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The project benefits of Building Information Modelling (BIM)

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Abstract

Theoretical developments in Building Information Modelling (BIM) suggest that not only is it useful for geometric modelling of a building's performance but also that it can assist in the management of construction projects. The purpose of this paper is to explore the extent to which the use of BIM has resulted in reported benefits on a cross-section of construction projects. This exploration is done by collecting secondary data from 35 construction projects that utilised BIM. A set of project success criteria were generated and content analysis was used to establish the extent to which each individual project met a criterion. The most frequently reported benefit related to the cost reduction and control through the project life cycle. Significant time savings were also reported. Negative benefits were mainly focused on the use of BIM software. Cost/benefit analysis, awareness raising and education and training are important activities to address the challenges of BIM usage.

Keywords: Business Information Modelling (BIM); Project benefits; Secondary data; Case studies

1. Introduction

Construction projects are becoming much more complex and difficult to manage (Alshawi and Ingirige, 2003; Chan et al., 2004; Williams, 2002). One complexity is the reciprocal interdependencies between different stakeholders, such as financing bodies, authorities, architects, engineers, lawyers, contractors, suppliers and trades (Clough et al., 2008). As a response to the increasing complexity of projects, information and communication technology [ICT] has been developing at a very fast pace (Taxén and Lillieskӧld, 2008). During the last decade, a major shift in ICT for the construction industry has been the proliferation of Building Information Modelling [BIM] in industrial and academic circles as the new Computer Aided Design (CAD) paradigm (Succar, 2009). BIM is currently the most common denomination for a new way of approaching the design, construction and maintenance of buildings. It has been defined as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Succar, 2009: 357). BIM has been utilised on high profile large-scale projects, such as the recently constructed London 2012 Olympic 6,000 seating Velodrome cycle track and the 48 floor Leadenhall Building "The Cheesegrater," which, at 225 m, will be one of the tallest buildings in the City of London on completion in 2014. In addition to such large scale projects BIM is also used on individual components of projects of a smaller scale. For example, the modular stairs in the new bus station at Slough, UK, that was officially opened in June 2011 was designed and fitted using BIM (Buildoffsite, 2011). Anticipating benefits from the use of BIM in respect of reduced transaction costs and less opportunity for errors to be made, the UK Government has stated that from 2014 onwards all contracts awarded will require the supply chain members to work collaboratively through the use of

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" fully collaborative 3D" BIM (CabinetOffice, 2011: 14). 3D BIM means all project and asset information, data and documentation must be in electronic form. Furthermore, the public and private sectors in the USA are collaborating to promote BIM's use (Underwood and Isikdag, 2011). However there is a view that the case for BIM is not totally proven, with the overall effectiveness of BIM utilisation still not completely justified (Jung and Joo, 2010).

Succar's definition of BIM above highlights its holistic nature, which includes not only software that allows the geometrical modelling and the input of information but also project management (PM)-related tools and processes. As such, taking a holistic perspective of BIM places it firmly in the construction PM domain. It has a potential use for construction project managers in improving collaboration between stakeholders, reducing the time needed for documentation of the project and, hence, producing beneficial project outcomes.

One strand of the BIM literature is to document in detail the use of BIM on specific project cases, such as Heathrow Terminal 5 (BSI, 2010) and Walt Disney Concert Hall (Haymaker and Fischer, 2001). What is lacking, though, is any cross-case synthesis to ascertain the extent to which the use of BIM leads to enhanced benefits to projects beyond the individual case under consideration. To address this gap in the literature this paper reports analysis of secondary data from 35 case studies relating to the use of BIM that have been documented in the academic literature or otherwise placed in the public domain; with the purpose of answering the question, has the use of BIM resulted in benefits to construction projects?

2. Literature review

Complex construction projects require inter-organizational associations (Maurer, 2010). To ensure success in inter-organizational project ventures, trust between the different project partners is acknowledged as a key success factor (Kadefors, 2004; Maurer, 2010). Because of the nature of work in these inter-organizational ventures there is a well recognized need for better integration, cooperation, and coordination of construction project teams (Cicmil and Marshall, 2005, cited in Maunula, 2008). Inter-organizational information systems [IOIS] are one possible way to cope with the integration, cooperation, and coordination challenges faced in construction (Maunula, 2008). IOIS are sometimes referred to as Web-based PM Systems [WPMS] (Forcada et al., 2007; Nitithamyong and Skibniewski, 2004), Web-Collaborative Extranets [WCEs] or Document Management Systems [DMS] (Ajam et al., 2010). Whatever the nomenclature used, such systems facilitate the sharing of diverse types of information in an accurate and timely way, which is a key to achieving successful project outcomes (Anumba et al., 2008). A document based way of working means that through the project life cycle there is an "unstructured stream of text or graphic entities" (BSI, 2010: 2). This unstructured stream is a challenge for better integrated practices, with the information exchanged at the document level generally "fuzzy, unformatted or difficult to interpret" (Ajam et al., 2010: 763). Ajam et al. (2010) argue that the proper use of an IOIS is that of going from document sharing practices to sharing information at the object or element level. Hence, BIM could be the key approach to adopt to ensure this integration and shift from the document paradigm to the Integrated Database paradigm happens.

