Enhancing Control of Built Assets through Computer Aided Design - Past, Present and Emerging Trends

Christy Oommen
Masters Research Student (IDBE),
Dept of Engineering & Architecture, University of Cambridge
&
Engineering & Construction Management Consultant
London, United Kingdom

Abstract

This paper presents the trends in Computer aided drafting and design within the Architecture, Engineering, Construction and Operations (AECO) industry by examining past, present and emerging technologies, standards, deliverables and stakeholders involved. The use of Computer Aided Design (CAD) has evolved from the drawing board in the pre 1970s, through two dimensional CAD in the 1980s to three dimensional CAD in the 1990s. In the year 2000 Building Information Modelling (BIM) became increasingly popular but there have been significant barriers to its adoption, few of them being interoperability and the lack of involvement of key stakeholders. To overcome these and progress to an Integrated Project Delivery (IPD) ecosystem, it is recommended that the industry should engage property owners and policy makers who can influence the sustained use of interoperable products and processes in the built environment. The acronym CAD has been widely used in the industry as Computer-aided-design but in this essay, CAD has been used to reflect the use of computers for drafting, design, analysis, simulation and collaboration.

1. Early beginnings

The construction industry adopted CAD as a direct replacement to the drawing board in the 1970s. CAD offered several benefits over the drawing board as drawings could be passed on between users, increasing drafting and design speed and reducing rework. Lines, arcs and circles which constituted the physical borders of columns, ceilings, doors, walls and windows, provided the means of communicating between the various disciplines. The productivity benefit of not having to redraw through each amendment and the ability to insert 'ready drawn' industry symbols provided a compelling business advantage.

2. Transformation from single entities to intelligent objects

Early CAD software between 1970 and 1980, provided users with a list of vectors (lines, circles and arcs), which were stored in a file. As time and technology progressed, these lines, arcs and circles were able to be segregated in many different ways - e.g. Blocks for quick insertion of repetitive groups of lines. CAD developers then added the ability to extend the data related to these entities and provided a chance to store more pertinent information in the database.

To interact in a meaningful way, CAD vendors began developing "Objects". These objects are programs broken into objects and are collections of data and processes that interact with other objects. These objects contained the behaviour and identity of the class they represent.
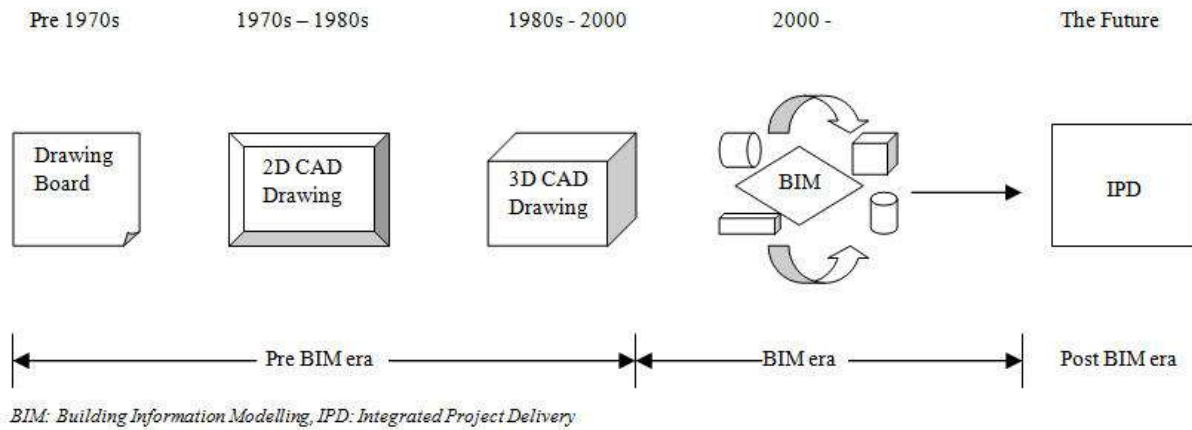
Fig 1.0: The Evolution of CAD

Now applying this to CAD, the idea was to move away from using the CAD software as an electronic drafting board and instead create intelligent real-world objects. Each real-world object (or class) is controlled by a small sub-program, which holds this behavioural intelligence to each instance (occurrence) of that object (door, wall, window etc.) in the drawing. This was a major advance from the use of a drawing to merely represent, to the ability to model and analyse with intelligent feedback.

