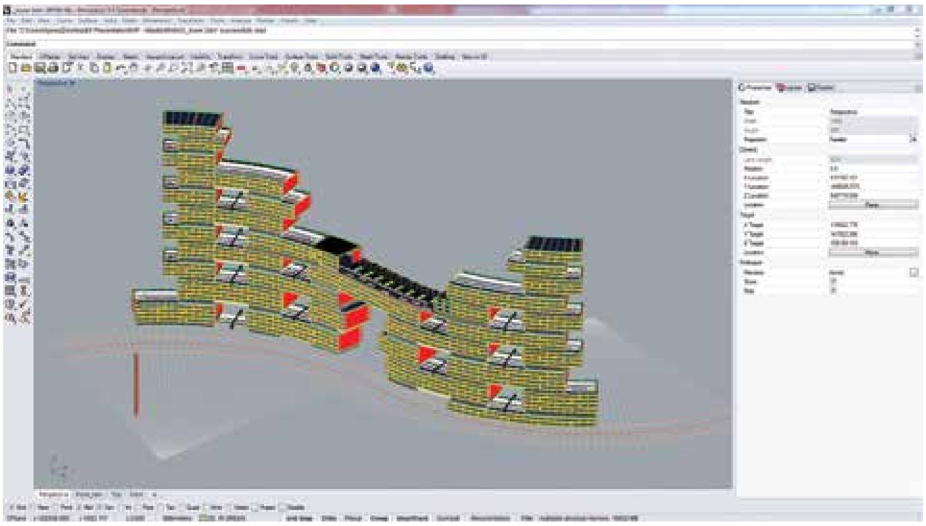

Figure 5. Royal Atlantis Resort Parametric Model Rhino Interface (Source: Ridley / KPF)

Figure 6. XuHui Commercial Development, Shanghai (Source: KPF)

implementation particularly in the building visualization where paneling and pattern generation is architecturally important.

Clash Detection and Coordination

By appending 3D models from the various consultants, coordination of the architectural and engineering design can take place, automatically detecting clashes (See Figure 2) and helping to review the integrity of the scheme at the current state of the model. The Virtual Building can be used as the basis of coordination workshops making possible to effectively visualize and manage design coordination. The best use of the VBM will be further exploited if contractually early contractor involvement during the design phase is permitted. This process allows input into the model from sub-contractors who traditionally are brought into the process far too late to efficiently influence the model development, thereby improving confidence in the design and reducing the chance of late changes and clashes between building systems on site.

Parametric and Generative Modeling

Parametric modeling captures and exploits the critical relationships between design intent and geometry via scripts, algorithms and rules. Objects can adapt to modify parameters as well as to react when other objects are changed defining a series of object relationships. By capturing the parameters of a building, such as geometric constraints, environmental parameters or material limitations, and their relationship to the building form, the design process can be automated and design iterations can be produced seamlessly.

Programming and scripting have been used in a variety of forms for many years now, such as to generate geometry and analysis models, or for specific uses such as sightline analysis. In the past scripting has been only accessible to those with computer programming skills but now simpler graphic scripting software, more compatibility between model formats and new programs that use the same scripting principles, have made parametric and generative modeling more accessible. As an example one common workflow is to create a design intent using software such as Rhino + Grasshopper and then communicate this information into BIM Authoring Software, this allows the use of a flexible design tool to talk with a documentation delivery software.

The production of Atlantis II (See Figure 3 and 4) involved the development of a fully parametric model of the overall building massing, façade system and internal room types. This model allowed the design team to control the shape design, offsets, setbacks and dimensions that would regenerate the model to according to design changes.

Using the same parametric concept, the Xuhui VBM (See Figure 5 and 6.), was created to respond to changes in both internal (mullion dimensions, panel thickness, mullion distribution) and external (e.g. levels or grids solar radiation or reflectance analysis) automatically modifying the parameters of the curtain system panels until they comply with a set of rules defined.

Construction Scheduling (4D)

Planning a construction site is notoriously difficult. 4D modeling is a powerful new tool that adds the time variable to a 3D Model providing an interactive ability to visualize, inform and rehearse construction sequences, driving more efficiency into the construction process (see Figure 7).

