The Use of Cloud Enabled Building Information Models – An Expert Analysis

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Abstract

The dependency of today's construction professionals to use singular commercial applications for design possibilities creates the risk of being dictated by the language-tools they use. This unknowingly approach to converting to the constraints of a particular computer application's style, reduces one's association with cutting-edge design as no single computer application can support all of the tasks associated with building-design and production. Interoperability depicts the need to pass data between applications, allowing multiple types of experts and applications to contribute to the work at hand. Cloud computing is a centralized heterogeneous platform that enables different applications to be connected to each other through using remote data servers. However, the possibility of providing an interoperable process based on binding several construction applications through a single repository platform 'cloud computing' required further analysis. The following Delphi questionnaires analysed the exchanging information opportunities of Building Information Modelling (BIM) as the possible solution for the integration of applications on a cloud platform. The survey structure is modelled to; (i) identify the most appropriate applications for advancing interoperability at the early design stage, (ii) detect the most severe barriers of BIM implementation from a business and legal viewpoint, (iii) examine the need for standards to address information exchange between design team, and (iv) explore the use of the most common interfaces for exchanging information. The anticipated findings will assist in identifying a model that will enhance the standardized passing of information between systems at the feasibility design stage of a construction project.

Keywords: Cloud Computing, BIM, Interoperability, Information Communication Technology, Information exchange

Introduction
Research Background

Advancing interoperability between design team applications has been a major challenge for advocates of open standards. Information Communication Technology (ICT) has the capability of streamlining communications between parties at the conceptual design phase to establish an early understanding of the tradeoffs between construction cost and energy efficiency. To a fragmented industry such as construction, the benefits of this service have still to be fully recognized. To the e-Business environment 'cloud computing' is known as the generic term for ICT. It serves as an umbrella term for the provision of services, such as storage, computing power, software development environments and applications, combined with service delivery through the internet to consumers and business.

The building Smart alliance and Open Geospatial Consortium Inc in the U.S. had developed and implemented an Architecture, Engineering, Construction, Owner Operator, Phase 1 Testbed that streamlines communications between parties at the conceptual design phase to establish an early understanding of the tradeoffs between construction cost and energy efficiency (Hecht and Singh 2010). The findings of this Testbed combined with a collaborative Research and Development (R&D) project 'Inpro' Sebastian (2010) co-funded by the European Commission to identify business and legal issues of BIM in construction were used as theoretical propositions underlying this survey.

Research Aims and Objectives

The overall aim of this paper was to establish a model for developing a cloud-based construction service through identifying standardized deliverables, obstacles and opportunities for growth. In order to achieve this aim the following objectives were investigated;

- Identifying the most appropriate applications for advancing interoperability at the early design stage,
- Detecting the most severe barriers of BIM implementation from a business and legal viewpoint,
- Examining the need for standards to address information exchange between design team, and
- Exploring the use of the most common interfaces for exchanging information.

Research Design

This paper presents the results of two Delphi questionnaires. The initial questionnaire undertaken by 16 international experts on construction ICT analyses the expert groups' opinion on the future of ICT in construction based on a cloud service which hosts construction-related applications. The methodology used for the questionnaires included both quantitative and qualitative open and closed-end questions. The attitudinal research focused on subjectively evaluating the opinion or view of the respondent towards a particular topic. The exploratory research was used to diagnose the situation, screen alternatives and discover new ideas. There are two types of experts; those whose expertise is a function of what they know (epistemic expertise), or what they do (performative expertise). An epistemic expertise has the capacity to provide justifications for a range of propositions in a domain while performative expertise is the capacity to perform a skill in accordance to the rules and virtues of a practice (Weinsten 1993).

The following questionnaire compiled the findings of the initial questionnaire and categorised the topics such as, interoperability for BIM software, contractual issues, and information exchange. The original panel of 16 had now reduced to 14. The methodology used for this questionnaire was designed as an extension to the initial questionnaire; for example the initial results for interoperability between three potential BIM applications required further investigation and rethinking. The respondents concern towards vendor reliability and recovering data in the previous questionnaire highlighted the barriers towards a cloud platform but also prompted measures to be investigated for BIM applications relating to contractual issues. Integration of BIM applications on a common database had been signalled out as a major benefit but the issues of successfully exchanging data required at a particular stage needed further research.

Methodology

The Structure of the Initial Survey comprised of the Following Sections:

Business process: The benefits of re-engineering a previous innovative solution with the concept of construction as a manufacturing process were investigated and compared to Kagioglou *et al.* (1999). Kagioglou *et al.* had identified that traditionally ICT had been seen as a driver behind changes in the design and construction process and indeed in many Business Process Re-engineering initiatives.

Cloud computing capabilities: This section Armbrust *et al.* (2009), obstacles to adopting and opportunities for growth of cloud computing, and also investigates Lowe's (2010) review of the five challenges associated with moving backup to the cloud. The final question in this section investigates if cloud computing has advanced from the many mistakes made by the Dot.com bubble (Wohl 2008).

Cloud based business opportunities: This section requests the respondents to refer to their own company when giving an opinion, such as, would cloud be a cost benefit to their firm? The respondent's knowledge is also called into question asking for evidence of expertise on whether cloud benefits are essential for business growth and do Small Medium Size Enterprises (SMEs) have the capability of using such a service.

