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OVERVIEW OF BUILDING INFORMATION MODELLING IN HEALTHCARE PROJECTS

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ABSTRACT

In this paper, we explore how BIM functionalities together with novel management concepts and methods have been utilized in thirteen hospital projects in the United States and the United Kingdom. Secondary data collection and analysis were used as the method. Initial findings indicate that the utilization of BIM enables a holistic view of project delivery and helps to integrate project parties into a collaborative process. The initiative to implement BIM must come from the top down to enable early involvement of all key stakeholders. It seems that it is rather resistance from people to adapt to the new way of working and thinking than immaturity of technology that hinders the utilization of BIM.

KEYWORDS

Building Information Modelling (BIM), Integrated Project Delivery (IPD), building model, information, design and construction

INTRODUCTION

Delivery of healthcare projects is complex and dynamic process, which requires balancing political, policy, design, and human choice and preferences (Passman, 2010). BIM as a collaboration platform has a profound impact on how healthcare projects are managed and delivered as shown by the findings of this paper. BIM enables early contribution of all the key stakeholders to support evidence-based decision making for planning, designing, constructing and managing facilities. In this paper it is explored how BIM functionalities together with novel management concepts and methods have been utilized in thirteen hospital projects in United States and United Kingdom. The structure of the paper, inspired by literature review and analyses of hospital projects, first defines the notion of BIM and addresses the major aspects that one has to be aware of when embarking to its journey. This is followed by introducing 12 case studies and their general characteristics to better understand when and where BIM can be used. The last part of this paper discusses the findings from the case study projects regarding the BIM enabled project delivery.

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BUILDING INFORMATION MODELLING (BIM): DEFINITION AND KEY CONSIDERATIONS

Implementation of BIM into practice can be challenging, especially when one lacks any previous experience and necessary knowledge. It is a strategic decision requiring many changes in all levels of project delivery (Kymmell, 2009). Against this backcloth, a definition of BIM is provided and key aspects to be considered are listed.

BIM - what does this three-letter acronym actually mean? The glossary of the BIM Handbook (Eastman et al. 2008), one of the best-known publications in this field, defines BIM as a verb or adjective phrase to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation. BIM is rather a process, which results in a building information model – (visual) information repository (Kymmell, 2009). A building information model or just a building model is a digital database of a particular building that contains information of its objects. BIM software tools are characterized by the ability to compile virtual models of buildings by using machine-readable parametric objects (Sacks et al. 2004).

Some of the major aspects that one must be aware of and consider when embarking on a BIM journey: choosing proper project delivery and contracting methods to enable holistic BIM approach (Eastman et al. 2008); developing a BIM execution plan to identify needed high value uses/functionalities, design workflow, intermediate deliverables, and develop infrastructure in forms of contracts, communication procedures, etc. (buildingSMART alliance™, 2009); understanding of interoperability to develop BIM program in a project or company; and understand the legal aspects of implementing BIM in project context in terms of model ownership and responsibility for model accuracy, as well as about concerns on the responsibility for the cost of producing and managing the model (Kymmell, 2009).

ANALYSIS OF BIM HOSPITAL PROJECTS

This analysis of thirteen different healthcare projects is based on the information obtained from case study reports, magazines and journal articles. This approach has its advantages and disadvantages, where one of the greatest disadvantages was regarding information availability in each of these sources that differed in matter of quality and quantity. Most of the case studies and articles covered design and construction stages of project delivery, but also included information about other project stages like facilities management.