Later in the project as more detailed programs are produced, the model can be used to describe the complex sequence of building without the need to read and understand pages of charts. The key aim is to highlight bottlenecks and site constraints in the staging of the works in order to optimize the overall time of construction. Site management is assisted by illustrating the true scope of works and the staging necessary to solve key constructability issues. It is a highly effective planning communication tool for disseminating construction impacts to stakeholders, or overlapping and multiple sub-contractors.

5D scheduling

When we combine the automated extraction of quantities over a time lined 4D model we add a fifth dimension, more commonly known as 5D. This process allows the exploration of the relationships between the objects' timeline within the linked construction Gannt program environment, and then report on their subsequent quantity or cost at a particular point in time usable for contract cost progress payments and more robust management of financials and variations such a VICO and CostX linked via Revit.

In simplistic terms, the consequence of task occurrence (or not) and their relationships to one another, allows us to investigate limitless permutations of quantities at any point in time. Some examples of this would be to extract cubic meters of concrete to be poured in the following week to a day works schedule, or a dollar value of work complete in monthly cost plan forecast. One of the great benefits of a 5D process is that rapid assessment and reassessment of costs is now possible. Any changes to the model and its impact on cost can be quickly (and automatically) assessed, additionally the manual take-off of quantities, which is often prone to human and scaling error, can be verified, or indeed may become superseded.

GIS Context

The existing built environment can be modeled by gathering readily available GIS spatial information either from existing information, aerial or terrestrial sampling and storing it in a manageable format. This information can be live or a record.

The Virtual Building model for the new development is then inserted into the city model which in turn can be positioned in real world coordinates for further macro studies. It can then be accessed for a number of different uses:

- integrating and assessing new developments for planning purposes
- noise mapping
- wind environments including wind farms
- accessibility assessments
- visual assessments
- overshadowing
- traffic and transport simulation
- heat-island effect simulation

Our understanding of city environments is becoming more critical than ever in our quest for a low-carbon consumption future. Using virtual modeling to understand the interaction between all the components of a city and how the whole organism performs is a critical part of this journey.

Environmental Performance Modeling

There are now pioneering methods emerging that will assist in planning optimal space, material and energy utilization, allowing the team to assess the optimum sustainable design outcome. These options can be maintained throughout the design period, with the rapid ability to schedule, analyze and compare options concurrently as they develop. For instance, a 3D model now offers a central database from which compliance reports for environmental rating systems such as LEED, BREEAM or GreenStar can be automatically created.

Sustainable design assessments can focus at a micro-level, for instance, embodied energy in the concrete, or at a macro-level at whole precincts to determine for example urban amenity, over-shadowing and street acoustics. In each case, changes and improvements can be readily interpreted using visual and aural models.

Similar testing levels are possible for smoke modeling as part of an overall performance-based fire engineering approach. Smoke modeling can now use geometry directly from the design 3D model providing a more precise assessment of evacuation times and smoke control performance.

Direct Fabrication and Manufacturing

The Virtual Building process enables advanced manufacturing technologies which extract fabrication data directly from the 3D model using Computer Numerically Controlled (CNC) technology, eliminating the need and risk associated with interpretation of 2D drawings. Digital fabrication can be used for routine assemblies, but can also enable the fabrication

