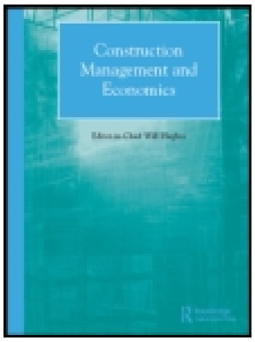

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Rethinking project management and exploring virtual design and construction as a potential solution

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The construction sector is facing widespread criticism of its low efficiency and poor performance. This has led to a rethink of contemporary project management (PM). However, current critical perspectives have failed to diagnose the practical problems existing in PM, and as a consequence, no promising solutions have been proposed. In this research, a combination of critical literature review, field works, case studies, open debates and interviews revealed five fundamentally problematic aspects of contemporary PM: (1) using artificial tools and methods; (2) cannot try before build; (3) discontinuity in construction processes; (4) ineffective information and knowledge management; and (5) creeping managerialism. These problems were then scrutinized by referring them to Virtual Design and Construction (VDC) as a potential solution. Strengths of VDC are explored, and hurdles that prevent it from gaining momentum are also evaluated. It is found that the problems of contemporary PM can largely be alleviated by the use of VDC although its many hurdles are yet to be overcome. This research provides new insights into how construction companies can adopt VDC technology to improve the problematic PM practices.

Keywords: Project management, virtual design and construction.

Introduction

Increasing demands for speed and efficiency in the face of greater complexity of modern construction projects have given rise to the need for management (Bennett, 1985). Since its diffusion into the construction sector, project management (PM) has been very helpful in accomplishing projects on time, within budget and meeting quality standards. However, the construction sector has also been criticized for its widespread problems such as late delivery, escalating project costs, unsatisfactory performance, uncashed welfare for its community and so on. As a consequence, this has triggered a rethink of PM which has examined critically how the construction industry can be improved by adopting better PM theories or methods (e.g. Melgrati and Damiani, 2002; Winter *et al.*, 2006).

In rethinking PM, a number of studies have paid close attention to the theoretical foundation upon which the discipline of PM is based. Morris (2002), for example, pointed out that the dominant strand of PM thinking is from the 'hard' system model which emphasizes the rational planning and control of projects. Koskela and Howell (2002) argued that the present doctrine of PM suffers from serious deficiencies in its theoretical base which essentially is obsolete. Winter *et al.* (2006), by conducting a UK Engineering and Physical Sciences Research Council (EPSRC) granted project, *Rethinking Project Management*, produced a comprehensive summary of contemporary thinking in PM and suggested five directions for further development. This stream of research is unfolded based on the premise that the problems with PM are rooted in its weak theoretical base and therefore in order to solve them a solid theoretical ground should be established in the first instance.

In contrast to the above research which tends to deal with PM problems by reformulating its theoretical base, the international management community has also shown great interest in the methods and practices of PM (Kloppenborg and Opfer, 2000). Over the past decades, a set of methods and practices such as the 'Gantt' chart, work breakdown structure (WBS), critical path method (CPM) and program evaluation

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and review technique (PERT) has been developed and put together as a PM Body of Knowledge (PMBoK) to facilitate PM. To manage today's projects with increasing sizes and complexities, emerging PM methods and practices are adopted. This stream of efforts tries to identify and solve problems through remedial ways. For example, when risk was becoming high in modern construction projects, risk management was developed and added into the PMBoK; with information technology (IT) increasingly used in the construction sector, IT management was included in PM. Winter *et al.* (2006) also admitted that

> the main argument was not that the extant PM body of thought … is worthless and should be abandoned, but rather that a new research network was needed to enrich and extend the field beyond its current intellectual foundations, and connect it more closely to the challenges of contemporary PM practice.

Research has been carried out to improve the unsatisfactory PM methods and practices. For example, Smith (1997) reported the use of applied behaviour analysis (ABA) to improve the performance of a diverse project team. This is a typical remedial approach as mentioned above. Voropajev (1998) introduced a new management function—change management—into the PMBoK during the process of PM globalization and unification. Notably, researchers (e.g. Bennett, 2000; Bresnen and Marshall, 2000) promoted partnering as a revolutionary way to solve the problems of PM. Indeed, partnering should be encouraged in the construction sector given that projects are becoming more complex and needing the joint effort of multidisciplinary teams. But partnering is not a panacea and its successful implementation requires other factors such as effective communication, strategic management, dispute resolving (Howlett, 2002). Efforts to understand the problems of PM have not been very successful so far, nor have sound solutions been proposed to tackle the problems.