Whilst the topic of BIM has been studied by academics (see, Aouad et al., 2006; Lee, 2008; Maunula, 2008; Succar, 2009); by professional groups (BSI, 2010; McGraw-Hill, 2008, 2009, 2010a, 2010b); and, naturally, by software vendors (Autodesk, 2007; Bentley, 2003) very little of the PM literature focuses on BIM from the PM point of view. An exception is Allison (2010), who addresses the BIM potential as a PM tool more directly. Allison describes 10 reasons why project manager should champion 5D BIM. Aouad et al. (2006) defined this multidimensional capacity of BIM as "nD" modelling, for it allows adding an almost infinite number of dimensions to the Building Model. 5D BIM is traditionally understood as BIM that includes, besides the 3D model – see introduction section for a definition of 3D, scheduling information (the 4th D) and information for estimating the project from the model (the 5th D). Although the work of Allison is from an employee of a BIM software vendor, and the potential of BIM for PM might be slightly exaggerated, the list of advantages for PM practitioners is a useful starting point. These advantages are compiled in Table 1, and are potential ways in which BIM can benefit Project Managers.

The rising interest in BIM can be seen in conjunction with new PM frameworks, such as Integrated Project Delivery (IPD), which increases the need for closer collaboration and more effective communication (Eastman et al., 2011). When people collaborate on a project, communicating specific characteristics of the project amongst the different parties involved requires documentation of these characteristics (Lee, 2008). Traditionally, this documentation was done on a paper or document basis (BSI, 2010). BIM takes the traditional paper-based tools of construction projects, puts them on a virtual environment and allows a level of efficiency, communication and collaboration that exceeds those of traditional construction processes (Lee, 2008). Hence "the coordination of complex project systems is perhaps the most popular application of BIM at this time. It is an ideal process to develop collaboration techniques and a commitment protocol among the team members…" (Grilo and Jardim-Goncalves, 2010: 524). BIM has also been linked to the development of lean approaches to the management of projects, as the enhanced collaboration and information sharing can contribute to the lean management's goal of reducing non-value-adding waste (Olatunji, 2011).

BIM has a potential use at all stages of the project life-cycle: it can be used by the owner to understand project needs, by the design team to analyze, design and develop the project, by the contractor to manage the construction of the project and by the facility manager during operation and decommissioning phases (Grilo and Jardim-Goncalves, 2010). Looking to the future leads to speculation that BIM will eventually lead to a virtual project design and construction approach, with a project being completely simulated before being undertaken for real (Froese, 2010). As such BIM will provide potential beneficial

Table 1
Potential benefit of using BIM for project managers (after Allison, 2010).

Potential benefit for PMs	Why?
Organize the project schedule and budget	An integrated 5D BIM model immediately updates both the schedule and budget when any design change occurs
Work well with the Design Team	By using the integrated 5D BIM model to visualize and explore the impact of changes, s/he can keep project scope in check and become a trustworthy liaison between the designers and Owner
Hiring and controlling the Subcontractors	Having a handle on clash detection and coordination plays a key role in keeping Sub-contractors' work predictable
Requests For Information (RFIs) and Change Orders	Utilizing Coordination Resolution in preconstruction, these numbers can be brought to near zero.
Optimize the Owner's experience and satisfaction	Owner received a big injection of confidence in the GC when the PM showed him/her how design decisions impacted cost and schedule
Project closeout	PM to present a 6D BIM – a facilities resource with information on warranties, specifications, maintenance schedules, and other valuable information
Profit margin	By thoroughly understanding the project in 5D, the PM has more tools at his disposal to keep tight reins, and more reports to monitor progress
Progressive Owners are mandating BIM on their projects:	Becoming the BIM expert, in both preconstruction and out in the field, makes the PM invaluable and a key player.
PM Firm Growth	Project's success with 5D BIM means the opportunity to grow the firm's reputation and helps the corporate team win new business.

project outcomes by enabling the rapid analysis of different scenarios related to the performance of a building through its life cycle (Schade et al., 2011). Steps towards this are already taking place, with construction projects that utilise BIM typically being built virtually 30–40 times (BuildOffsite, 2011).

BIM has the potential to be the catalyst for Project Managers to reengineer their processes to better integrate the different stakeholders involved in modern construction projects. This re-engineering has been likened to the move towards applying lean principles. Arayici et al. (2011) elaborate on this by forming seven pillars of a BIM implementation strategy: eliminate waste, increase feedback, delay decisions to achieve consensus, deliver fast, build-in integrity, empower the team and see the whole. By doing this PMs will achieve better project outputs and outcomes. Furthermore, PMs are well placed to promote the use of BIM as they have an influence on the resourcing of project teams (Gu and London, 2010). As such they can act as a catalyst and promoter of BIM, as well as a recipient.