Table 1: Overview of the hospital projects examined

No	Project	Location	Project time
1	*Camino Group Medical Building*	*Mountain View, California, US*	*2003 - 2007*
2	*Sutter Medical Castro Valley*	*Castro Valley, California, US*	*2007 - 2012*
3	*Phoenix Children's Hospital*	*Phoenix, Arizona, US*	*Construction 2008 - 2012*
4	*Maryland General Hospital*	*Baltimore, Maryland, US*	*2010*
5	*The Kaiser Permanente Oakland Medical Centre*	*Oakland, California, US*	*-*
6	*Saint Bartholomew's and Royal London Hospital*	*West Smithfield and Whitechapel, London, UK*	*Construction 2006 - 2016*
7	*Ann & Robert H. Lurie Children's Hospital*	*Chicago, Illinois, US*	*2004 - 2012*
8	*Good Samaritan Hospital*	*Puyallup, Washington, US*	*2007 - 2011*
9	*Sherman Replacement Hospital*	*Chicago, Illinois, US*	*Construction completed 2010*
10	*Middle Tennessee Medical Centre*	*Murfreesboro, Tennessee, US*	*Construction completed 2010*
11	*Las Vegas Hospital & Community Living Centre*	*North Las Vegas, Nevada, US*	*2006 - 2011*
12	*Maple Grove Hospital*	*Maple Grove, Minnesota, US*	*Construction completed 2009*

Eleven projects explored were from United States, with the exception of the *Saint Bartholomew* and *Royal London Hospital* projects from the United Kingdom. Table 1 presents general information about these projects. Table 2 includes information about strategic properties of projects: type, project delivery and contracting methods, sustainability and implementation of lean. BIM can be implemented in all kinds of projects as illustrated by the projects chosen for the purpose of this paper, not only in new build projects. It can also be used for refurbishment, expansion and replacement projects, and still, can be beneficial due to its nature. Clients have also understood the necessity of using project delivery and contracting methods that enable early collaboration and the emergence of problem solving teams (Thomson et al, 2009). In all of these hospital projects, the general contractors have been involved early to let them contribute their knowledge to design regarding construction 'means and methods'. Hospitals are energy intensive facilities and this is what has made owners to focus on sustainable goals to drive down the operating and maintenance costs (Autodesk, 2008 a, and Autodesk 2008 b). Frequently clients impose the requirement to deliver healthcare projects in accordance to the LEED (Leadership in Energy and Environmental Design) specifications, a certificate developed by U.S. Green Building Council.

Table 2: Strategic characteristics of hospital projects

No	Project type	Project delivery and contracting methods	Sustainability	Use of lean
1	*New Build*	*Started Design-Bid-Build; later evolved to IPD*	*N/A*	*Lean*
2	*New Build*	*Integrated Form of Agreements (IFOA)*	*LEED*	*Lean*
3	*Expansion*	*Construction Manager at Risk; construction portion Guaranteed Maximum Price*	*Yes*	*N/A*
4	*Expansion*	*Construction Manager at Risk with Guaranteed Maximum Price*	*N/A*	*N/A*
5	*Replacement*	*Integrated approach (not specified)*	*N/A*	*Lean*
6	*Refurbishment and new build*	*Private Finance Initiative (PFI)*	*Yes*	*N/A*
7	*New Build*	*Hybrid of Design-Build and Conventional Design-Bid-Build (client integrating processes and stakeholders)*	*N/A*	*Lean*
8	*Expansion*	*Joint-Venture (Guaranteed Maximum Price)*	*LEED*	*N/A*
9	*Replacement*	*Joint-Venture (Guaranteed Maximum Price)*	*Environmentally friendly hospital*	*N/A*
10	*Replacement*	*Early involvement of key contractors and trades*	*N/A*	*Lean*
11	*New Build*	*Joint-Venture (contract not specified)*	*Yes*	*N/A*
12	*New Build*	*N/A*	*Yes*	*N/A*

In five of the hospital projects lean principles and methods were applied. *Camino Group Medical Building* project team believed that the use of a shared 3D model linked to lean construction techniques led to reduced project cost, time, and helped to increase productivity on site (Eastman et al. 2008). Lean refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System (TPS) to construction. Like in the TPS, the focus in lean construction is on reduction of waste, increase of value to the customer, and continuous improvement (Sacks et al. 2009).

Table 3 lists BIM functionalities by project and its stage of use. This list is not exhaustive. Functionalities described are from Sacks' et al (2010) research, where due to the nature of their work they focused on exhibited functionality, rather than the core technology. It must be also noted that these functionalities are overlapping and are extending throughout the project delivery stages. For example, visualization can be used in all stages of facility lifecycle, even during exploitation of facility for facilities management. In the projects observed here, BIM has been mainly used for design, less for construction and other phases. Still, the *Saint Bartholomew*'s and *Royal London Hospital* project shows that general contractors are starting to pay attention on using BIM during execution.