In relation to the Previous Findings the Structure of the Second Survey comprised of the Following Sections:

Interoperability for BIM software: This section of the questionnaire comprised of questions based on Testbed AECOO-1 and the Inpro projects. The starting question requested the experts' opinion on whether the outlined process for advancing interoperability for BIM software should be focusing on Building Performance Energy Analysis (BPEA), 5D BIM cost estimating software, and information exchange. The second question queried the need for increasing interoperability standards in the BIM marketplace. The 'Inpro project' and Smith (2007) emphasized that by using open standard BIM there was no need to start from scratch as a large amount of systems was already available.

Contractual issues: As this section related to the legal entities associated with BIM, the Inpro project was used. A rating scale of 1 to 5; with 1 being the highest; was used for both questions. The first question listed statements based on the most severe barriers of BIM implementation from the business and legal viewpoints and the second question followed with statements based on the type of contractual terms that should be included in a BIM based project to facilitate open and neutral collaboration processes.

Information Exchange: The information exchange section comprised of two questions formatted to; (i) likert scale, and (ii) rating scale. The first question requested the opinion of the expert by ranking the statements relating to using the industry's most common exchange file mechanism IFC-STEP (Industry foundation Classes – Standard Transfer eXchange for Product Model data) and IFC-XML (eXtensible Markup Language). The second question was structured with two statements taken from Testbed AECOO-1 examining the need for having an open exchange data model. The remaining questions were taken from literature such as Hecht (2008), questioning the use of Sensor Web Enablement (SWE) in relation to BIM, and CISCO and Johnson Controls (2008), analyzing whether BIM Facilities Management would be greatly enhanced by Building Automated Systems (BAS).

Findings and Discussions 'The Future of ICT Through The Use of Cloud Computing'

Business Process

Question 1: The experts were asked if they would agree that developing a cloud collaboration tool based on combining the open Application Performance Interface (API) of accountancy, project management, and BIM applications, would benefit the industry in having a standard supply chain service.

The overwhelming positive response to the question illustrated in Figure 1 showed 50% of the experts agreeing and 29% strongly agreeing. However, after further analysis of this open-ended question, the experts identified areas for concern such as security and the difficulty involved with combining open API's with different applications. The majority of the experts acknowledged that the key to integrated BIM is a common database preferably in the cloud containing information about component parts of building modelled in disparate software programs.
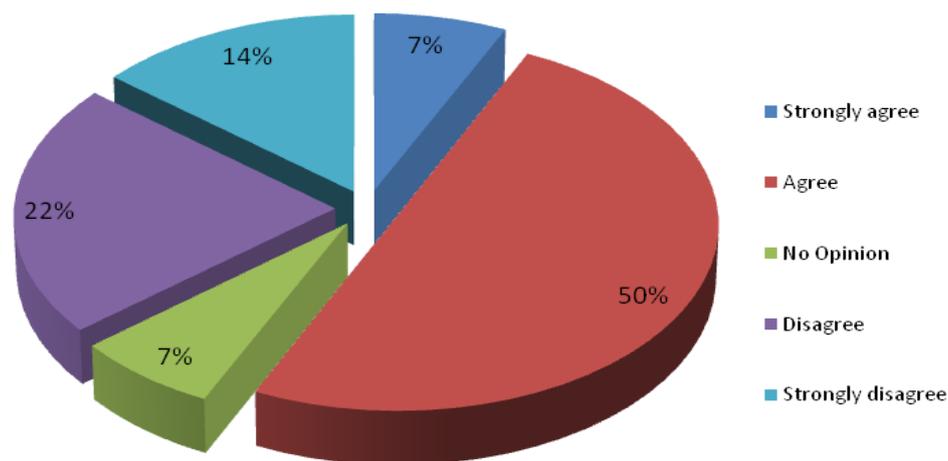
Figure 1 Developing a cloud collaboration tool based on combining open API's of accountancy, project management, and BIM applications

Question 2: A second question asked for the strength of their organisations disagreements with statements made by Kagioglou et al. (1999) regarding the identification of ICT requirements needed to support a process protocol.

The experts had mixed concerns about two statements, namely, (i) the need for a coherent and explicit set of process-related principles to be managed by the whole industry with the intention of changing the strategic management of the common process and (ii) the need for construction operations that form part of a common process controlled by a single integrated team. The problem relating to the first issue can be traced to the fact that companies prefer to manage their own standard procedures until they have to collaborate with the rest of the design team. The second problem refers to the notion of integrated systems being less competitive in comparison to an open standard system. In contrast; the expert panel strongly agreed that the required model should be capable of representing the driver's interest of all stakeholders and be interchangeable allowing interfaces between existing practices.

Other strong indicators identified were the need for a generic and adaptable set of principles, standardised deliverables and a key emphasis on designing and planning to minimise errors during construction. To the question of the construction industry involvement being extended beyond completion a high level of agreement (70%) was evident. The majority of the experts agreed with the process protocols, however, the notion of having the whole industry reviewing the process and controlling the integrated system did receive negative responses.

Cloud Computing Capabilities
Question 3: The third question featured statements relating to the obstacles to and opportunities for growth of cloud computing.