Countering the potential benefits of BIM to project is the challenges that need to be overcome if effective multi-disciplinary collaborative team working, supported by the optimal use of BIM, is to be achieved. Not least the changing roles of key parties, such as clients, architects, contractors, sub-contractors and suppliers, the new contractual relationships and the re-engineered collaborative processes (Sebastian, 2011). One key role likely to be affected by the introduction of BIM is that of the project manager. The impact of an enhanced use of technology on the day-to-day activities of the project manager and the ultimate impact this has on the outputs and outcome of the project are still not clear (Aranda-Mena et al., 2009). There is also the fragmented nature of the construction industry to consider, which means that knowledge gained by a team during the undertaking of a project is often not retained and used on future projects. It is not clear whether BIM is able to overcome this structural problem (Lindner and Wald, 2011).

3. Method

To explore whether the use of BIM has resulted in benefits to construction projects, secondary data documenting completed construction projects that implemented BIM were gathered. Empirical studies in aspects of project management practices often use self-reported data. Yet alternative approaches utilising secondary data have their advantages, including a reduction in distortions due to self-reporting and access to information about events (Harris, 2001). The sources of the data were case studies in academic journals or which had been placed in the public domain via the world-wide-web. Those 35 case studies found where positive or negative effects of using BIM were mentioned were sourced as suitable for further analysis as a convenience sample. The data were analyzed to establish in which specific ways the projects benefited (or did not benefit, as the case may be) from the use of BIM. This analysis was done by deriving a list of success criteria related to the output of the project, in terms of meeting time, cost and quality objectives and also related to the management of the process, such as effective scope management and communications. As such they encompassed both project and project management success and reflect the notion of project success being a multi-dimensional concept (Shenhar et al., 2001). It is noted that terminology is fluid in this area, with the terms "success criteria," "critical success factors" and "key results areas" often used to mean the same thing. Here we use the term "success criteria" to mean how success is defined. Linked to each success criterion will be quantitative measures by which success, against the criterion, is measured – the Key Performance Indicators.

To provide a structure to aid data analysis and presentation of the results, the success criteria were grouped based on the Project Management Institute's (PMI) Project Management Body of Knowledge (PMBOK) Knowledge Areas (PMI, 2008). These Knowledge Areas were chosen as they provide a comprehensive high-level framework encompassing all the dimensions of success. The role and influence of BIM on the completed construction projects was compared with the role and influence expected from a Project Manager, using the success criteria that were derived (see Table 2).

As shown in Table 2 the Coordination Success Criterion was created from the Integration Management PMBOK Knowledge Area. The change in nomenclature was done after analysing the case studies and finding that the word coordination was often

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Table 2
Success criteria based on PMBOK knowledge areas.

PMBOK knowledge area	Definition (after PMI, 2008)	Criterion	Positive consideration
Integration Management	Unification, consolidation, articulation, and integrative actions	Coordination*	Improvement
Scope Management	Defining and controlling what is and is not included in the project	Scope	Clarification
Time Management	Accomplish timely completion of the project	Time	Reduction or Control
Cost Management	Planning, estimating, budgeting, and controlling costs	Cost	Reduction or Control
Quality Management	Quality planning, quality assurance, and quality control	Quality	Increase or Control
Human resource Management	Organize and manage the project team	Organization	Improvement
Communications Management	Timely and appropriate generation, collection, distribution, storage, retrieval, and disposition of project information	Communication	Improvement
Risk (uncertainty) Management	Increase the probability and impact of positive events, and decrease the probability and impact of adverse events	Risk	Negative risk reduction
Procurement Management	Purchase or acquire the products, services, or results needed from outside the project team to perform the work	Procurement	Help

*Integration was changed to Coordination as the term was more usually found in case studies and it was deemed to have a very similar meaning.

mentioned but not integration. However, in the Integration Management chapter of the PMBOK, coordination embraces most of its meaning i.e. "…identifying that a change needs to occur or has occurred" or "…reviewing and approving requested changes" (PMI, 2008: 93).

Details of the cases including project name, city and country in which the project was located, timescales for the design and construction phases (where stated), budget – in millions of Euros (again where stated), size in square metres and type of building are provided in Table 3.

It is worth noting that half of the case studies shown in Table 3 are projects from the United States of America (USA). This is probably due to the higher penetration rates of BIM in the USA compared to other regions and hence there are currently a relatively higher number of scholars and professional bodies publishing articles about the subject emanating from the USA.

Each documented case was considered, using content analysis to identify the benefits (positive and negative) of BIM. The content analysis process developed by Harris (2001) was followed. The unit of analysis adopted was the "phrase," which may vary from a single word to a whole sentence (Harris, 2001: 198). In this case the phrase represented "project benefit." A mark was made for each phrase identified in a case. These marks were then translated to one of the success criteria described in Table 2. When undertaking the translation none were found to fit into the last category "Procurement," so this category was removed and replaced with "Software Issues" (as the content analysis showed this to be an important emergent theme – albeit in respect of negative benefits, across a number of cases). The output of the translation activity is presented in Table 4.