Two-dimensional drafting is being replaced with 3D modelling systems that represent the objects making up a building. Parametric 3D modelling applications are available that incorporate the objects and relations in different disciplines within the construction industry.

The Finnish Funding Agency for Technology and Innovation commissioned in 2007 a survey for the construction industry[a], the results of which show that the use of manual drafting by designers is falling by 55% while that of 2D computer drafting is falling by 32%. The survey also showed that

Building Information Modelling (BIM) planned to grow by 85%.

3. Building Information Modelling

BIM is a paradigm shift from traditional drafting and design and is sometimes wrongly referred to as a product. BIM is an ecosystem of technology, processes and policies and is presented by B. Succar[1] in Fig 2 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". Table 1 sets out several of the widely used terms relating to BIM, by both research and industry literature.
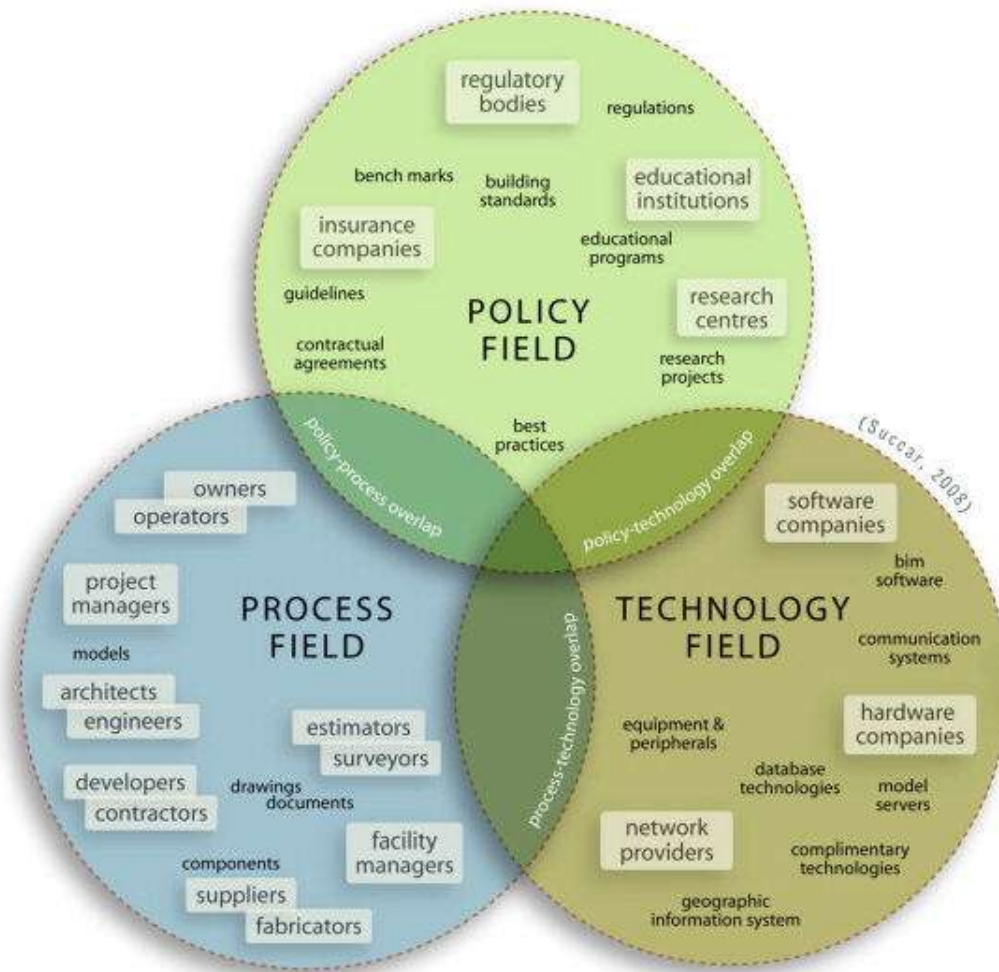
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[a] VTT Finnish ICT Barometer 2007 – A web survey by the Technical Research Centre of Finland for Tekes (The Finnish Funding Agency for Technology and Innovation)