The option of using FedExing Disks (international mail service) to solve the issue of data transfer bottlenecks for large data transfers received an insufficient agreeing response of 43% and a disagreement response of 28%. The no opinion mark of 29% indicated that this should not be the main deterrent and alternative options should be identified. The highest agreement responses by the expert group were allocated to standardizing API's meaning Software as a Service (SaaS) developer could deploy services and data across multiple cloud computing providers. It is important that failure of a single company would not take all copies of customer data with it. The option of scaling storage presented an environmental solution by carefully utilizing resources which could reduce the impact of the data centre on

the environment through short-term usage. Scalable storage and data lock-in received a total agreement result of 86% and 85% respectively with no disagreeing responses. Another high level of agreement response was the data confidentially and auditability with its suggested solution of deploying encryption, virtual Local Area Networks (LANs) and networks middle boxes; for example firewalls and packet fillers.

The solution for data confidentially also suggested having geographical storage such as, services located in both the U.S. and Europe to deal with concerns about international law enforcements having the power to search email communications and various records, which received no negative responses. Inventing a debugger that relies on distributed Virtual Machines (VM) also resulted in a high undecided response. Other ideas, such as improving VM support to combat performance and unpredictability, and using multiple cloud providers to prevent Distributed Denial of Service, resulted in an above average agreement response of 57%. The expert group also concluded that the option of pay-for-use licenses did seem attractive. In summary, the solutions to the obstacles were broadly favourable to the group; however the solution for bottlenecks (FedExing) needs more consideration.

Question 4: The experts were asked to rank their opinion on attitudinal statements relating to the major challenges for moving backup to the cloud.

The issue of additional costs increasing because of the lack of knowledge on how backup is perceived and needs meet one's requirements in comparison with one's selected vendor's pricing produced a disagree response of 36% and an undecided response of 14%. This response was the highest disagreement result indicating that it is not a major challenge. In a similar reaction the challenge of backup services outsourced to the cloud with the upstream speeds often capped at very low rates, meaning a cloud-based backup would saturate an upstream connection; received a 57% agreeing mark and disagreeing mark of 29%. A considerable challenge noted by the expert group was security; which is a repeat of the answer for the previous question 3; where deployment of encryption was one preferred solution. However, this statement relates to compliance issues, such as special attention on contractual language, geographical diversity (if your provider offers geographical redundancy in their service) and termination agreements.

In reviewing of challenge of security; the expert group identified a high level agreeing rank of 79%, but this rank was eclipsed by the main concern (that of vendor reliability) which received 100% agreement. This statement presented the issue of negotiating up front about what happens to one's data if a company goes out of business or is acquired. In continuation to the previous challenge; the statement citing the possible solution of working with one's provider to assess their ability and willingness to help one quickly recover from disaster scored an agreement of 86% and an agreement rank of 14%. All of the noted challenges are recognized as a potentially serious issues for customers moving backup to the cloud; however, none more so than vendor reliability and recovery.

Question 5: This question asked the experts for their opinion on the advancements made by cloud computing in contrast to the mistakes made by the Dot.com bubble.

In this question the expert group were requested to rank their opinions on statements relating to the problems of the Dot.com market crash and why cloud computing will not suffer a similar fate. The two most significant corrections were market requirements and a better educated market; both receiving just over 90% agreement mark. The market requirements referred to new cloud applications that attempt to match what the best application in their category offers and then proceed to provide a better interface, better integration with other applications and more web features. A better educated market meant cloud computing would offer access to applications more quickly than traditional decision and implementation processes. This statement also referred to the fact that cloud computing customers do not

own the physical infrastructure, instead avoiding capital expenditure by renting usage from a third-party provider.

The market strategy of vendors focusing only on a particular part of a marketplace meant that vendors are not actively focusing on multiple demographics unless they have multiple product and market strategies; this resulted in an agree response of 84%. The issue surrounding stronger business models identifying that cloud vendors plan to monetise their software by either making a charge for each user or each transaction received a modest agreeing response of 67%. This was probably in recognition of the fact that different size enterprises will require different models. The most undecided response of 46% was in relation to better financing; taking into context that venture capitalists have entered in numbers into the market and provided additional development and more sustainable marketing investments. The reason for the expert group's lack of enthusiasm associated with this correction is possibly related to the fact that the western world has not yet recovered from the global recession.
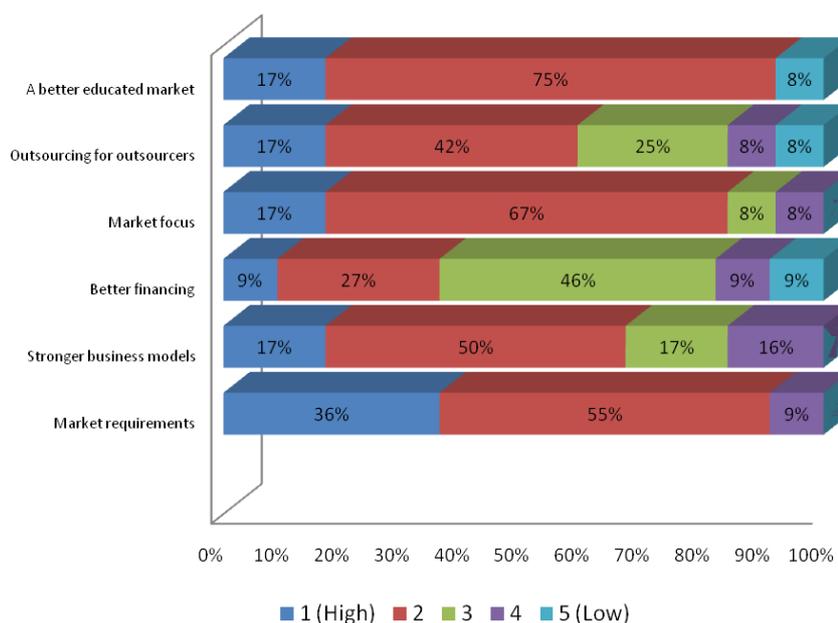
Figure 2 The cloud advancements on the mistakes made by the Dot.com bubble (Sourced from, Wohl 2008)