The projects were then organized using the added score for each of them (positive benefits minus negative benefits). This is not an attempt to find which case demonstrates the most beneficial use of BIM but to organize the data in a way that highlights were there are more positive than negative benefits. Hence the numbers on the score column should not be seen as an indicator of how successful or unsuccessful those case study projects were, but simply how many success criteria were mentioned positively or negatively. For example, the case study of the Cascadia Center (McGraw-Hill, 2010b) in Table 4 shows a score of −3. This means that 3 aspects of the use of BIM related to the Coordination, Organization and Software success criteria were mentioned as challenging or causing difficulties (negative benefit) and no specific positive benefits mentioned, but it does not mean that the use of BIM overall was negative.

Positive and negative benefits in each case were separated into two different columns. For each success criterion positive and negative benefits were counted separately, rather than giving a total score for each (positive minus negative count). With this approach, it is possible to see which success criterion appears more times as a positive factor and which ones appear as challenges or problems. Next the different success criteria were organised according to the frequency of occurrence each was mentioned as a positive factor (see Table 5). Table 5 also shows the times and number of projects to which the success criteria were mentioned as a negative benefit and the number (and %) of projects that were incorporated in the figures.

The approach taken to quantify the number of projects in which a success criterion had a positive effect was conservative in nature. In some cases, a success criterion was mentioned once in a positive manner and once in a negative manner. In those situations, the project was not counted as one where the success criterion had positive effects (or negative) regardless of which effect seemed more influential on the project outcome. For example, on the CMG Medical Office Building, described by Khanzode et al. (2008) the Coordination success criterion was counted once as positive for the "improved workflow due to the use of 3D/4D models" and once as negative for the uncertainty of "how should the coordination process be structured and managed?" Although it seems from these two quotes that the positive effects of using BIM in terms of Coordination were more important than the challenges created, the project was not counted as one where Coordination had positive effects.

4. Results

The 35 cases were reported in the literature over a 2 year period: 2008–2010, although as shown in Table 3, design and construction periods ranged more widely, with some design activities starting in the early-mid 1990's. However an analysis of the mean number of benefits based on reporting dates show no marked differences: i.e. mean = 2 for the 15 cases published

Table 3
Details of the selected cases.

Project name	City	Country	Design	Construction	Budget	Size	Type	Reference from literature
Shanghai Tower	Shanghai	China	2007–2008	2008–2014	1,716 M €	380,000 m²	Office Skyscraper	McGraw-Hill (2010b)
Aylesbury Crown Court	Aylesbury	UK	–2011	2011–	43 M €	5,200 m²	Government	McGraw-Hill (2010a)
ESEAN Children's Hospital	Nantes	France	2004–2007	2007–2009	13 M €	7,000 m²	Healthcare	McGraw-Hill (2010a)
CMG Medical Office Building	Mountain View, CA	USA	–2007	2005–2007	76 M €	23,000 m²	Healthcare	Khanzode et al. (2008)
La Bongarde	Paris	France	2003–2010	Not started	uk	86,000 m²	Retail	McGraw-Hill (2010a)
Palomar Medical Centre West	Escondido, CA	USA	2004–	–2012	377 M €	69,000 m²	Healthcare	McGraw-Hill (2010b)
Research 2	Aurora, CO	USA	2002–2006	2006–2007	157 M €	50,000 m²	Laboratories	McGraw-Hill (2009)
Springfield Literacy Centre	Springfield, PA	USA	2006–2007	2007–2008	12 M €	4,600 m²	Education	McGraw-Hill (2008)
St Helens and Knowsley PFI	Merseyside	UK	–2006	2006–2010	434 M €	120,000 m²	Healthcare	BSI (2010)
Endeavour House	Stansted	UK					Office	BSI (2010)
Palace Exchange	Enfield	UK			37 M €	18,000 m²	Retail	BSI (2010)
General Motors plant, Flint	Flint, MI	USA		2006		44,200 m²	Industrial	BSI (2010)
Eagle Ridge		Canada	2006	2006			Residential	Kaner et al. (2008)
Dickinson School of Law	Old Main	USA		2007–2009	47 M €	10,500 m²	Education	Leicht and Messner (2008)
Blackfoot Crossing	Calgary	Canada		before 2007			Museum	Kaner et al. (2008)
Modi'in		Israel		before 2007			Retail	Kaner et al. (2008)
Walt Disney Concert Hall	Los Angeles, CA	USA	1987–1991	1992–1996 200–2003	214 M €		Concert Hall	(Haymaker and Fischer, 2001)
Audubon Centre	Audubon, OH	USA	2004–2008	2008–2009		1,700 m²	Civic Centre	McGraw-Hill (2010b)
School of Cinematic Art	Los Angeles, CA	USA	2005–2006	2006–2009	129 M €	12,700 m²	Education	McGraw-Hill (2010b)
Expeditionary Hospital		Middle East	2006	2006–2007		8,920 m²	Healthcare	Manning & Messner (2008)
Maximilianeum Expansion	Munich	Germany	2009–2010	2010–2012	14 M €	4,500 m²	Residential	McGraw-Hill (2010a)
Precast Shelter		Israel		before 2007			Shelter	Kaner et al. (2008)
Heathrow Express recovery		UK	1995–				Railway	BSI (2010)
Terminal 5, Heathrow	London	UK	1992–1999	2002–2008	5,208 M €	371,000 m²	Airport Terminal	BSI (2010)
UCSF Cardiovascular	San Francisco, CA	USA	2005–2007	2008–2010	198 M €	22,000 m²	Laboratory	McGraw-Hill (2008)
Texas A&M Health Science Centre	Bryan, TX	USA	–2008	2008–2010	81 M €	24,000 m²	Education	McGraw-Hill (2009)
St Joseph Mission Hospital	Orange, CA	USA		2008–2009			Healthcare	McGraw-Hill (2009)
Department of Energy	Amarillo, TC	USA			78 M €	4,200 m²	Industrial	McGraw-Hill (2009)
SF Public Utilities Commission	San Francisco, CA	USA	2001–	–2012		2,600 m²	Government	McGraw-Hill (2010b)
ShoWare Centre	Kent, WA	USA		–2009	43 M €	14,000 m²	Sports Arena	McGraw-Hill (2010b)
US Food and Drug Admin HQ	Silver Spring, MD	USA	1996–	2010–2013		113,000 m²	Lab + Office	McGraw-Hill (2010b)
Festival Place	Basingstoke	UK		–2002	136 M €		Retail	BSI (2010)
Sutter Health Medical Centre	Castro Valley, CA	USA	2007–2009	2009–2013	250 M €		Healthcare	McGraw-Hill (2009)
University Campus Suffolk	Ipswich	UK	2006–2007	2007–2008	25 M €	10,500 m²	Education	McGraw-Hill (2010a)
Cascadia Centre	Bothell, WA	USA		2011–2012		5,000 m²	Education	McGraw-Hill (2010b)

