Use of Building Information Models: a contractor’s point of view

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Summary
The so-called Virtual Construction technology promotes a wide use of digital mock-ups and computer simulations for modelling the tri-dimensional (3D) geometry and analysing the behaviours of a structure. The aim is to identify and anticipate problems as soon as possible during the design and construction processes in order to make the most adequate decision in the right time. A global management and storage of all the data defining the structure guarantee to all the stakeholders access to the right updated information and will avoid re-keying the needed data.

The present paper provides an overview on the use of that technology in civil engineering based on a contractor’s experience. Promising results have been identified when using a stand-alone system. Problems remain to be solved when applying it in a collaborative environment. The important facet is not the tools availability but the ability of an organisation to adopt virtual construction and reap the benefits that the technology can bring. As such, the need to get the company culture and process in place is paramount.

Keywords: Building Information Model – Virtual Construction – computer simulation.

1. Introduction
Traditionally a construction project is defined by a set of documents including technical drawings and descriptions. The whole art of the designer lies in its ability to provide a complete description of the project out to the minimum number of documents and including all project information. A realistic mock-up may be built up in order to envision the future structure more easily. But it is a difficult work, costly and anyway incomplete because of the scaling. Therefore it is often not made. In fact, the complete 3D-model is only in the brain of each stakeholder, assuming that all actors will get the same vision based on the documents defining the project.

The tremendous improvements of Information Technology (IT) have led to the development of tools able to visualise and handle 3D-digital mock-ups representing structures in a way acceptable by the designers. The structure is totally defined in the digital mock-up with completeness in accordance with the chosen level of detail. The technical documents have to be considered only as specific views derived from the 3D-model and are used for easier understanding. Linked to dedicated analysis tools, digital mock-up technology leads to the so-called virtual construction, a process by which the problems arising during the whole lifecycle are visualised and solved using the capabilities of computer simulation. Such an approach allows exploring and assessing alternative solutions more easily and quickly than conventional practice.

The virtual construction approach is widely used throughout the manufacturing industry, in particular the automotive and aerospace sectors. The aim is to reduce time to market and prototyping costs. Initially this aim was driven by the need of managing complex geometrical shapes and numerically controlled machine tools. Moreover such a choice allows today benefiting largely of the tremendous capabilities of computer simulation.
The appropriation of virtual construction has gone much slower in the construction sector. The main reasons are well-known: no mass production, no complex geometrical shape, no numerically controlled machine tool, structures built on job sites and not in factories, low cost materials, fragmented sector, low investments and profits. This matter of fact has lead to a conservative attitude maintaining the use of 2D-drawings during the whole life cycle. Thanks to the continuous large improvements and cost reductions of Information and Communication Technologies (ICT), the dissemination in the construction sector will today be favoured assuming the processes will be revisited to take into account the promising capabilities of virtual construction.

A first step has been reached by using scanners and document management systems in order to improve the management of the document lifecycle, i.e. to track and store digital documents or images of paper documents. However the consistency management of all the documents remains into the hands of the coordination team. Today all the documents are digitalized to reduce paper consumption and information technology is used for exchanging and tracking documents. But the process itself remains the same. A drawing is always a 2D-technical document, which means a specific view of the structure hand-managed and hand-updated by the designer according to the project progress. And other views or other scales need other hand-drawings. Finally, it is important to notice that today, on job sites, 2D-drawings are the only paper documents used by workers.

2. Virtual Construction

Virtual Construction allows visualising and assessing the different problems encountered during the whole life cycle of a structure (including design, construction, operation) by using widely computer simulation. It offers better envision of the planned structure, better understanding of its behaviour, easier exploration of alternatives and more efficient way for risks evaluation.

Virtual Construction is based on the following technologies:

- **Tools for visualising and handling large 3D-objects.** All the stakeholders share the same vision of the planned structure. Aggregating objects offers holistic visualisation, multiple points of view, and walkthrough capabilities.

- **Global data storage.** All the stakeholders share the same updated data. There is no need to retype data and therefore less errors and less waste of time.

- **Computer simulations** based on 3D-model geometry and additional specific analysis axes such as clash detection, environmental impact, local integration, construction scheduling and methods, behaviours (structural, wind, noise, vibrations, thermal, safety)… This allows exploring and assessing trade or discipline solutions.