The least positive response was outsourcers referring to the idea that vendors now believe it is better to partner for infrastructure than to invest in and run it oneself. The caution shown here was a repeat of the bandwidth issue (if backup services are to be outsourced to the cloud) in the previous question; it was identified as a challenge.

Cloud Based Business Opportunities
Question 6: The experts were asked for their opinion on cloud computing relating to the statements highlighted in Table 1.

In the expert group's opinion there is a lack of knowledge in the construction industry on the various types of construction cloud applications and due to the fragmented nature of the industry; a collaboration tool that provides interoperable software is a necessity. This claim was further enhanced by the group's strong agreement 85% indicating that the future of ICT is a service deployed from a centralized data centre across a network providing access to applications from a central provider. The highest disagreement rating of 38% was related to the notion that the traditional packaged desktop and enterprise applications will soon be made obsolete by web-based, outsourced products and services which is somewhat in

contrast to the agreement (77%) response that suggests that cloud computing is an efficient and cost effective outsourcing process that gives company management more time to focus on their business.

Summary of statements supporting cloud computing	Strongly agree	Agree	No Opinion	Disagree	Strongly disagree
The future of ICT is a service deployed from a centralised data centre across a network providing access to the applications from a central provider (cloud computing).	39%	46%	0%	8%	7%
The traditional packaged desktop and enterprise applications will soon be made obsolete by Web-based, outsourced products and services that remove the responsibility for installation, maintenance and upgrades.	23%	31%	0%	38%	8%
The cloud solution generates better opportunities for companies by enabling them to select more ICT priorities from an ever growing menu of applications.	31%	46%	15%	8%	0%
Cloud is an efficient and cost effective outsourcing process that gives a company management the time and opportunity to focus on the core competencies of their business.	23%	54%	15%	8%	0%
Cloud: Pas As You Go (pay for usage rather than for software licenses & hardware infrastructure) is a process that would be of cost benefit to my firm.	23%	46%	23%	8%	0%
Cloud computing present's information risk – but probably not significantly more than in a traditional outsourced environment.	0%	69%	16%	15%	0%
Vendors do not believe that construction SMEs have the capability of using cloud computing.	8%	38%	23%	31%	0%
There is a lack of knowledge in the construction industry on the various types of construction cloud apps.	46%	46%	8%	0%	0%
The downturn in the industry will result in less investment in ICT. This crisis should be used as an opportunity to focus on how to improve things in the long run, cloud computing can act as a major agitator to this concept.	39%	46%	8%	7%	0%
The fragmented nature of the construction industry needs collaboration tools and interoperable software such as, cloud collaborator tool.	61%	31%	0%	0%	8%

Table 1 Summary of statements supporting cloud computing

A similar result was also recorded for the statement that cloud solutions generate better opportunities by enabling enterprises to select more ICT features from an ever-growing menu of applications. The expert group has overwhelmingly stated that cloud is the future of ICT but they are still reluctant to predict that this is the end for traditional packaged desktop and enterprise applications. The pay-as-you-go payment option only received a modest 69% approval; however the response to this question may have also been affected by also asking the respondent would they themselves implement it. In contrast to questions relating to the

risk of security, the view that cloud computing presents information risk, but probably not significantly more than in a traditional outsourced environment, indicates that the group does acknowledge cloud's credibility. Redmond *et al.* (2010) identified through a study of the barriers for adoption of cloud computing that vendors do not necessarily believe that construction SMEs have the capability of using cloud computing. The expert group's opinion on this matter resulted in a mixed outcome of 46% in favour, 23% undecided, and 31% disagreeing.

Question 7: The experts were asked to rank perceived benefits of cloud computing for the construction industry.

The eight proposed perceived benefits of cloud computing from Ramanujam's (2007) key points as to why Cloud/On-Demand would be a smart choice for companies. In analysing the expert group's responses again disaster recovery was evidently a concern, with the experts indicating a disagreement response of 23%. The highest disagreement response of 25% was directed towards having the ability to manage a premise-based facility so attention can be redirected towards the customer. The highest agreeing response of 92% highlighted the benefit of allowing one to pay-as-you-go, pay for usage rather than for software licenses and hardware infrastructure. This was in contrast to the previous question (summary of cloud computing) where the respondents only delivered a 69% confidence mark. Both managing a premise facility and frequent updates had the highest undecided percentage rank of 25%. The notion of having access to the best of breed technology did; however; result in a positive 75% whereas managing a premise facility represented the most negative responses of all the benefits.