Table 4
Positive and negative benefits of using BIM on selected cases.

Project name	Coor.		Scope		Time		Cost		Qual.		Org.		Com.		Risk		Soft.		Score
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	
Shanghai Tower	1		1		1		2		1										**6**
Aylesbury Crown Court	1				1		2		1				1						**6**
ESEAN Children's Hospital	1				1		2						1						**5**
CMG Medical Office Building	1	−1			2		2		1			−1	1						**5**
La Bongarde					1		1						2						**4**
Palomar Medical Centre West	1						1		1		1								**4**
Research 2	1				3		1									−1			**4**
Springfield Literacy Centre					1		1		1				1						**4**
St Helens and Knowsley PFI	1				1	−1	2	−1					1						**3**
Endeavour House							3												**3**
Palace Exchange	1					−1	2	−1					2						**3**
General Motors plant, Flint					2		1												**3**
Eagle Ridge	1						1		1				1					−1	**3**
Dickinson School of Law	1						1	−2	1						1				**2**
Blackfoot Crossing							1		1										**2**
Modi'in					1		1												**2**
Walt Disney Concert Hall		−2	1								1		1		2			−1	**2**
Audubon Centre									2										**2**
School of Cinematic Art					1		1												**2**
Expeditionary Hospital	2	−1	1										1		1			−3	**1**
Maximilianeum Expansion	1	−1											1						**1**
Precast Shelter									1				1					−1	**1**
Heathrow Express recovery															1				**1**
Terminal 5, Heathrow							1												**1**
UCSF Cardiovascular					1														**1**
Texas A&M Health Science Centre					1										1	−1			**1**
St Joseph Mission Hospital							1												**1**
Department of Energy						−1	1								1				**1**
SF Public Utilities Commission									1										**1**
ShoWare Centre							1												**1**
US Food and Drug Admin HQ		−1							1						1			−1	**0**
Festival Place						−1	1												**0**
Sutter Health Medical Centre																			**0**
University Campus Suffolk	1							−2					1					−1	**−1**
Cascadia Centre		−1										−1						−1	**−3**
	Coor.		**Scope**		**Time**		**Cost**		**Qual.**		**Org.**		**Com.**		**Risk**		**Soft.**		**Average**
	14	−7	3	0	17	−4	30	−6	13	0	2	−2	15	0	8	−2	0	−9	2.057

in 2008/9 and mean = 2.1 for the 20 cases published in 2010. The list of cases in Table 3 is ordered based on the score of net benefits for the project. Hence, as shown in Table 3, the first two on the list, Shanghai Tower and Aylesbury Crown Court, had the most net benefits, 6 each. Whilst the bottom two, University Campus Suffolk and Cascadia Centre, had the least, −1 and −3 respectively.

Table 3 shows that in terms of location, the 5 projects in which the most benefits were reported were spread across 4 countries: china, UK, France and the USA. At the other end of

Table 5
The success criteria ranking of BIM use.