- **Concurrent engineering.** A construction project is from the beginning a collaborative activity involving a large number of different actors due to various skills, expertises and trades. Due to the fragmentation of the sector, these actors are often employed by different companies of various sizes, including large contractors and engineering companies as well as small and medium enterprises or craftsmen. Collaboration is driven by contracts. Collaboration means exchange of data and information sharing. And therefore it implies coordination of the shared information. The coordination process is a key process aiming to maintain information consistency and to guarantee that the structure will be erected according to the client specifications. All disciplines work in parallel using data that are updated regularly to take into account clashes, coordination actions and increasing level of detail, having in background the cost and time key constraints.
The main reasons regarding the slow dissemination of such technologies in the construction sector are well-known and detailed hereafter:

- **There is no mass production.** The structure is built at a specific location and has to cope with specific local conditions. Therefore purposes of the structure, land geometries, geotechnical characteristics, specific environmental constraints, local regulations are all drivers of the architectural option and the structure shape. Finally the structure is at each time unique and the ability to reuse components in other projects is relatively poor.

- **The construction site is not a factory.** The structure is directly erected on the site where it will be operated. The job site is going to brave the bad weather. Its organisation is temporary, changing all along the project progress. It is not comparable to a production line in a factory. As the structure erection is going on, parts already built could be temporarily used for supporting erection tools needed for building other parts. The distinction, used in manufacturing industries between component production and component assembly cannot apply, components used in civil engineering structures being often unique and produced on site.

- **Lack of accuracy and need of adaptability.** The structure is implemented on land between existing buildings. Geometrical information related to these surroundings is not easy to capture and consequently more or less accurate. In addition, some measurements could change in time due to settlement, creep, thermal effect… Consequently there is a need to be able to adapt project data in situ.

- **Measurement amplitude.** The biggest manufacturing products reach measurements less than hundred meters. Large civil infrastructures could be about some kilometres long, even having detail sizes in the range of centimetres or less. If not managed carefully in a holistic approach, this could lead to large data bases and numerical overflows. In addition, the sphericity of the Earth cannot be neglected for such long distances.

- **Realistic mock-ups.** Scaled realistic mock-ups are sometimes built up to show the structure implemented into the surrounding land and existing buildings. The main difficulty is the modelling of the surrounding landscape. In addition, due to the scaling factor, it is difficult to simulate the behaviour of the planned structure with realistic mock-ups. Therefore the design is driven by codes based on conservative assumptions. Simulation tools would be a real opportunity to be able to communicate on environmental impacts of projects and/or to test structures subjected to extreme loadings and conditions.

- **IT equipment.** Due to the numerous and different stakeholders, there is a large gap regarding IT equipment as well from hardware as from software point of view. Exchange of large-sized digitalised data requires adequate telecommunication lines. The required IT equipment is available in offices and becomes more and more adequate on job sites, thanks to the Information and Communication Technologies (ICT) cost decrease.

- **No real software package market.** Due to the large scope of activities and the large diversity of IT equipment, there is today no general software package addressing all the needs of virtual construction. End-users have to use various software packages dealing with different topics such as terrain modelling, structure modelling, structural analysis, animations, construction scheduling, clash detection… Up to now there is neither complete software solution nor leading software editor

- **Interoperability** Due to the lack of a global software solution, interoperability between various software packages becomes a great challenge.
Nevertheless usage is rising up. The large communication covering the latest improvements of computer simulation tools and the related success stories in the aerospace and automotive sectors lead decision makers and opinion leaders to request more and more digital mock-ups for large projects acceptance. We live in a world of images and people need more and more images to better understand and accept new projects that will change and impact their daily life. Such a request will be for sure a key driver for the application of virtual construction in the construction sector.

3. Standalone Usage

Regarding the features described here above, there are today a lot of software packages available on the market [1] [2] [3] [4] [5]. Virtual construction technology is already applicable. The only condition, but of paramount importance, is to cross the cultural gap between technical drawing up to digital mock-up. In other words, how to move from a set of lines supposed to represent a part of the structure according to a specific point of view to a 3D-object modelling the same part whatever the selected point of view is.

When this step is reached, 3D-modelling is possible. And usage is done generally in a standalone mode, which means with only one end-user. This limitation will be detailed hereafter.

Let us come back to the traditional set of documents defining a construction project. The Document Breakdown Structure is driven by tacit rules, based on the assumption that a document is created by only one person responsible of the data and offering his expertise as added value. In the same way, this assumption is extended to a 3D-model that is created by only one person. But very quickly a problem appears. As the level of detail or the project size increases, the number of data to be created increases accordingly and the task cannot be accomplished in due time because of the amount of work, of the various needed skills that cannot be managed by a unique expert. More the mock-up becomes complicated, more its control and validation becomes difficult, indeed unmanageable. Collaboration work is needed and the associated process has to be defined.