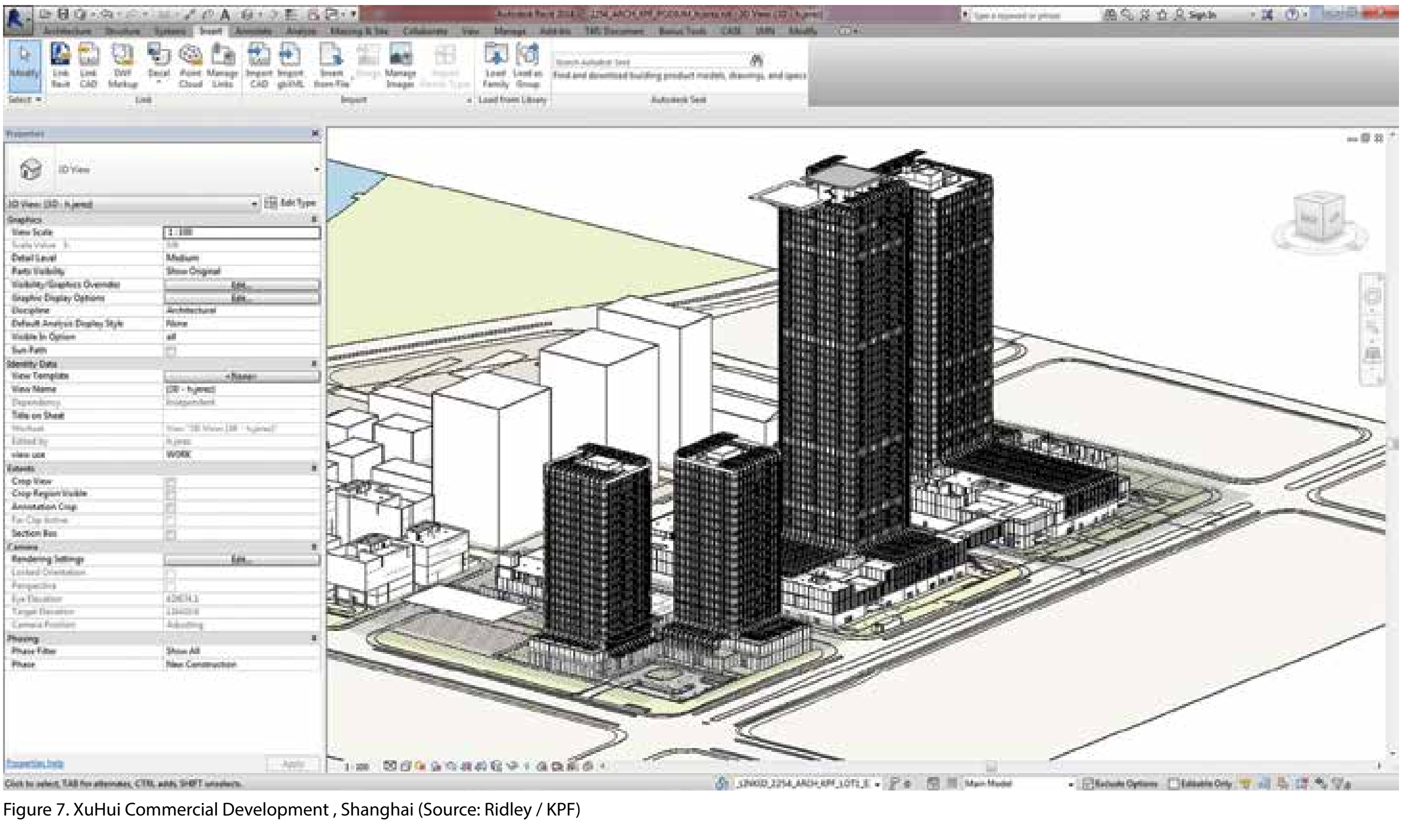

Figure 7. XuHui Commercial Development , Shanghai (Source: Ridley / KPF)

of more complex shapes and assemblies that would not be possible using conventional methods. This technology is used extensively in the steel industry, but can be adapted for precast concrete construction as well.

The potential to save money and time by eliminating the design drawing and/or workshop drawing process is self evident – a pointer to the potential for a 'drawing-free' future, and a key step towards the "Virtual Building".

Supply Chain Management

Having guided a collaborative design and planning system, the Virtual Building model can be manipulated and interrogated to further effect during the construction phase. Interactive project review meetings with builders and sub-contractors can be hosted, and discussions documented with views from the model. This promotes cross trade co-ordination through the trial construction, and helps maximize the benefits of the collective specialisms offered by the sub-contactors

During the early stages of the project, designers tend to use generic components to represent the building systems. Such components can be used to produce accurate tender information, but eventually will be replaced by specific components that the general contractor and sub-contractors intend to use for construction. The object-oriented nature of the Virtual Building model means that components of varying levels of detail can be easily inserted or exchanged at any stage of the process.

The digital model can also be linked to order information, allowing components to be tracked from production to delivery, storage on site and final installation.

Asset or Facilities Management

The Virtual Building is not only useful during the design and construction process, but also can be an effective tool for facility management throughout the lifetime of the building.