Success criterion	Positive benefit			Negative benefit		
	Total instances	Total number of projects	% of total projects	Total instances	Total number of projects	% of total projects
Cost reduction or control	29	21	60.00%	3	2	5.71%
Time reduction or control	17	12	34.29%	4	3	8.57%
Communication improvement	15	13	37.14%	0	0	0.00%
Coordination improvement	14	12	34.29%	7	3	8.57%
Quality increase or control	13	12	34.29%	0	0	0.00%
Negative risk reduction	8	6	17.14%	2	1	2.86%
Scope clarification	3	3	8.57%	0	0	0.00%
Organization improvement	2	2	5.71%	2	2	5.71%
Software issues	0	0	0.00%	9	7	20.00%

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the spectrum 2 of the projects with the least number of reported benefits were in the UK and 2 in the USA. Given that BIM traction is greatest in the USA, there is no evidence from the cases that this traction is reflected by a greater instance of reported benefits for their projects. It is noteworthy that the bottom 2 projects, one in the UK and one in the USA, were both in education and of relatively small size (University Campus, UK [10,500 m^2] and Cascadia Centre, USA [5,000 m^2]), giving some indication that utilising BIM on such small scale projects could be less likely to yield the level of benefit compared to projects of a larger scale (compare these projects to the one top of the list – Shanghai Tower, China [380,000 m^2]). However further analysis reveals no strong pattern emerges in respect of the type or size of building which BIM is more or less beneficial. An education facility in the USA was in the top 10 of net number of benefits (Springfield Literacy Centre). Also 2 of the top 5 were healthcare projects (ESEAN Children's Hospital – France and CMG Medical Office Building – Mountain View, USA) yet another USA healthcare project (Sutter Health Medical Centre) was one of the bottom 3 for new benefits realised. Furthermore, 2 relatively small scale projects were in the top 3 for benefits (Aylesbury Crown Court, UK [5,200 m^2] and ESEAN Children's Hospital, France [7,000 m^2]). This lack of any strong pattern also holds true for budget.

As summarised in Table 5, with the specific details in Table 4, the Cost success criterion was most often seen as receiving a positive effect from the use of BIM. Cost reduction or control benefits were mentioned on 29 occasions, covering 21 (60%) of the case studies. Some instances articulated cost savings or increases in terms of the total construction costs, whilst some focused on one particular phase, such as the construction or design phase. The cost reduction or control benefits were of significant value, with some of the most striking statements being: "cost savings of 9.8% of project costs" (Endeavour House – BSI, 2010); "savings of around 9% (estimated) realized in the construction phase" (Festival Place – BSI, 2010); "no change orders originating from field conflicts" (Dickinson School of law – Leicht and Messner, 2008) and "minimize staffing of the project" (Esean Children's Hospital – McGraw-Hill, 2010a). On the other hand, the same success criterion was mentioned with negative connotations 6 times in the case studies. In 2 (5.71%) of the projects, negative effects on cost were mentioned more times than positive effects. The nature of these negative outcomes on costs was generally less significant than the positive ones. Some examples include "CAD rework cost £20–30k" (St Helens and Knowsley PFI – BSI, 2010) and "invest in computer upgrades, training of its staff and technical support" (University Campus Suffolk – McGraw-Hill, 2010a).

The success criterion with the 2nd highest positive benefits of using BIM was Time. The effect of using BIM showed a positive effect on 12 (34%) of the projects. This success criterion was mentioned with positive connotations 17 times, mainly in respect of the schedule for the design stage of the project. There were relatively fewer references to time savings that could arise through the construction period, such as a more efficient process resulting from a BIM-generated simulation of construction works. The following are some examples of the comments related to time savings: "[the] project was two months ahead of schedule," "significant time savings once the construction model took shape" (Research 2 – McGraw-Hill, 2009) and "without [BIM], it would have taken two months to design this scheme, and we were able to do it in a couple of weeks" (Aylesbury Crown Court – McGraw-Hill, 2010a). Negative effects were only mentioned 4 times and only 3 projects mentioned more negative effects on time than positive ones. These negative effects were generally related to extra time needed for "creating the initial model" (Festival Place - BSI, 2010) or "restructuring the drawings" (Palace Exchange – BSI, 2010). All 4 instances were related to extra time needed to model the project or rework that needed to be done due to converting the project from traditional CAD standards to a BIM platform.

The effects of BIM on the Communication success criterion were all positive. Communication improvements were mentioned 15 times in 13 (37.14%) of the 35 case studies. Some of benefits on communication were: "information exchange saving up to 50% of effort" (Palace Exchange – BSI, 2010); "information is a lot easier to find compared to traditional 2D drawings" (CMG Medical Office Building – Khanzode et al., 2008) ; and "better communicate changes with the owner" (Esean Children's Hospital – McGraw-Hill, 2010a).