Table 3: Use of BIM functionalities by project and its stage

	Project											
Stage/Functionality	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Design												
Visualization of form	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Model changes tracking		*x*										
Predictive analysis of performance		*x*	*x*					*x*		*x*		*x*
Automated generation of drawings and documents	*x*	*x*	*x*			*x*	*x*	*x*				*x*
Modelling temporary structures (scaffolding) and existing structures			*x*									
Automated clash checking	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*
Online communication of product and process information	*x*	*x*	*x*	*x*		*x*						
Online meeting sessions		*x*						*x*				
Reuse of model information		*x*			*x*	*x*	*x*	*x*				
Site planning			*x*					*x*				
4D and 5D scheduling			*x*		*x*			*x*				
Construction												
Information for survey and scanning systems			*x*				*x*				*x*	
Project statues tracking						*x*						
As-built model				*x*		*x*			*x*			

BIM ENABLED PROJECT DELIVERY

This section focuses on the main findings from the 13 case projects; these findings are also related to insights from literature review. More importantly, the link between BIM functionalities and novel management methods in different project stages is examined.

Feasibility study

The first step always is to identify, determine and understand the project scope. BIM enables rapid visual creation, consideration and assessment of project alternatives (Sacks et al 2010), as the outcome of modelling process is a virtual repository of building information with its object parameters and properties. From that database, it is possible to extract information for various purposes.

Links between building information to energy, structural, MEP (mechanical, electrical and plumbing) analyses in the matter of dimensioning, conformance to requirements and sustainability goals can be created. In *Maple Grove Hospital*, Dunham engineers extracted space and room information from the architect's model within the MEP specific software environment and then imported that information via green building extensible mark-up (gbXML) into third-party software for load calculations. Airflow and load calculations for each room were posted back to the MEP specific software model as room attributes to begin equipment and ductwork sizing. This streamlined the load analysis process, and helped Dunham optimize the building systems for maximum performance and efficiency (Autodesk, 2008 b). Another example is *Good Samaritan Hospital*, where the project team included light shelves into the BIM model, which made it very easy for the mechanical engineers to understand them and include the effects in the HVAC cooling load calculations (Bovey, 2008). In *Phoenix Children's Hospital*, structural analysis performed early in the design resulted in identification of unique, high-grade steel material and bracing requirements allowing to identify a unique steel supplier and pre-purchase (prior to a period of steel price escalation) steel resulting in a $2 million total savings (MacKenzie, 2009).

BIM models (visualization) can also help project team members develop shared understanding and provide a common language for design conversations. This complements the use of lean method called Set-Based Design (SBD), originating from Toyota Motor Company (Wong et al. 2009). SBD, also implemented in *Sutter Medical Castro Valley* project (Chambers, 2010), is a methodology whereby a designer (or team) considers a set of design alternatives (rather than a single 'point' design) and postpones commitment to a specific design to the last responsible minute (Parrish et al. 2007). Visualizing these differences offers project teams an opportunity to discuss value trade-offs between alternatives (Wong et al. 2009). This approach is beneficial in early project stages but can be used in following phases as well. Thus, implementing SBD together with BIM can provide assurance to find the sustainable design solution and add greater value for client (Wong et al. 2009).

Design

The core idea of IPD is to create a collaborative environment by aligning stakeholders' objectives with project objectives, thereby developing a culture for pain/gain share (Khemlani, 2009). IPD can be implemented separately from BIM but BIM is used as a collaboration platform. This has created opportunity for another management method called Target Value Design (TVD) to emerge. TVD – lean management practice that drives design to deliver customer values and develops design within project constraints (Ballard 2008). Traditionally, design solution is basis for cost estimation, and value engineering is used when necessary to cut project costs. Implementation of BIM facilitates the TVD process as quantities can be extracted automatically and directly from model and linked with estimating applications to get automated cost feedback. *Sutter Medical Castro Valley* project team gained a better understanding of how design decisions and changes influenced the cost of the project, thereby emphasizing learning by doing (Tiwari et al. 2009).