Findings and Discussions 'Evaluating a Cloud Integrated Model through BIM'

Advancing interoperability for BIM software

Question 8: This question asked the experts to identify whether the following three processes were the most favourable option for advancing interoperability for BIM software (i) BPEA, (ii) Quantity Takeoffs for Cost Estimation, and (iii) Request for information.
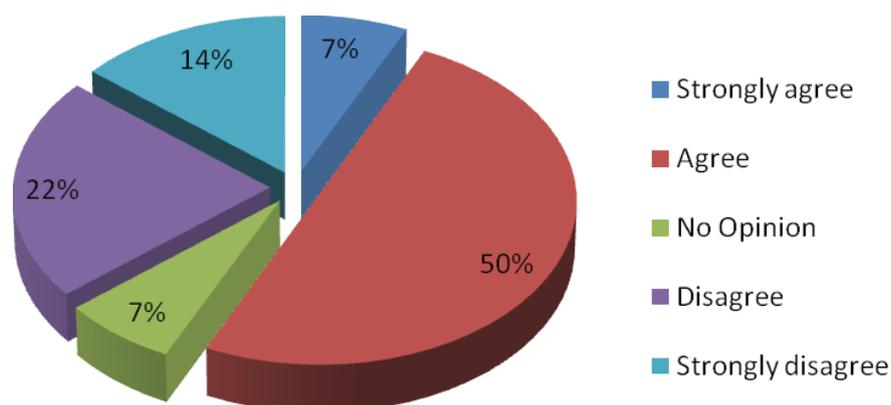

Figure 3 Advancing interoperability for BIM software

The results indicated that 57%, representing 8 respondents, felt that the three most favorable services for advancing interoperability for BIM software are (i) BPEA, (ii) Quantity Takeoffs for Cost Estimation, and (iii) Request for information (RFI). However, 36% disagreed and one individual had no opinion. The question itself tested the idea that the most beneficial stage to advance interoperability is at the conceptual stage and that the three main business areas that are most likely to require interoperability are as previously stated. The open-end answers recognized several different approaches to advancing

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60

interoperability such as one respondent's view that data transparency and quality, spatial co-ordination, understanding of data in a spatial context, and management of the supply chain data are the main business processes. Another respondent identified RFI workflows, quantities and estimating, and quantities by location for scheduling. There was also a respondent who correctly pointed out that building performance is not only about energy, but it is also about comfort and future services provided by buildings. In summarizing the result of this question over half of the respondents agreed that the most favourable process for advancing interoperability for BIM software is (i) BPEA, (ii) Quantity Takeoffs for Cost Estimation, and (iii) Request for information.

Question 9: The experts were questioned on their opinion of increasing interoperability standards in the BIM marketplace as highlighted in Table 2.

Increasing interoperability standards	Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree
The market is increasingly demanding that open standards be more broadly applied to BIM.	14%	79%	0%	7%	0%
Viable software interoperability requires the acceptance of an open data model.	22%	50%	14%	14%	0%
Within a design project, there is little need to share all aspects of the design between project participants.	21%	36%	0%	43%	0%
Multidisciplinary project teams that share tools and information achieve better results than using traditional applications.	36%	57%	7%	0%	0%
With open-sourced BIM designers can plug into an existing variety of typologies, systems and subsystems.	7%	36%	36%	21%	0%

Table 2 Increasing interoperability standards in the BIM marketplace

The notion that the market is increasingly demanding that open standards are more broadly applied to BIM technologies; so that each partner in a project can comfortably adapt their internal processes; received a majority positive indication of 93%. Only one respondent disagreed which clearly identifies that the way forward for interoperability for BIM is to engage in open standards. The second statement; relating to viable software interoperability in the capital facilities industry requiring the acceptance of an open data model and the use of service interfaces contained within provider's software; obtained a positive 72% and negative 14% with another two respondents indicating no opinion. This 72% can be seen to support the National Building Information Modeling standards view that an open data model would provide an industry-wide means of communication enabling every software application used across the lifecycle to become interoperable. The Testbed AECOO-1 maintained that within a design project, there is little need to share all aspects of the design between project participants, and what is relevant is to exchange elements of design between the lead architecture firms or lead general contractor and subcontractor with specific areas such as lighting, energy usage, building cost and Heating Ventilation and Air Conditioning (HVAC). The expert panel projected a mixed response to this statement with only 57% agreeing. The 43% of the expert panel that did not entirely agree with the Testbed AECOO-1 model was because some of the experts are inclined to believe that all information should be shared no

matter what process stage the project is reviewing. The next statement was designed to clarify the need to have interoperable applications shifting away from legacy systems. The response from the expert panel clearly agreed with this concept delivering a positive response of 93% and only 7% having no opinion. The final statement referred to the idea that by using open-standard BIM, designers do not need to start from scratch as a large variety of building typologies systems and subsystems are available as the basis of their design.

This enables buildings with high architectural quality to be designed, produced and delivered according to systematic procedures which allow effective control and value optimization for the clients and end users. Only 43% of the expert panel agreed with this concept, 36% had no opinion and 21% disagreed. The open standard content was meant to represent a model server and open communication platform for information sharing. It is possible that the expert group confused this with Open Source Software (OSS) where co-operation is promoted between the user and owner of a software product by removing obstacles imposed by the owner, such as copyright law. The overall conclusion of this section depicts that there is a need to share information through open standards with an industry demand for applications to become more interoperable.