Effects relating to the Coordination success criterion were mentioned 14 times. Twelve (34.29%) of the projects had more positive than negative instances related to the Success criteria. These positive instances were typically due to the use of clash detection only possible by using BIM or due to the elimination of coordination sessions due to the automatic coordination and improved workflow modelling that BIM allows. Overall BIM facilitated integrated design strategies and Integrated Project Delivery [IPD], with a typical comment being from Palomar Medical Center (McGraw-Hill, 2010b): "… BIM facilitated the integrated design approach." Negative effects were mentioned 7 times, although only on 3 (8.57%) of the projects were there more negative than positive benefits. Sometimes a "lack of understanding of interoperability [of BIM systems] limitations and abilities" (Expeditionary Hospital – Manning and Messner, 2008) posed problems. When the project was too big, software issues caused by the BIM program not being able to handle so much information could force the creation of multiple models "to be able to work on the project" (US Food and Drug Administration Headquarters – McGraw-Hill, 2010b). This last point is a software issue, but because of the problems of coordination that it causes it is also considered as a negative effect related to the Coordination success criterion.

In addition to the Communication success criterion Quality was another criterion in which only positive benefits were perceived. On 12 projects (34.29%) there were 13 instances of quality-related benefits from BIM. Benefits came from design and documentation quality aspects, such as "more accurate design" (Audubon Center – McGraw-Hill, 2010b) and "higher-quality […] deliverables" (Sutter Health Medical Center – McGraw-Hill, 2009). BIM implementation also facilitated sustainable design

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and construction i.e. "improved "Daylighting" analysis" of the SF Public Utilities Commission (McGraw-Hill, 2010b); the "greener building" and cost savings "in many of the green elements" of the Shanghai Tower (McGraw-Hill, 2010b) and the "more sustainable construction process" at the Palomar Medical Center (McGraw-Hill, 2010b). These comments show that savings against one criterion, such as Quality, which in the two examples above can be defined in terms of the sustainability of the construction and operation of a building, can have a knock on effect on another criterion. In the two examples there were identified cost savings in the construction phase but more significantly, from a whole life cycle perspective, the reduced operational and maintenance costs of a green building.

There were 8 instances of BIM having a positive impact on the Risk success criterion, with 6 (17.14%) of the projects having more positive instances than negative ones. Some cases saw "BIM as a way to drive the risk out of its bid" (Texas A&M Health Science Center – McGraw-Hill, 2009) and as a way of reduced risk by allowing "better informed decisions" (US Food and Drug Administration Headquarters – McGraw-Hill, 2010b). A negative impact relating to risk came from the need of "upfront investment for the modelling of the project to win the bid" (Texas A&M Health Science Center – McGraw-Hill, 2009) that could have not been recovered should the company have lost the bid, or the need to clarify certain "model ownership issues for liability reasons" (Research 2 – McGraw-Hill, 2009).

The use of BIM had a positive benefit to the Scope success criterion in 3 (8.57%) of the projects. The main benefit related to the 3D visualization capacity of implementing BIM. This is probably one of the reasons it is not mentioned more often in the cases, since traditional 3D modelling tools not using BIM processes already help scope clarification. It is relevant though to note that no negative effects in respect of scope management were mentioned in any of the projects.

The Organization criterion is the only one that showed an equal number of positive and negative instances across an equal number of projects. Positive benefits included "improved team building" at the Walt Disney Concert Hall project (Haymaker and Fischer, 2001) and "added capabilities that architects at the firm did not previously have" at the Maximilianeum Expansion (McGraw-Hill, 2010a). The negative effects were based on the project team not knowing how to better organize the team to take advantage of BIM (CMG Medical Office Building – Khanzode et al., 2008) or the frustrations from not all the stakeholders embracing fully the integrated BIM approach (Cascadia Center – McGraw-Hill, 2010b).

Seven (20%) of the projects reported negative instances in relation to the Software criterion. In particular interoperability issues between BIM packages were highlighted as a major negative effect which can work against the promise of enhanced collaboration between the different organisations involved in a project. Specific issues included: software unable to handle large amounts of data (US Food and Drug Admin HQ – McGraw-Hill, 2010b); inability of packages to exchange data (Cascadia Centre – McGraw-Hill, 2010b); and a lack of knowledge and experience of software programming (Expeditionary Hospital – Manning and Messner, 2008).

5. Discussion and areas for further research

The data obtained from the case studies suggest that BIM is an effective tool in improving certain key aspects of the delivery of construction projects. Of the success criteria created for the analysis of the case studies, Cost was the one most positively influenced by the implementation of BIM followed by Time, Communication, Coordination Improvement and Quality. The negative benefits or challenges of implementing BIM implementation are relatively fewer, and most of them are focused on software or hardware issues. These challenges seem to relate to the management of change associated with the adoption of BIM and could be addressed with such initiatives as better training for all employees involved and stakeholder engagement activities to allow key actors to get used to a new way of working. The data shows that most of the a priori benefits of using BIM for Project Managers (Allison, 2010) shown in Table 1 are actually being reported in real-life case studies. The exception to this general finding relates to benefits in project closeout, for which there were no reports of BIM being useful to this activity. Hence, the findings provide some evidence to support the prediction that BIM can lead to a virtual project design approach (Froese, 2010), certainly in respect of the early stages of the project life cycle.