On the other hand, the use of Virtual Design and Construction (VDC) is increasingly observed in the construction industry. Generally speaking, VDC is the use of virtual tools (e.g. visual simulation, virtual reality) and multidisciplinary performance models in order to improve construction business. VDC appears to be a promising approach to solve the many problems existing in current construction practices. Some anecdotal examples have suggested that VDC will bring a significant change to the way people manage construction projects (e.g. Huang *et al.*, 2007). However, no comprehensive study is reported to investigate the state-of-the-art of this approach, especially how it will change project management.

The aims of this research are: (1) to examine the main problems existing in contemporary PM; and (2) to explore whether VDC can be adopted as a revolutionary way to solve these problems. In the following sections, first we outline the concepts of PM and VDC. Secondly, research methodology is described. In the next section, data are analysed; a discussion is conducted to deepen understanding; and research findings are presented. Finally key conclusions are drawn together. This research will provide new insights into how construction companies can adopt VDC to improve problematic PM practices. The intended audience for the paper is the practitioners and academics who are seeking innovations to improve current PM practice. Those organizations that are utilizing or promoting VDC may also find this research of interest.

The concepts: PM and VDC

Project management

Project management (PM) can be viewed as an innovation of organization structure. In a rapidly changing and increasingly turbulent environment, it was found that some forms of project organization were better suited to the kind of one-off problems and opportunities that they had to deal with (Maylor *et al.*, 2006). This gave rise to the trend to organizing work through projects but also changing the organization structures to carry out the work. 'Management by projects' has become a powerful way to integrate organizational functions and motivate groups to achieve higher levels of performance and productivity (Van Der Merwe, 2002).

Lively debates on the concept of PM have taken place. PM has both narrow and broad senses. Initially PM referred to traditional core approaches such as scheduling, cost control and quality management that help to deliver project targets. This traditional PM is called the 'narrow sense PM'. However, Morris (1994) argues strongly that PM is about the total process, not just about realizing a specification to time, cost and quality. In the face of the increasing complexity and higher requirements of modern projects, together with the uncertainty and rapidly changing environment, the traditional PM approach will become obsolete without the adoption of integral processes and strategic thinking. Morris' argument has been gradually accepted (e.g. Winch, 2002; Maylor, 2003; Winter *et al.*, 2006). The term 'project management' has been expanded, standing for not only the traditional PM but also these 'newer' aspects such as strategy, technology, finance and so on. In addition, the term 'contemporary PM' is frequently used although it is rarely explicitly defined. Kloppenborg (2009) uses it to include proven methods developed over the past 50 years, as well as new methods that are emerging. In this paper, the term 'contemporary PM' stands for the state-of-the-art theories, methods and practices that facilitate the management of modern construction projects.

Virtual Design and Construction

A consensus on the definition of Virtual Design and Construction (VDC) is yet to be agreed. It is a concept that is still continually evolving. Fischer and Kunz (2004) define VDC as 'the use of multi-disciplinary performance models of design-construction projects, including the Product (i.e. facilities), Work Processes and Organisation of the design–construction–operation team in order to support business objectives'.

Three stages of development of VDC have been suggested (Fischer, 2006). The first phase is *visualization*. Traditionally, design was conducted by using two-dimensional (2D) approaches, and a construction process was guided by methods such as CPM and bar charts. The aim of visualization is to represent design and rehearse construction processes through visual simulation, three-dimensional (3D) technologies and virtual reality. The second phase of VDC is *integration*. It tries to integrate various processes and different disciplines involved in a project. The third stage of VDC is to *automate* some tasks of design and construction processes. Currently, design and construction planning are creative work undertaken exclusively by human beings; VDC only provides a good platform for this work. The status quo of VDC is mainly staying on visualization, and it is shifting to the integration of construction.