By linking components in the Virtual Building to a facility management database the building manager can operate and run the asset using a visual interface. The Virtual Building database can be designed to hold drawings, specifications and maintenance history for the components within the model, current standardization efforts have led to the production of COBie parameters, a set of parameters commonly used in facility management that promotes construction operations building information exchange of Virtual Buildings with FM Databases.

Hence an asset manager could simply click on a room in order to find relevant information for that room. Alternatively the manager could move directly from the database to the location in the model to identify a component in question. Or the model could be set up to warn of faults or scheduled maintenance, or monitor energy usage.

The process of reordering components or scheduling maintenance becomes greatly simplified, as the manager only need point to the element in question in the model and all relevant specifications are brought up from the database. This could be particularly powerful for façade elements where breakages are common and geometric and performance data must be precisely adhered to when reordering.

Pedestrian Simulation

Software has now been developed to permit the Virtual Building space to be inhabited by agents or avatars, pre-programmed with human behavioral patterns, to see how they will react to different physical environments and people density.

The process involves creation or adaptation of a 3D model with all the primary physical and spatial features that one would find in the final built form. The agents can be programmed to behave in ways that mimic human behavior, for instance; pausing at a café for a cup of coffee, or stopping at a flight information board, or destination preferences.

This approach can be used to understand vertical transportation restrictions and circulation at podium levels, allowing the identification of undesired flows, egress assessment as well as best commercial exposure locations, etc. and most importantly means of escape and disaster planning / simulation that are predictive of major environmental, structural and security situation.

Real-time Interaction

The current state of gaming technology applied together with models rich on information creates an opportunity enable interaction with 3D spaces and objects in the same way videogames are. Artificial Intelligence can be added to pedestrians and traffic flows creating a real time simulation. An example of this can be seen in SimCity, a game where the goal is to create a city that needs to adapt to different requirement of the community taking care of parameters like rent prices, people satisfaction energy requirements, etc. Restricted by budget factors it allows the player to customize various building types and fit outs in real time for exploration.

The technology is currently available and has been used different fields ranging from training to marketing. It is possible to use this gaming technology with a Virtual Building model rich in information to explore new interactive applications like induction, safety, multi site management and maybe in the future control site remotely.

Overcoming the obstacles to the adoption of the Virtual Building Model

Interoperability

The Virtual Building Model process is best enacted if all consultants are using the same software, a situation that is commonly not supported, however if this is not possible data can be exchanged using International Foundation Classes (IFC) interoperability standards. Alternatively, software such as NavisWorks, Solibri and Tekla BIMSight can be used to import and view models from different software platforms and run virtual design workshops. During the review process we can rotate and zoom in on issues, isolate them, redline, add appropriate comments and then assign and track actions. Closer collaborative working practices should now be developed using these tools.

Collaboration

One key benefit is organized collaboration saving the duplication of efforts, for example, the architect through not having to continually re-digitize structural information. Nevertheless this presents at the same time one of the major obstacles in a collaborative Virtual Building, which is the structure and organization of sharing and communication protocols.

During the construction phase, the subcontractor's models can be added to the process to provide further assurance on fit. This can be considered to be a virtual dress rehearsal for the construction process, saving potentially costly remedial works on site.

A combination of the Architectural, MEP, Facade and Structural designer and sub-contractor models within a single interactive, free to view model offers a very powerful design review tool. The ability to combine