Contractual Issues

Question 10: The experts were asked to rank in order the most severe barriers to BIM implementation from the business and legal viewpoints as indicated in Table 3.

The barriers were categorized into five main issues and structured in a rating scale format. The first barrier signified that there is a lack of immediate benefits of BIM for the stakeholders. This produced a response of 50% disagreeing and 36% agreeing indicating that the expert panel partially sympathizes with the stakeholders need for Immediate ROI. However, the 50% level of disagreement demonstrates that there are immediate benefits to BIM possibly referring to its ability to identify early cost savings. The next barrier highlighted the issue of changing roles, responsibilities and payment arrangements resulting in 50% agreeing, 21% disagreeing, with no opinion at 29%. The Inpro project claims that there is a lack of clarity over the changing roles and responsibilities; for example is the architect still the lead designer in the integrated design and engineering? Who is in charge of the total quality of the design? Who assures that all interface problems (clashes) are solved and that the model is fully secured? These are just some of the issues and the results of the expert panel showed a 50% acknowledgement of this barrier and 29% unsure which demonstrates that this is an issue that needs to be resolved. The barrier associated with the uncertainty of the legal status and intellectual property rights of the model generated a high (79%) agreement with this statement of which 22% of the panel ranked it as a number 1 (the highest barrier) and only 14% disagreed. The major issue relating to this barrier is to what extent anyone can claim ownership of the intellectual property; if the model is deemed to be collaborative work, then ownership may not be vested in a single party.

Barriers of BIM Implementation	1 (High)	2	3	4	5 (Low)
Lack of immediate benefits	7%	29%	14%	36%	14%
The changing roles	14%	36%	29%	14%	7%
Uncertainty of the legal status	22%	57%	7%	7%	7%
Inadequacy of existing frameworks	23%	39%	23%	15%	0%
Lack of consent on protection of information	7%	14%	43%	22%	14%

Table 3 Barriers of BIM implementation

The following barrier; concerning the inadequacy of the existing contractual frameworks, including the agreements on liability and risk locations; presented a response of 62% agreeing and a no opinion of 23%. There are major concerns with who is liable for information in the digital model and how the users are protected and this may be the reason for the 62% of the expert panel agreeing with this barrier. The final barrier referred to the lack of consensus on the protection of information in conversion and interoperability and against loss and misuse of data.

The response received a mixed reaction from the panel with 43% identifying no opinion, 36% disagreeing, and 21% agreeing. The barrier itself is related to the notion that there is a requirement within the industry for an agreement on the standard of care and possible conflict resolution on data management as an integral part of the contract. The results of the survey are inconclusive possibly because there are already standards and agreements available for use of data management; however they are country-specific. The results of the 5 statements emphasized the major barriers to implementing BIM with the structure of a single model created by many disciplines as the main problem due to claim of ownership, who is liable, who is in charge of the total design, whether it should be an integral part of a contract, and can the stakeholders benefit of such a model.

In response to the open-ended question requesting further barriers to be identified; the expert panel views varied. One expert claimed that there is a lack of understanding of how to use BIM and lean business methods particularly in a collaborative business arrangement; this view was supported by another expert who also considered the lack of understanding of how to effectively use BIM in a team environment as a major barrier.

Question 11: This question asked the experts to rank contractual terms that should be included in a BIM based project to facilitate an open and neutral collaboration process, as illustrated in Figure 4.

The previous question list of barriers analyzed the problems associated with implementing BIM. This question focuses on rectifying that situation and identifying the contract clauses needed. The question was formatted to rating scales 1 – 5 (1 being the highest). The first statement highlighted the contractual issue of agreeing on modeling protocols, sharing and integration of open technology and then proposing a solution: endorsing internationally accepted open standards. The expert panel rated this option 58% in favour and 24% against.

The ability to have clauses relating to the workflows, level of authorization, and access rights in a BIM based decision-making virtual project received a response of only 50% in favor and a low 14% against. The highest no opinion of all the statements (36%) was in reference to this statement. This response was very much in line with question 3 relating to the level of clarity over the changing roles and responsibilities, where the results of both statements indicate a high no opinion and an average of 50% in favour. The concept of including a clause for the intellectual property of the foreground and background information and knowledge provided an average 62% in favour.