Contractors can contribute their knowledge, construction specific information (also including information about temporary structures and site conditions) to design processes, which results in a model they can use for their own purposes; e.g. estimating, detailing for fabrication, site planning, production planning (4D – 3D model linked with construction schedule) and resources planning (5D – linking 4D with budget) (Eastman et al. 2008). BIM process gives project teams opportunity to virtually plan and build construction projects before any bigger commitments to money and time are made; i.e. enhanced constructability analysis (Kala et al. 2010). In the *Kaiser Permanente Oakland Medical Centre* replacement project, the 3D modelling process was implemented in parallel with traditional project delivery method. Constructability reviews, through modelling the design documents, found more than 200 issues at each stage that were not found by the parallel traditional constructability process (Kala et al. 2010). This resulted in reduction of errors occurring in the execution stage.

In implementing new methods and achieving targeted outcomes, project teams are using iterative modelling coordination meetings to reduce clashes, errors and omissions in the design; e.g. clashes between MEP systems and other structures. *Maple Grove Hospital* project team said: "The software's 3D modelling environment helped our engineers visualize the design and fit all the piping, ductwork, and equipment into tight spaces" (Autodesk, 2008 b). It is not only important for gaining flawless building information model but also to enhance common understanding and knowledge through project team virtually building a project (Kymmell, 2009). These meetings can be tracked by using BIM-based applications that have capability to compare older and new versions of models by means of colour coding. In *Sutter Medical Castro Valley* project this helped to prevent a major issue emerging by comparing what had changed since the last model coordination meeting, and it turned out that in addition to the new beams that had been added, the depths of some of the existing beams had also been changed causing collisions (Tiwari et al. 2009 and Khemlani, 2009).

In the hospital projects studied here, the site planning capability was not extensively used. In *Phoenix Children's Hospital* project, some site planning was done in terms of a site logistics plan based on the building model (MacKenzie, 2009). This was about how to organize construction site in matter of laying materials, site offices, fences, existing utilities, etc. However, there are also other possibilities for using modelling for site planning.

BIM-based applications provide for the extraction of accurate and consistent drawings of any set of objects or specified view of the project (Eastman et al. 2008). This should significantly reduce the time needed and errors associated with generating construction drawings. In the *Sutter Medical Castro Valley* project, the approach was to produce a multi-disciplinary, fully coordinated 3D model first, delay the production of paper documents until the last responsible moment, and then produce them with as little rework as possible (Khemlani, 2009). The same occurred in *Phoenix Children's Hospital*: HKS's (architect) use of BIM enabled them to work in a truly integrated fashion with contractors and their clients; allowing more time for designing rather than construction document production (MacKenzie, 2009). Beyond the traditional drawings, Dunham (sub-contractor on *Maple Grove Hospital* project) used the software to automatically create 3D isometric drawings and shaded images of highly congested areas, which were incorporated into construction documents - to more clearly communicate the engineering design to the system installation contractors and the owner (Autodesk, 2008 b). Studies have shown that incomplete project documentation is the main reason for obstacles, problems and rework on site (Kala et al, 2010; Pikas, 2010). A solution is provided by BIM-based clash detection, providing many advantages over traditional 2D coordination methods (Eastman et al, 2008). It allows automatic geometry-based clash detection to be combined with semantic and rule-based clash analysis for identifying qualified and structured clashes. "BIM Handbook" distinguishes two different clashes: hard clash, objects occupying same space; and soft clash/clearance clash, objects are so close that there is insufficient space for access (Eastman et al. 2008).

Construction

A general contractor's main responsibility is to plan the realisation of the project, coordinate the execution and manage the conformance of outcomes. Harnessing BIM capabilities and using IPD have enabled contractors to do major part of planning prior to the construction phase. The company, Walsh Group from *Sherman Replacement Hospital* project, believes the success of the preconstruction phase will determine the project's overall success (Libby, 2009). However, this does not mean that they do not have to do planning during construction, often, they are required to do detailed planning; e.g. in *Phoenix Children's Hospital* project modelling, including temporary structures, and 4D sequencing allowed an expedited erection plan and lean process (as needed) delivery of steel which helped them to better comprehend the tight site conditions (MacKenzie, 2009). This planning and modelling information can be used also for coordinating execution and conformance control.