The fact that there is no leading software or editor induces interoperability between the different 3D-models associated to the various available software packages. Exchange format are not yet fully standardized, even if the so-called Industry Foundation Classes (IFC) [6] are available, and tools to control the translation are emerging. This need of exchange standards is essential and all the stakeholders have to work together. Virtual construction is a global approach, so it induces a common collaborative way of working.

Decision makers and opinion leaders ask for more and more 3D-digital mock-ups for accepting large projects. This request can be satisfied because the level of detail is low and the work can be achieved by a small team. Today answering to such a kind of request is possible and boosts a larger usage in the construction sector. But we must have in mind that for going further, a second step has to be jumped.

Today due to job site organisation 2D-technical drawings are the only paper documents used by workers. Nevertheless this shall not imply that 3D-models cannot be used. The expected 2D-drawings are specific points of view of the 3D-model which therefore maintains the global consistency. As long as the model can be managed by one designer, it works and results are huge. But as soon as more than one designer is needed, due to the project size or the necessary skill range
or the time frame, it does not work properly. The difficulty is clearly at collaboration level, i.e. regarding the organisation of the 3D-model and its use in the coordination process.

Let us come back to the Document Breakdown Structure. The drivers of the breakdown are to give a document to one designer taking into account skills, delay to produce the document, project organisation…. In the same manner, a Product Breakdown Structure could be applied to the global 3D-model based on similar organisational rules. The Document Breakdown Structure will be maintained, assuming that the documents are only derived from the 3D-models. They will be used for their final need on the job site and also as additional tools to control and validate the information created through the 3D-models.

Projects are continuously changing. As long as the project goes on, the level of detail increases. Conflicts are detected; solutions are proposed and assessed during coordination meetings. It is mandatory to track these modifications in order to be sure to always use the latest updated data. Traditionally this coordination process is guaranteed by revision codes on the 2D-drawings. The fact that the 3D-model will become the unique repository of all the data of the project induces to store the revision codes into the 3D-model. The object level seems the adequate level assuming that each object is linked to a digital file and that the associated data are not too large.

4. Collaborative Work

In most cases, due to the size and/or the complexity of the project, the level of detail, the timescale, the various trades involved and the various localisations of the team, the 3D-model can no more be managed by only one person and a collaborative work becomes essential. In addition, the more the project becomes complicated, the more its control and validation become tricky.

Traditionally 2D-drawings are used. Information is stored via graphic shapes. Such a representation maintains the angles. Dimensions are given, in addition with other non geometric information. Transmission of the information contained in the drawing requires transmission of the medium plus reading and interpretation of the document by the addressee. Therefore the transmission is implicitly based on the involvement of both eyes and brain. Reusing of the information requires again both eyes and brain. It is based on the so-called WYSIWYG principle, i.e. “What You See Is What You Get”. Consequently the amount of information contained in a drawing is limited to allow full appropriation by the end-user. And that is certainly why assessment and approval is linked globally to the whole drawing.

Today, the use of 2D-drawings on construction sites cannot be ignored. Such an information medium is fully compatible with the current way of working. Replacing 2D-drawings means to revisit drastically construction processes. This use is based on the certainty of relying on the right document, updated and “good for work”. So metadata are necessary to track each document, including document identification, revision number, date, author, checker, validation responsible, status… The status “Approved – good for work” is mandatory for building. Signatures appended on the 2D-drawings are linked to this tracking. They guarantee that the information contained in the 2D-drawing with the given revision number is “frozen” and trustable. A copy of an original signed document is currently accepted, the need being to be sure that the associated data are frozen.

A digital file issued from a CAD system, and certified by an electronic signature that guarantee that the file cannot be modified, could be accepted. The key problem is the ability to prove that the information used is frozen and good for work.
In a quality management system, validation should not be confused with verification. Validation relates to meeting the needs of an external customer. Verification is an internal quality process of determining compliance with a regulation or a specification. The difference between validation and verification is often summarised by the following sentence: validation is ensuring “you built the right product” and verification is ensuring “you built the product right”. In other words, verification is testing to confirm that the product complies with its requirements and specifications, while validation is testing to confirm that the product satisfies external customer needs.

Moving to a 3D global digital mock-up, the first questions rising up are: How can I appropriate such a large amount of information? What shall be approved? A 3D digital mock-up allows easily validating assemblies and interferences. On the contrary, without an easy access to dimensions, implicit checks by the expert become difficult. Is the regulation for disabled people fulfilled for this project? All the habits based on visual control used with 2D-drawings are disturbed.

Holism versus reductionism? 2D-drawing approach is typically reductionist thinking, focusing on the drawing and needing to manage the global consistency of the project “by hand”. That is why coordination is a tricky and critical work.