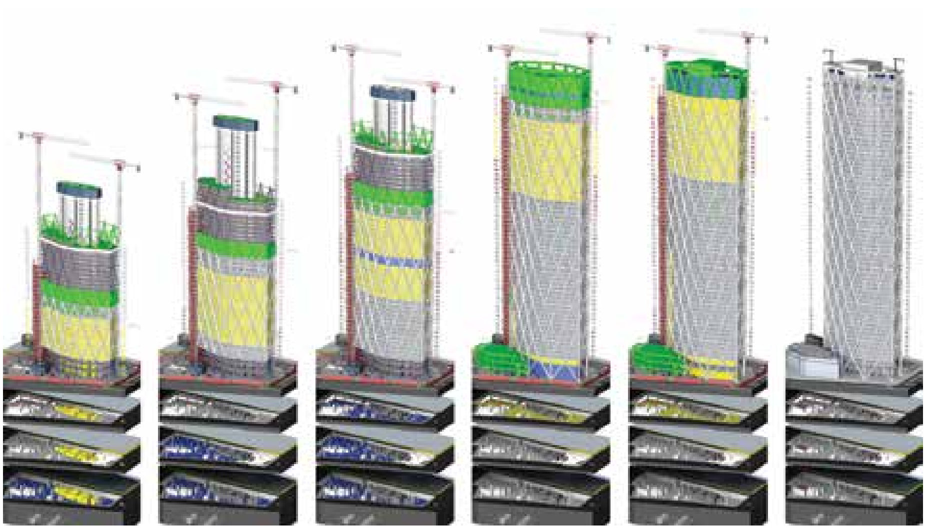

Figure 8. Tower Construction Sequencing Canary Wharf, London England (Source: Freeform 3D Ltd / Synchro Ltd)

3D models over one-another in the Virtual Building environment promotes a "right first time" approach to the design, procurement and construction process.

Processing Power

In theory all the information and models can be merged together in order to see the final product, however in practice there are items that still needs to develop further, that includes hardware as well as software. Currently practitioners face limitations in both CPU performance and the quality of cloud based services. This requires a strategy on how models are composed, divided and evolved as the progress through stages demands extra information to be included.

With the advent of more accessible cloud technology and high processing power single large multi discipline interconnected models can be visualized and become immediately reactive to multiple levels of design iterations… this is where the interaction with games engine technology and methodologies of SIM City are immediately apparent.

Legal Implications

Currently liability in AEC market is based on standard documentation, 2D drawings and specifications not considering the complexities introduced in a VBM environment. The fact that models now contain much more information than the one available in 2D documents creates and extra risk for the consultants, giving place to misinterpretations. Also, for the VBM to support the processes before mentioned, is required a further development by adding and managing the information contained in the model. Since this is not normally a part of standard contracts they need to be adjusted to reflect the new works needed to evolve a 2D document into a 3D Model and then into a 3D smart database.

The U.S and other countries are developing contractual procedures to allow deeper and more meaningful use of 3D models across the design and particularly the construction deliveries. With this progression the use of 2D 'dumb' drawings that are inherently uncoordinated will slowly be superseded with detailed, immersive and data rich virtual buildings that will ultimately reduce cost, time and at the same time improve quality through the contractual agreements in place to manage deliverables.

Conclusion

Full virtual prototyping of a building is no longer a dream for our distant future. As technology develops, the potential exists for the creation of a complete Virtual Building Models in which all aspects of the building and its internal relationships can be tested and understood in an automated fashion.

The challenge for the property and construction industry today is to embrace and accept the 3D enabled technology on offer now, to produce a more streamlined, 'right-first-time' approach to building design, construction and operation. Forward thinking clients already have an expectation of 3D based design. As technology advances these are the clients who will expect the model's object content to be packed with any conceivable aspect of data that can give them an advantage, or give them operational certainty.

The resulting VBM's will open far reaching opportunities within the future management and business operations related to the building industry.

It is possible with current technology the establishment of an Integrated Virtual Building that will contain up to date and coordinated information at any point during the phases of the Project from its very inception to disposal. A series of new processes are enabled with this technology but as benefits appear there are issues introduced as well, at technical and organizational level.

The main problem to sort out is communication and collaboration protocols. The model becomes a central common place that reflects the state of collaboration of all the teams involved. Such a team effort requires a clear organization, otherwise if collaboration does not work, the model will reflect inconsistencies and incompleteness. Therefore the use of a collaboration plan is of utterly importance in the setup and successful use of a Virtual Building.

If we compare Virtual Buildings or virtualization of buildings against credit cards or virtualization of money, construction will be at early days when a person needed to create a record of the card and call the bank to verify are funds available, the communication link is been segmented, requiring someone to bridge the gaps making the process semi-automatic. Nowadays we can buy online with the credit card in a seamless transaction where the account updates in real time, in the same way VDC needs to move from the current semi-automatic process in place to linked network of information where all the participants do not need to do rework but they are rather connected to someone else's work.