The realization of VDC relies on specific solutions that are still evolving, and its wider utilization depends on how its benefits are recognized by users. It is noted that the growth of VDC is closely associated with various research centres or companies that are researching and promoting it. There are many VDC solutions such as Virtual Construction Environment (VCE) (Waly and Thabet, 2002), DIVERCITY (Sarshar *et al.*, 2004), the Pro IT (2006) by the Confederation of Finnish Construction Industries RT, the approach by the Center of Integrated Facility Engineering (CIFE) at Stanford University, the approach by the AutoDesk, and the Construction Virtual Prototyping Lab (CVPL) at the Hong Kong Polytechnic University. Some of these approaches mutually reinforce each other while others compete in terms of theories, technologies and applications.

Research method

A triangulated methodology is adopted including literature review, field works, case studies, open debates and interviews. First, a literature review was conducted to explore the existing problems with PM. It also explores VDC by looking at its strengths and weaknesses. The literature review was augmented by conducting brainstorming among different groups, and by exploratory studies to consultancy works undertaken by the authors. As a result, three tentative sets of factors are produced: a list of existing problems of PM, a list of strengths of VDC and a list of its weaknesses.

Secondly, the tentative factors were evaluated in construction practices in order to understand the problems of contemporary PM and whether VDC is a promising solution for these problems. A questionnaire survey is a possible approach. But regarding the widespread questionnaire fatigue in the construction sector and particularly the difficulty in ensuring data quality, the authors decided to conduct the survey in focus groups that we know are experienced in PM and VDC. But soon the authors discovered obvious bias. For example, the focus groups, most of them having a working relationship with the authors, were too 'friendly'; they tended to give some favourable evaluation of the factors. It was therefore decided to adopt an indirect way—to conduct qualitative research such as interviews and to allow the important factors to emerge (i.e. grounded) from the interviews.

Thirty interviews were conducted as the third step. Among the interviews, 25 were with practitioners covering different levels of company roles, ranging from general managers through to site managers. The other five interviews were conducted with senior researchers in academia. All 30 interviews were semi-structured. The tentative sets of factors identified previously were used as a guideline for this task. The interviews were conducted in Mandarin, Cantonese and English. Data collection was enhanced by a range of less formal methods such as participation in site meetings, telephone conversations and e-mail exchanges.

Next, data were analysed by using software. The data were fed into the NVivo 7, a popular qualitative analysis tool for conducting content analysis. If a factor is strongly emphasized by a particular interviewee or is frequently mentioned by many interviewees, this factor will be assigned a weight and come into focus. Thus, by analysing all the qualitative data, the problems of PM and potentials of VDC were distilled. By cross-referencing the results from the literature review and interviews, a refined list of factors was derived as tentative research findings. The refined factors indicate the urgent problems existing in PM and how VDC can be a potential solution to these problems.

The tentative research findings were then validated by several real-life cases where VDC has been applied.

These projects are: (a) a high-rise office building; (b) a railway station project; (c) a sports complex; (d) several public housing projects; and (e) an experimental housing industrialization project. These projects represent different project conditions for implementing VDC. Based on the validation, a more refined list of problems in PM was produced and the strengths and weaknesses of VDC were identified. How VDC can potentially solve these problems is explored in depth.

This research was presented in a conference as a keynote speech, and it stimulated hot debate. The research findings were debated by putting them into the context of a UK EPSRC project—the Grand Challenge (KIM, 2006). The present research was also given a closer scrutiny by leading scholars and practitioners on a workshop held in Hong Kong in November 2007. The data supporting this research were also collected through collaborating with other organizations such as the DS in France, CIFE in USA, and so on. In parallel to these research activities is the ongoing literature review, enabling the mutual validation of knowledge from the literature and from practices. No significant difference of VDC practices in different regions has been detected; the interests and concerns seem all similar and will be reported below.

Analysis, discussion and findings

Project management revisited

Artificial tools and methods for PM

Construction projects are managed through using a set of artificial tools and methods such as 2D line drawings, three-view projection, PERT, CPM, bar charts, which for decades have been laid down as common knowledge for PM. It is continually evolving, in particular with the advancement of IT. For example, software packages such as AutoCAD, Microsoft Project and Primavera P6 have been developed to enhance PM. These methods and tools were state-of-the-art approaches in their time, and the way to manage projects has been significantly improved with the invention of these approaches.