The objects in a building model have attributes, and one of the attributes is location. The location of each component is established according to the coordinates system. It is an important factor that model is placed into a coordinates system and it is usually done by architect, who has to consider all the aspects that the orientation of the building affects. A model in coordinates system offers another dimension to coordinate and control work. Information about coordinates (xyz) can be extracted from model and may be used for survey and scanning systems for various purposes (Eastman et al. 2008, Tudor, 2010 and MacKenzie, 2009). The projects examined here reveal that survey and scanning systems and methods can be used for three general purposes:

1. Surveying and scanning existing structures and systems; results can be used to do BIM modelling (Raphael, 2010).
2. Extracting information about coordinates form model enables using it in survey and scanning systems for layout and installation works (Tudor, 2010 and MacKenzie, 2009).
3. Quality control by surveying and scanning new structures and systems; results can be used to compare reality with planned BIM model (Tudor, 2010).

During construction, it is important to monitor the progress of construction works to compare planned activities with work completed for tracking the progress of the project and the performance of the stakeholders to focus on tasks that have fallen behind schedule (Harty et al. 2010). This is often complicated in traditional project delivery processes as communication is based on 2D drawings. In the *Saint Bartholomew's* and *Royal London Hospital* project, hand-held devices were used to record the information about the actual start and completion of work on site. This information was fed back to the BIM application, and was used to produce a comparative animated model (4D model) showing actual activity on the site over time (Harty et al. 2010). These two models were then run side-by-side to check actual against planned activity allowing better communication between project parties. Monitoring can also be used to track material delivery, handovers from design to construction and from construction to client, resources flow, etc as different kind of information can be attached to objects in the model (Eastman et al. 2008).

A new emerging trend is the use of Radio Frequency Identification (RFID) technology to link the physical building components with digital information (Eastman et al. 2008). It is useful for on-site inspection of work and documentation, real-time project progress management, and quality assurance which are important aspects of implementing lean in construction (Pedersen, 2010). There are case studies and experiments of using RFID but as this capability was not used in hospital projects studied here, then it is beyond this work to go into more detail. Conceptually similar approach is when using bar codes, can be less expensive, as was done in *Maryland General Hospital* project but for a different purpose. They used it for facilities management purpose, where each piece of equipment was tagged with a unique barcode in an accessible location that enabled seamless information exchange from field to database and from database directly to field into handheld devices (Dave, 2010).

Facilities management

The workflow of BIM process enables to record and deliver as-built information which can be linked with facilities management system and processes. Although, the nature of the model and information may need to be adjusted for this purposes (Kymmell, 2009). In the *Maryland General Hospital* project, the main objective in implementing BIM for closeout and facility maintenance was to create a central database containing closeout documentation and maintenance of information that can be easily accessed in the field, and easily maintained and linked to a 3D model for better visualization (Dave, 2010). This helped to better visualise the facilities management processes, and improve the response times in case of maintenance calls (Dave, 2010). This can make maintenance and management of facilities more efficient and provide improvements across the lifecycle of the building.

BIM in refurbishment and/or expansion projects

Many hospital projects are about expanding and/or refurbishing old facilities as it was in the case of *Phoenix Children's Hospital* (MacKenzie, 2009). During construction, hospital services were not allowed to be disrupted, which made sequencing and phasing of work a key issue. The 3D graphic nature of BIM allowed the project team for *Phoenix Children's Hospital* to comprehend the complexity of this project in much shorter period of time and to develop more creative options (MacKenzie, 2009). "Rather than out on the field, where a conflict can potentially stop construction and ultimately affect cost and schedule, we will do real-time problem solving in the 3D model prior to construction without affecting the project schedule," said a member of *Sherman Replacement Hospital* project team (Libby, 2009).

These projects can be even more complex than new build projects because of the task of fitting new structures and systems with already working and existing ones. Findings of this study show that BIM can be used in these types of projects and can benefit project team. In general, projects must pass the same stages of delivery as usual but a bit different approach is needed due to the nature of these projects. Existing structures must be mapped and transformed into 3D object-based model which is enabling to more accurately assess, communicate and fit new systems with existing ones to plan, execute and control construction works.