The general finding indicates that BIM is an appropriate tool for project managers and should be considered by the PM profession as a way to help manage construction projects. Overall, data from case studies show that the negative effects from using BIM on managing costs are much less and generally less relevant than the positive effects of implementing BIM tools and processes. Some of this extra costs, such as CAD rework, training or computer upgrades, are costs that can be reduced or eliminated by implementing BIM from the beginning of projects or simply by the fact that once people are trained and computers upgraded those costs will not be so prominent. While the time savings influenced the overall project duration and had positive effects on the schedule's critical path, time increases were often related to extra modelling time or converting drawings into a model. This is a clear sign that the positive effects on time are much more important than the negative ones – in terms of criticality. It also provides evidence that adopting BIM tools from the beginning of projects and by all stakeholders has the potential to minimize the negative effects on time. Quality benefits relate to both the quality of conformance, i.e. a more accurate process and improved documentation and enhanced designs i.e. the incorporation of sustainability-related features. Clearly there are technical issues related to the capacity and capability of current software, though one would anticipate such issues being resolved as the IT industry matures in its response to the BIM-related needs of the market.

The Knowledge Areas of the PMI's PMBOK extend beyond the Iron Triangle of cost, time and quality, reflecting the importance of success criteria related to such factors as the organization, stakeholders and the management of information. The findings that BIM is a tool that contributes beyond the Iron Triangle, by allowing better integration, cooperation and

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coordination aligns with the PM literature, with some of the key aspects required for the correct delivery of complex construction projects being better integration, cooperation, and coordination of construction project teams (Cicmil and Marshall, 2005, cited in Maunula, 2008). Moreover, as Morris and Hough (1987, cited in Williams, 2002) state that the application of conventional systems developed for ordinary projects have been found to be inappropriate for complex projects, the evidence from the analysis of the documented cases is that the use of BIM, which can be classed as an "unconventional system," has potential benefits to the management of construction projects.

In terms of further research, this paper reports an analysis of documented cases in which BIM has been used on projects. In analysing the extent to which the use of BIM has resulted in benefits to construction projects the research has taken a cross-project perspective. The next logical step would be to undertake a more finely grained analysis of the use of BIM on the individual projects to discover the extent to which benefits are contingent upon specific project characteristics, such as project size, value and complexity. In addition such fine-grained analysis could focus on aspects of project management that are specific to construction projects. This could be done through extending the success criteria to include some of those specified by the PMI in their construction extension to the PMBOK, for example: safety management – the processes required to ensure accident prevention and personal injury/property damage avoidance; environmental management – the practices to ensure that the project follows laws/regulations relating to the environment; financial management – the steps to acquire/manage the financial resources for the project; and claim management – the processes to prevent/eliminate construction claims from arising (PMI, 2007). Also, the collection of primary data using questionnaires or interviews would provide the opportunity to validate the results obtained through another research method.

6. Conclusions

Given the benefits to projects documented in the case studies it is a moot point why there has not been a greater take up of BIM on construction projects. Clearly there are still some challenges ahead and practitioners need to be aware of these challenges in order to ensure the benefits of BIM are realised. There needs to be a marketing and selling of BIM, supported by a rigorous cost/benefit analysis, in order to convince practitioners as to the benefits of its use and to justify the upfront investment. Although the price of the most popular BIM software packages is similar to that of the common CAD software – and given that some vendors are selling packages that include both BIM and CAD platforms for the price of what used to be a CAD-only – package, the initial costs are still substantial, especially for smaller firms. Yet in the long run, the increased productivity potentially achieved with BIM – and in some cases the access to project work where BIM is mandated – should be enough for organisations to get a good Return on Investment (ROI) on adopting BIM. Perhaps more difficult to address are the challenges related to people. Whilst there are interoperability issues between different BIM software packages, such technical issues are likely to be resolved over time by the IT companies supplying the packages.

Less easy to resolve are related issues in terms of people agreeing common IT platforms, cooperating with each other to readily share their BIM data models and not restricting the flow of information to and from other parties by looking to protect ownership and intellectual property rights of BIM-generated output. Alongside cost/benefit analysis, there also needs to be more awareness raising and a general up-skilling within the sector. Hence senior managers in construction companies will need to invest in BIM education and training of staff. Practitioners also need to see the potential of BIM in the wider context. For example a likely driver for BIM is linked to the sustainability and green agenda, with BIM providing benefits as clients and other key stakeholders demand sustainable buildings constructed using sustainable methods. These demands require greater interdependency and earlier involvement and cooperation between the different project participants i.e. those involved in planning and design, construction and facilities management. Key to this is an integrated design approach and an effective stakeholder engagement process, which also considers the users' needs throughout the design phase – which BIM can facilitate. But as was stated earlier in this section, using BIM to its full potential to deliver on the sustainability agenda will only be achievable if the people using it adapt and adopt working practices to suit.

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