However, these tools and methods are unnatural although they are viewed as 'conventional'. These approaches express the design and construction of a project in 2D formats. Project stakeholders have complained that they feel effectively disenfranchised from the design-construction process because it is so arcane and complex to use these traditional approaches (Kunz and Fischer, 2005). There is a pressing need to represent the world in the way that it naturally exists (i.e. three dimensional, 3D) given that new technologies such as 3D CAD, virtual reality (VR) provide the possibility of doing so. This is echoed by an interviewee:

> In order to solve the current problems in project management, I suggested to unlearn all the traditional 2D stuff. Young students should be directly taught with 3D when they enter colleges. The distorted world needs to be distorted back.

Cannot try before build

A widely mentioned shortcoming of PM through the study is that in traditional PM it is not possible to try different design and construction schemes before a project is actually built. This leads to two major problems. First, design errors arising from the design stage cannot be effectively identified in advance. They would cause substantial disruption or loss when the errors were discovered. As is widely known, real project processes are difficult to reverse, if not completely impossible. Design review and clash detection are being conducted in many projects. But without the assistance of helpful tools their effectiveness is often limited. Secondly, different construction schemes cannot be tried and rehearsed in advance. These schemes were developed at planning stage which is a critical process that determines the successful delivery of a project (Huang *et al.*, 2007). In practice, project planning relies heavily on rules of thumb and experienced persons. This resonates with a metaphor given by an interviewee:

> construction is similar to playing blind chess; every move of construction activity is planned and communicated without a real visible chess board in place, and even worse, you don't have the 'undo' button.

'Cannot try before build' makes construction a very risky business. A construction project is by and large an experimental process guided by design and planning information which may be full of imperfections and mistakes. Even worse, as discussed above, the information is presented in an artificial way where the imperfections and mistakes cannot be easily picked up. As a result, reworking has been ubiquitous and time and cost overruns are common. It would be of great benefit if there were a virtual and simulated environment which would allow a project to try different schemes before it is actually built.

Discontinuity in construction processes

Discontinuity as a problem in contemporary PM is increasingly mentioned. For a long period construction theorists or practitioners have not questioned the fact that a project was divided into several stages from inception, design, finance, construction, operation, through to demolition. On the contrary, this has been perceived as an organizational innovation, and different types of companies, e.g. design firms, contractors, suppliers, have been established purposely for different specialisms.

In view of the poor performance caused by the discontinued construction processes, there is a strong stream of thinking that calls for a higher integration of project processes. For example, contractors and facility managers are invited to join in the design stage; post-occupancy evaluation (POE) is conducted. Whole life cycle thinking such as lifelong costing and project sustainability is advocated. Various integrated procurement systems (IPS) such as BOT, PFI and design and build (D+B) were devised to encourage the alignment of construction processes. Indeed, discontinued project processes should be reunited to achieve better performance of a project. However, discontinuity is still widely observed in construction, although anecdotal evidence showed that undertaking of some construction projects has been improved by partnering. Discontinuity has caused many problems, e.g. wide gaps exist between what is designed and what is constructed; interoperability is low thus causing poor communication between project parties. A reunion of discontinued construction processes has moved to the forefront of solutions for improving contemporary PM.

Ineffective information/knowledge management

Effective management of information/knowledge (I/K) is frequently advised both in literature and by the interviewees. Managing a construction project is essentially making a web of decisions across its process based on the I/K available. In view of this, Winch (2002) suggested regarding a project as an information processing system, and the management of a construction project, fundamentally, is about managing the project information flow. However, current PM practice does not easily lend itself to achieving effective I/K management. Architectural information, for example, cannot be wholly transferred to the construction process, and contractors' concerns cannot be properly expressed at the design stage. Loss of I/K from one stage to another has caused many problems in the construction sector (Carrillo *et al.*, 2006; KIM, 2006).

In addition, the continual improvement of performance relies on learning from the past and the creation of new knowledge. This is also problematic in the construction sector. I/K generated from a project, i.e. design rationale, facility management records, was often discarded with the dissolution of a project team. As a result, similar mistakes recur in different projects. This is echoed in the interviews; an interviewee pointed out that in her company, a mistake that was spotted 20 years ago occurred again and again in other projects. Project teams are not sharing I/K and learning from each other, and construction companies are still 're-inventing the wheel' (Carrillo *et al.*, 2006). Nonetheless, I/K has not been effectively managed in this sector in spite of widespread acceptance of its importance. One of the problems is that it lacks a uniform platform where I/K can be consistently stored and retrieved when needed.