The Inpro project had perceived a possible solution for the legal status of such a model by enabling the model to serve as a contract document that is used between contractual parties, but is not to be submitted to permit-issuing agencies. This received a favorable response of 61%, 23% no opinion and 16% not in favour. The Inpro project identified that if this is not the case the model may become a document which provides the visualization of the design intent from contract documents. This may also be the reason why the results reflecting the previous solutions have such a mixed response. The final statement emphasizes that depending on the selected contract form and procurement method, particular contract terms should be considered as additional clauses to the contract. The

clauses identified were establishment of partnering and the legal entity of the enterprise, format roles and responsibilities, agreement on payment features, and dispute resolution using BIM. The survey supported these clauses with 79% of the expert panel agreeing and only 14% not. In summarizing the key issues identified, one expert stated 'integrated agreements only work if the team members trust each other, trusted business relationships emerge over time, it is naive to think we can "catch the magic in a bottle" via a contract'.
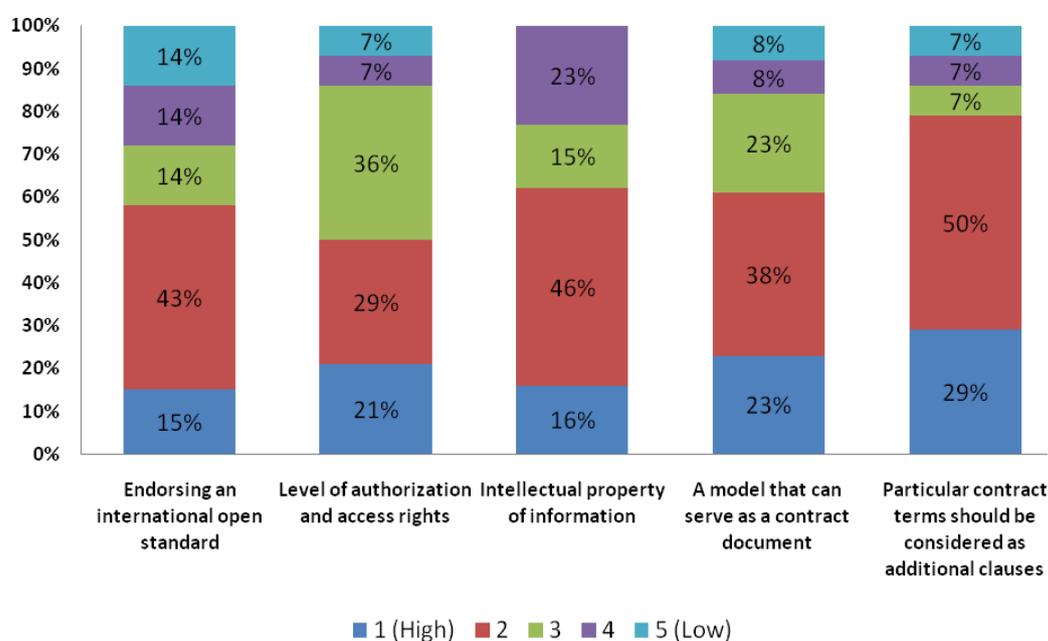

Figure 4 Contractual terms to facilitate open and neutral collaboration

Information Exchange

Question 12: The experts were asked to indicate their opinion on the statements relating to IFC and XML, as highlighted in Figure 5.

This question allows analysis of statements based on whether the construction industry will pass files via STEP or XML. The first statement perceives the computer language EXPRESS; which is one of the main products of ISO-STEP and used to represent conceptual or abstracted objects, materials, geometry, assemblies, process and relations as an foreign format for providers to maintain and stresses that it is not presently in their code product offerings and that IFCs will continue to be marginalized. The results showed that there were an equal number of experts who agreed to those who probably did not understand the statement with comments such as, 'I'm not sure what EXPRESS is but it sounds bad' (36%), while 28% disagreed. The following statement investigated the issue of using an EXPRESS language to pass information in a web service, and referencing it as a poor fit with insufficient mainstream market adoption. This statement received a high no opinion of 57%, 28% disagreeing and only 15% agreeing. The notion that the industry has already moved towards the exclusive use of XML standards with encodings such as Open Building Information eXchange made for web services integration to BIM software resulted in a no opinion and disagreement of 36% with only 29% agreeing.

In review of the previous statements; the final statement summarized that XML is designed to work with web services and there is already available software standards to facilitate the adoption of existing AEC-based XML encoding and schema. The issue as to whether EXPRESS creates an extra cost barrier received a high no opinion from the expert panel (43%). However, 33% of the expert panel did agree in comparison to 14% disagreeing.
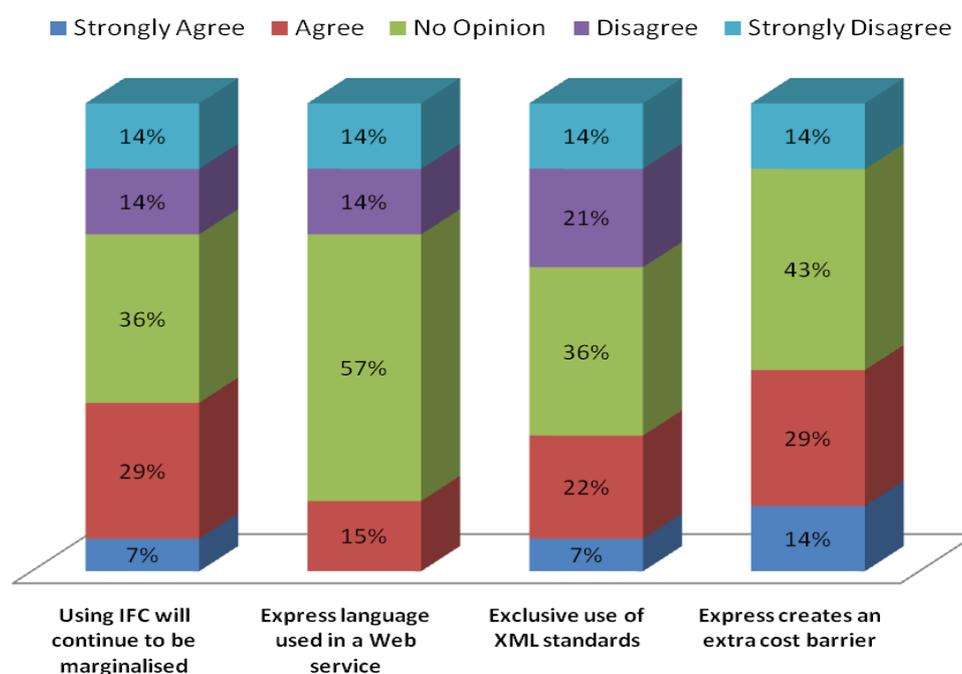
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64