Such a reductionist approach is also used in the current design process. The different phases allow envisioning progressively the details of the project, from feasibility study to shop drawings. To maintain the adequate limit of information contained in the drawing, the drawing scale is modified accordingly. In addition each trade has its specific drawings in order to favour flexibility and to maintain liability limits.

Digital mock-up approach aims at replacing physical prototype, leading to a description by objects, products and parts. Each object can be breakdown again into sub-objects, and so on as necessary. Digital mock-up allows designing complex products and validating their design all without ever needing to build a physical model. This technology allows also assembling different objects in order to validate a larger subset.

Having in mind the 2D-drawing approach, the approval status has to be linked to objects, more precisely to some adequate levels of the tree describing the product breakdown. These adequate levels have to be chosen on a case by case basis depending on the complexity or the maturity of the associated objects. To be consistent, a 3D-model or a 3D-model assembly will be linked to the object carrying the status. And as for 2D-drawings, objects could be specific for trades or disciplines.

To make easier visualisation and validation, some graphical rules should be established defining colours and layers associated with different types of data. Filters and highlights based on these rules facilitate interpretation, checking and appropriation. In addition, to maintain the 2D-drawing approach, a set of specific drawings should be associated to each object carrying an approval status in order to provide the associated set of drawings with the equivalent derived approval status.

Coming back to both eyes and brain used by the expert to check some regulation fulfilment, it should be noticed that other industries have cope with such a problem by including “links between objects” to describe the expert knowledge. This approach is the so-called Knowledge Based Engineering (KBE). It strongly makes control easier and reduces the need of explicit dimensions. The key-words are “thrust” and “trustworthy”. In the construction sector, in particular in Norway and Finland, developments have already been carried out in such a way, by Selvaag BlueThink [7] and Solibri [8]. This is also the ambition of the SMARTCodes [9].
Based on a complementary holistic approach, conflicts could be identified by simulation or checking tools. Therefore all the expert abilities would be focused on decision making in order to solve the conflicts, which should be their key activity.

Collaborative work could be viewed on different basis:

- Information sharing between different disciplines. For instance, the geometry is often the foundation of computer simulation. Nevertheless, the geometry usage is not exactly the same for each discipline, depending on the needed level of detail. Therefore extraction and adaptation of data have to take into account the specificities of the foreseen analysis.

- Information sharing between different companies acting in the frame of a common project. The digital mock-up must be able to take into account the liabilities and intellectual property rights of each partner, which means to manage access rights including read or write access depending on partner’s liabilities or rights.

- Information sharing in the frame of the validation process including clash detection, solution proposals, assessments and modification tracking.

- Information sharing with the job site.

To implement successfully 3D-models to be used for collaborative work, the following steps are recommended:

- Define and specify the aims of the 3D-model. Data to be modelled and tools to be used are fully depending on that initial choice. For instance, architecture, structural analysis, quantity take-off...

- Define the phase of the design process, and therefore the level of detail and the involved stakeholders.

- Describe the Product Breakdown Structure, identify the Objects that will carry the approval status, identify the 3D sub-models and define digital file naming rules accordingly.

- Describe the Document Breakdown Structure, define the relationship with the 3D-models and detail digital file naming accordingly.

- Define the general Project Reference Point, in order to make easy aggregation of the different models,

- Define colours and layers organisation,

- Select discipline related software packages,

- Define data sharing process, select data exchange formats and software packages for checking the exchange,

- Describe the validation process, including the clash detection process and software packages used for clash detection. Detail the process dealing with the identification of conflicts and the decision making organisation to solve the conflicts,

- Describe the process for tracking and logging modifications.

To be managed efficiently, information must be structured. Such structuring could be seen as heavy and constraining and some could argue that this will kill innovation and creativity. It is well known that badly managed structures could lead to inefficient databases and loose of control. Document managing systems currently used on large construction projects have already shown the benefits of structuring. The strategic need of involving at the early beginning of the project, all the stakeholders in the process definition has often been exhibited. The person in charge of the process, the so-called document controller, has a key role. Such a strategic implementation in 3D-modelling will be for sure more tricky.

5. Conclusions

The technology is here. The challenge is to move from traditional 2D-technical drawing to 3D-digital mock-up and to implement exchange standards and tools to check the exchange process.
Processes have to be revisited in order to take into account all the new capabilities of such a technology. The validation process is a key point. The model controller is a key role and has to be assisted by Knowledge Based Engineering.

Our way of thinking have to be changed, and this change will involve all the stakeholders. However, the potential opportunities demonstrated in other industries are too exciting to ignore them.

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