Creeping managerialism

Management of projects is sliding into the swamp of 'creeping managerialism'. Over the years with the increase of the complexity and size of modern projects, more managerial positions have been created. For example, new positions such as IT managers and logistic managers which had not been seen before in this industry were created. As a result, the size of management teams has been significantly increased. It has led to sophisticated bureaucracy while long-standing problems such as low productivity, delayed delivery time, and cost overrun seemingly remain unsolved.

The creeping managerialism also adds to management costs. The cost formula in construction shows that the direct costs account for up to 70% of the overall construction cost and indirect costs such as overheads, contingencies and profit take up about 30% (Patrascu, 1988). Given that contingency costs are unavoidable, management cost escalates, and the margin for labour is then usually squeezed by managerial level. Construction workers are stressed, and in some cases tensions between workers and management were reported. Social responsibilities that are assumed by the construction industry, such as improving the built environment, bringing welfare for the construction community, have not been cashed. The importance of management is often highlighted but the reduction of managerialism has rarely been considered as a solution. It is time to rethink management in construction and trim down the creeping managerialism by adopting new thinking.

In summary, through analysing the data from a critical literature review, fieldwork, case studies, open debates and interviews, fundamentally problematic aspects of contemporary PM were identified. They are grouped into five categories as listed in Table 1 and they should come into focus on the agenda for improving PM.

Is Virtual Design and Construction the way forward?

The problematic aspects of PM were scrutinized by deliberately referring them to Virtual Design and Construction (VDC) as a potential solution. Research

Table 1 A list of fundamental incapabilities of contemporary project management

(1) *Artificial tools and methods for PM*: PM is using a set of unnatural tools and methods which distorted the world; it is time to represent the real world in a more understandable way.
(2) *Cannot try before build*: The lack of capability to 'try before build' makes construction a very risky business; rework has been ubiquitous, and time and cost overruns are common.
(3) *Discontinuity in construction processes*: Discontinued construction processes lead to low performance in many construction projects; contemporary PM calls for a higher level of integration.
(4) *Ineffective information/knowledge management*: In spite of widespread acceptance of its importance, no consistent approach has been devised to effectively manage project information/knowledge (I/K).
(5) *Creeping managerialism*: Nowadays the management team is bigger than ever while long-standing problems remain unsolved in PM.

was conducted to investigate strengths of VDC, and how the problems of contemporary PM can be overcome or alleviated by these strengths. Hurdles that prevent VDC from wider application were also evaluated.

Advantages of Virtual Design and Construction

By analysing the research data, advantages of VDC were identified. They lie in eight areas: (1) inspiration of novel design; (2) design error detection; (3) construction plan rehearsal and optimization; (4) detection of unsafe areas; (5) construction site management; (6) construction communication; (7) project information and knowledge management; and (8) reduction of creeping managerialism.

Inspiration of novel design

Novel design can be created with the assistance of VDC. Unlike the traditional design process that often needs to stop and express schemes in 2D drawings, designers focus on design schemes by using 3D approaches. 3D design and construction schemes are easier to understand and implement. Creativity can be further enhanced by some libraries such as AutoCAD Revit and Google Warehouse, which provide 3D design pieces. Designing is able to achieve 'what you see is what you get'.

Design error detection

By simulating in a 3D virtual environment, design errors can be more efficiently detected and corrected before they cause significant rework. Design error detection is widely conducted in the construction sector. However in many cases, owing to various constraints (e.g. incomplete information, limited time, inexperienced designers), the effectiveness is relatively low. VDC provides a more effective environment for conducting this work owing to its 3D presentation.

The benefit has been seen in two case studies conducted by the authors. One was a hypothetical scenario in a PFI hospital project in London: because of lack of consideration at the design stage, the door of an operating theatre is too narrow for admitting a large x-ray machine. In this instance, the machine will be taken apart by the manufacturer and reassembled in the theatre completely at the hospital's cost. Virtual design review helps avoid this. Another real-life example was the experimental housing industrialization project as mentioned in the research methodology section; by using VDC, clashes between the scaffolding and the metal falsework for precast beams were detected. Otherwise, even though only 30cm long, these clashes could cause severe halt of the construction process. Nonetheless, the advantage should not be overstated. This is supported by an interviewee, an engineer with more than 30 years' experience:

> I can detect all design errors from drawings but through this VDC it will be quicker and those less experienced young men can do so.