Figure 5 shows the respondents preference between IFC – XML

The open-end question provided mixed comments from the experts, with one expert openly stating that they were unsure of what EXPRESS means. For those who did, the response varied from stating that XML is fine for a quick fix but is problematic for the long haul, to the identification from another expert that they are trying to incorporate Associated General Contracting (agc) XML (a set of XML schemas designed to automate and streamline the exchange of information) and IFC-compatibility. In summarizing the comments of one expert was 'a robust model such as EXPRESS needs to underpin a complex environment such as this, and there needs to be debates as to how data and process tools are implemented as web services, but you cannot escape the need to finish the modeling and design'.

Question 13: This question asked the experts in their opinion to rank statements based on information exchange requirements, as shown in Table 4.

This question posed a series of statements relating to information exchange and the concept of using semantic tagging, sensor web enablement and Building Automated Systems. The initial statement targeted the industry's requirements for software interoperability through exchange definitions, adoption of an open exchange data model and a common interface to the exchange data model for use by any participating application. The results were overwhelming in favor of this concept with only 7% both disagreeing and no opinion. The following statement reviewed the concept of using MVDs and IDMs for incorporation in specifications to be implemented in software. The majority of the experts agreed with this concept (76%). The notion of using semantic tagging in assisting the overall schema for building information in identifying (i) energy efficiency, (ii) manufacturer name, (iii) serial number, and (iv) warranty received 50% in favour but a split between no opinion (29%) and disagreeing (21%) equaled the positive response. In identifying if sensor web enablement (a type of sensor network on geographic information system that is especially suited for environmental monitoring) should be incorporated into a BIM model to optimize energy usage, the expert panel gave a negative indication with 36% of the panel having no opinion and 43% disagreeing, while only 21% were in favour. The final statement is similar in context to the previous statement (analyzing a system for facilities management) in reviewing

whether a BAS for importing HVAC after hours and utility meter readings into accounting systems and automatically generating tenant bills that would greatly enhance a BIM Facilities Management system. The expert panel was more in favor of this concept with 46% agreeing, however 23% had no opinion and 31% disagreed, illustrating that neither of these FM systems indicated potential successful adoption.

Information Exchange	1 (High)	2	3	4	5 (Low)
Adoption of an open exchange data model	36%	50%	7%	0%	7%
Incorporating IDM and MVD into specifications	29%	43%	14%	0%	14%
Semantic tagging assist overall schema for building information	0%	50%	29%	14%	7%
Sensor Web Enablement incorporated into a BIM	14%	7%	36%	36%	7%
BAS would greatly enhance a BIM FM	15%	31%	23%	8%	23%

Table 4 Information exchange requirements

Conclusions

The majority of respondents viewed cloud computing as a positive form of physical infrastructure that would increase efficiency and productivity. The notion of using an integrated BIM process through a cloud service was registered as a key benefit to component parts of the building modeled in disparate software programs. The 3 main core sections of the initial questionnaire, business process, cloud computing capabilities, and cloud-based business opportunities all provided evidence that a service based on cloud computing and standardized deliverables would enhance greater market opportunities for the construction industry. Cloud-based as-built-BIM was acknowledged as a service that would increase business decisions. However, whether applications such as, accountancy and project management should also feature as the main drivers failed to encourage a confident conclusion.

In further analyzing the main 3 BIM applications to be tested for advancing interoperability at the early design stage, BPEA, 5D, and request for information were deemed the most favorable. The issue of using propriety file based exchange mechanisms between BIM applications was viewed as a negative approach in comparison to the market demands for open standards between multidisciplinary project teams. A centralized web hosted database was recognized as the main platform for enhancing standardized passing of information between systems. However, ownership and who is in charge of the model are significant barriers against implementations.

The process of using IFC-STEP in comparison to IFC-XML favored XML because of its web services integration ability with BIM. However, on further investigating EXPRESS language the majority of the respondents were unsure of its meaning. In respect to semantic tagging, SWE and BAS for incorporation into BIM the majority of responses relating to a high no opinion reflected a lack of knowledge on the topic. Overall, the respondents did acknowledge the potential benefits of a service model based on 'Cloud BIM' for analyzing energy performance of buildings through the use of 5D estimating. The results of this research has determined that the market is increasingly demanding that open standards are to be applied to BIM and that be having multidisciplinary project teams that work together with data sharing tools and common information models can exchange information faster than standard legacy systems possibly through the use of web services.

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67