For mapping existing structures and systems, laser survey and scanning methods can be used. This was done in *Las Vegas Hospital & Community Living Center* project.

Discussion

Throughout this paper many benefits and challenges have been described based on the findings of analysing 13 hospital projects. The findings clearly show that BIM has a profound impact on how healthcare project can and are delivered. Using BIM together with complementing management practises and methods, like lean construction methods, can help project teams to tackle the complexity, dynamics and challenging target goals to deliver hospital projects. The BIM capability of enabling virtual construction and high level of project visualization helps to develop a common understanding among project partners and solve major problems earlier. Such problems, like errors and omissions in construction documentation, usually become visible during the construction phase, where making changes and stopping work is very costly. That said it is also important to emphasize that BIM enables holistic view of projects when used together project delivery and contracting methods that enable early participation of key stakeholders.

Findings of this paper show that the use of BIM has been limited mostly to design and to some extent to construction phase. This gives a reason to believe that all the benefits and achievements delivered by using BIM until now are only a scratch on the surface and major benefits are yet to come. For example, extended use of RFID technology will bridge the gap between physical world and digital environment. Furthermore, BIM has been beneficially implemented in various kinds of hospital projects, not only in new build projects. For example, in *Las Vegas Hospital & Community Living Center* laser scanning technology was used to map existing structures and systems for having a reference for BIM modelling, where new and old systems will be aligned.

Case projects also reflect that healthcare projects have complex building services systems that cause many obstacles for the projects teams to successfully deliver outcomes. These kinds of systems in hospital projects can account for 40-60% of the project value (Khanzode 2010). Not only that these systems are expensive, these often are colliding as a result of traditional design processes where communication is based on 2D paper based modes (Eastman et al. 2008). Use of 3D intelligent parametric objects for modelling results in virtual model (prototype) of facility. Visual and intelligent nature of model provides to automatically identify the hard clashes and the soft clashes by working together on model in weekly design coordination meetings (Tiwari et al. 2009). This helps to reduce uncertainty for contractor during construction stage.

Implementing BIM has also challenges that one has to be aware of. Some of the challenges have been discussed above, like project delivery and contracting methods, BIM execution planning, etc. There are also some challenges that have not been explicitly mentioned yet and which are probably most complicated to overcome. *Camino Group Medical Building* project team said (Eastman et al, 2008): "Not every participant has the skills, resources and experience to fully participate in the project goals. Also it is taking time of teams to learn how to collaborate effectively." There are more examples like that from other projects. This reflects that it is rather the hesitancy from people than immature technology that causes challenges as BIM is a new way of organizing and managing information that requires project teams to adapt the new way of thinking and working. Therefore, someone has to take leadership to guide a project team and motivate others to come along. In different hospital projects studied here, it has usually been architect, engineer, contractor or sub-contractor who has understood the benefits that BIM implementation gives them. In *Camino Group Medical Building* and *Sutter Medical Castro Valley* it has been a client who has taken an initiative to require BIM implementation. This has many benefits over one project party taking responsibility as it enables more holistic BIM approach.

CONCLUSIONS

Hospitals are capital intensive projects with their unique characteristics; e.g. building services systems in hospital projects are commonly highly complex and cut a large piece from budget. Implementation of BIM together with complementing management practices and methods have been shown to have profound impact on how healthcare projects are and can be developed and delivered. It is highly recommended to use collaborative project delivery and contracting methods to maximize the benefits provided by BIM. Strong leadership is required to lead the project, and the people involved. BIM can be utilised in all kinds of projects and it is only hesitancy from people that hinders BIM gaining its full potential. It is not anymore a new trend and there are stakeholders who have understood the benefits that BIM implementation promises, value maximization and waste reduction. Findings of this study reflect that it is only the scratch of the surface that has been achieved up to now, there is a prospect of increasing gains as the situation is dynamic, new software and new features in existing software emerge and people learn to better utilize BIM opportunities by aligning with existing and new processes. Those already on the learning curve will be among the first ones materializing the benefits from BIM implementation. Thus, it is important to start now in any hospital project.

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