Construction plan rehearsal and optimization

With the assistance of VDC, construction plans can be rehearsed in advance and an optimal one can be chosen without real physical building being built. In the aforementioned high-rise office building project, a cycle for building a typical floor of the project is optimized to four days. This seems to be the most efficient method and it is now standard practice for constructing high-rise buildings in Hong Kong. With the help of VDC, the construction team enjoyed the speed from day one since the process had been already rehearsed and learnt virtually in the VDC system. The advantage of VDC resonates with CIFE's measurable goals for construction—ensuring three major AEC projects to be designed 'within a year' and constructed within 'six months' (CIFE, 2007).

Detection of unsafe areas

By using VDC, unsafe areas can be more effectively detected in comparison with traditional methods. By virtually walking on the work surface, unsafe areas can be detected in advance. For example, by using VDC, it was discovered that in the housing project scaffolding was not fully enclosed by a handrail around some corners which could cause construction workers to fall. The path for hoisting and installing the big outrigger in the high-rise building project was found to be not clear enough, which could lead to conflicts. Given time and sufficient knowledge, it would be possible to detect all potentially unsafe areas from 2D drawings. But through using VDC, this work is easier and more effective.

Construction site management

Construction sites can be better organized with the assistance of VDC. The advantage has been seen in the example of the high-rise office building, which is erected in a very confined area closely surrounded by other high-rise buildings. In the housing industrialization project, VDC competed against a Japanese company which uses its honoured just-in-time (JIT) approach. The JIT method depends highly upon the configuration of construction sites. It turned out that VDC and JIT can be mutually augmented in organizing construction sites, in turn achieving higher efficiency. The advantage lies in the capacity that VDC allows for trying different configurations of construction sites and an optimal one can be selected without erecting any physical structure.

Construction communication

Effective communication is of vital importance to the successful undertaking of modern construction projects. Communication practices are widely reported as unsatisfactory in the constructions sector which in turn results in problems such as schedule delays, cost overruns and inadequate quality (Dainty *et al.*, 2006; Emmitt and Gorse, 2007). One of the interviewees made a comment:

> it is unfair to say that we are not communicative at all, simply individual parties have no sharing platform, thus decisions are made from their own point of view.

VDC integrates people, construction processes and available resources based on a sharing understanding of a given project. Thus VDC enables improved communication practice in construction.

A Building Information Model (BIM) will be produced, and it will serve as the major communication vehicle throughout the life cycle of a project. Again taking the high-rise office building project as an instance, designers, clients and contractors communicated based on the BIM as a uniform platform. The benefit of VDC in improving communication was also seen in the sports complex project where offsite prefabrication was massive and different task groups were working in parallel on the same site.

Project information and knowledge management

Information/knowledge (I/K), which is vitally important for the success of a project, can be more effectively managed throughout its life cycle by using VDC. I/K is retained in a BIM, which according to Whyte *et al.* (2008) can be viewed as a set of visualized knowledge. It is a 'holding ground' for different types of practitioner knowledge and it often changes and evolves as knowledge develops (Henderson, 1999). In our case studies, the electronic BIMs from the design stage acted as 'tendering document' directly at the bidding stage. The BIMs were further enriched by adding I/K during the construction stage, e.g. the installation of machinery and electronics. The KIM Project (2006) envisages that the I/K should be used in the operation stage where I/K is often missing when needed. Owing to the potential of continuous I/K management throughout a project life cycle, the discontinuity of project can be reduced to a certain extent by using VDC. It provides a uniform platform to facilitate integration (e.g. by retaining project information and knowledge).

Reduction of creeping managerialism

It can be seen that VDC is able to improve construction safety, site management, communication, bureaucracy, information and knowledge management. Thus it is able to trim down some managerial positions that become redundant. The creeping managerialism in construction can be alleviated.

However, in our research, no real example of reducing creeping managerialism has been recorded. The interviews show that managers were defensive when the authors raised this idea since reducing managerialism often has significant impact on organization structure. It is more readily embraced when this point is expressed in the alternative way that current management capacity can manage more projects with the assistance of the VDC technology.

Hurdles for wider application of Virtual Design and Construction

Widespread application of VDC is yet to be achieved in construction owing to many hurdles. This research evaluates the various hurdles which are grouped as follows: (1) technical hurdles; (2) new costs; (3) willingness to pay for VDC; and (4) risk of change.

Technical hurdles

VDC is supposed to improve interoperability but existing VDC solutions present a new challenge; the lack of software compatibility makes it difficult to communicate between different VDC solutions. The case studies suggest that it is often for a client to adopt a software package, either DS or Autodesk, and then contractors follow the same stream of packages to maintain the compatibility. Design speed is another problem when using VDC in real-life projects. It takes a long time to create all the detailed 3D models of building, temporary work and plant, to the desired level of detail and accuracy (Huang *et al.*, 2007).

New costs

While bringing many benefits, VDC increases cost. Companies face the extra cost of learning VDC and unlearning their old approaches. The cost–benefit relationship of VDC needs to be quantitatively measured (e.g. Gilligan and Kunz, 2007; Huang *et al.*, 2007). In this research, it is discovered that VDC has been implemented well in areas where benefits can be tangibly measured, e.g. clash detection, construction flow for a typical floor. However, VDC has not been widely applied to all project processes despite the fact that anecdotal evidence of its success is reported every now and then.

Willingness to pay for VDC

Even when the benefits are obvious, controversies over who should pay for VDC are frequently recorded by the authors. VDC aims for integration while the fact is that different project players are still acting as different profit centres. It is also not a simple matter of 'who benefits, who pays' since the benefits cannot be explicitly allocated to different stages or participants. The interviewees strongly recommended that clients should be the driving force to promote the vision of VDC. As an exceptional case, an interviewee from the London PFI hospital project stated that 'all parties just happened to agree on using 3D design and construction from the very beginning, then we use it'.

Risk of change

As stated earlier, the shift to VDC means significant impact on many aspects of current construction methods while the industry is viewed as being slow to respond to changes. Moreover, the VDC modelling and particularly the model-based VDC analysis methods are still undergoing theoretical development (Kunz and Fischer, 2005). Both academia and the industry are struggling with which aspect of people, processes or technologies should be at the core of VDC. The changing theoretical foundation provides a convenient and often appropriate excuse to avoid the use of VDC (Kunz and Fischer, 2005).

Conclusions

Contemporary project management (PM) is facing many challenges with the increasing demands for speed and efficiency in modern construction projects. This led to a rethinking of PM to investigate how the sector can be improved by adopting better PM theories, methods or tools. The critical perspective in this research revealed five fundamentally problematic aspects of contemporary PM: (1) using artificial tools and methods; (2) cannot try before build; (3) discontinuity in construction processes; (4) ineffective information and knowledge management; and (5) creeping managerialism.

The emergence of Virtual Design and Construction (VDC) technology provides a promising approach to alleviate or solve the above problems. This research identified eight virtues of VDC. While it is not necessarily a panacea to solve all the problems in contemporary PM, VDC is set to significantly change the traditional ways of conducting projects. It is envisaged that VDC is the way forward to improve contemporary PM; old construction protocols will be significantly changed; traditional mindsets and behaviours in construction will also alter with the wider application of VDC.

Various hurdles that prevent VDC from wider application are identified in this research. The hurdles lie in four aspects: (1) technical hurdles; (2) new costs; (3) willingness to pay for VDC; and (4) risk of change. Future research is recommended to look at how to create all the detailed 3D models of building, temporary work and plant to the desired level of detail and accuracy so that VDC can be quicker. To increase the compatibility of various VDC solutions is an urgent issue. The development of Industry Foundation Classes (IFC) is one of the initiatives to deal with the issue but more integral efforts are required. A further suggestion is to identify, quantify and price the benefits of VDC. This not only provides hard evidence to encourage wider application of VDC but also allows stakeholders to pay for what they have benefited from the adoption of VDC.

The authors appreciate that there are limitations in this study. First, the research findings are applicable to an international construction context since no significant difference of VDC practices in different regions has been detected. But we did not devise an effective instrument for measuring this regional variation. Second, this study investigated the inclusivity of VDC with other approaches (e.g. JIT, partnering) that are introduced to improve the contemporary PM but did not explore the potential conflict between VDC and the other approaches.

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