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Fig 2: Three Interlocking Fields of BIM activity – venn diagram (adapted from B. Succar[1])

Widely used terms relating to Building Information Modelling

Sample terms	Organisation or Researcher
Asset Lifecycle Information System	Fully Integrated & Automated Technology
Building Information Modelling	Autodesk, Bentley Systems and others
Building Product Models	Charles Eastman
BuildingSMART™	International Alliance for Interoperability
Integrated Design Systems	International Council for Research and Innovation in Building and Construction (CIB)
Integrated Project Delivery	American Institute of Architects
nD Modelling	University of Salford — School of the Built Environment
Virtual Building™	Graphisoft
Virtual Design and Construction & 4D Product Models	Stanford University— Centre for Integrated Facility Engineering

Other terms: Integrated Model, Object Oriented Building Model, Single Building Model etc.

Table 1 (adapted from B. Succar[1])

4.0 Obstacles to the widespread deployment and use of Information Technology

4.1 Data integrity, flexibility and a seamless flow of design information

Prior to the advent of CAD, communicating design intent was best made possible through a schematic sketch and/or a hand drawing. With the evolution of time and technology, users expected a high level of data integrity and flexibility when communicating designs and drawings. Ensuring a seamless flow of data through these drawing exchanges is vital to meeting project time and cost schedules. However, all CAD vendors have their own file formats. These file formats are not 'open', in that they do not enable other vendors access. The other problem facing drawing translation is that CAD engines are all built differently. While some only supports 64 layers, others support unlimited layers. So what happens to all the layers past 64 when a drawing file from one CAD vendor is passed on to a user with another vendor's CAD software?

There are many thousands of standard 'classes' in the AECO industry that need to be defined. Each vendor will implement their own object definitions – that is to say one vendor's wall will be different to another's interpretation of a wall and so on. BIM data flows are varied and include the transfer of structured/computable (ex: databases), semi-structured (ex: spreadsheets) or non-structured/non-computable data (ex: images) between computer systems[2, 3].

4.2 Interoperability

Interoperability can be defined as the ability of two or more applications to exchange and utilize the information that has been exchanged. This exchange of information can be between proprietary (ex: RVT and DGN), open-proprietary (like DWF and many eXtensible Markup Languages) or non-proprietary file formats (ex: IFC and CIS/2). An exchange without major loss of object data richness can be deemed to be called as interoperable. So how will different CAD software, exchange this more complex data? Now not only do we have a problem of file formats and disparate CAD engines but we now also have to somehow transfer the object intelligence.

A 2004 report[4] prepared for the National Institute for Standards and Technology (NIST) estimates the cost of inadequate interoperability in the U.S. capital facilities industry to be \$15.8 billion per year. Under pre-BIM conditions (Fig 1.0), the industry suffers from low investment in technology and lack of interoperability[b] [c]. Widespread deployment and use of BIM is one of five "breakthrough" opportunities outlined in the McGraw Hill Smart Market Report 2009[5] that could improve efficiency and productivity in two to 10 years. The results of a study conducted by surveying thousands of AEC participants (Fig 3.0) identify several key areas to improve the value of BIM.

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[b] CWIC - The building technology and construction industry technology roadmap. In: A. Dawson, Editor, Collaborative Working In Consortium, Melbourne (2004).

[c] NIST, Cost analysis of inadequate interoperability in the U.S capital facilities industry In: A.C. Gallaher, J.L. Dettbarn Jr. and L.T. Gilday, Editors, M.P.O.C, National Institute of Standards and Technology (2004).
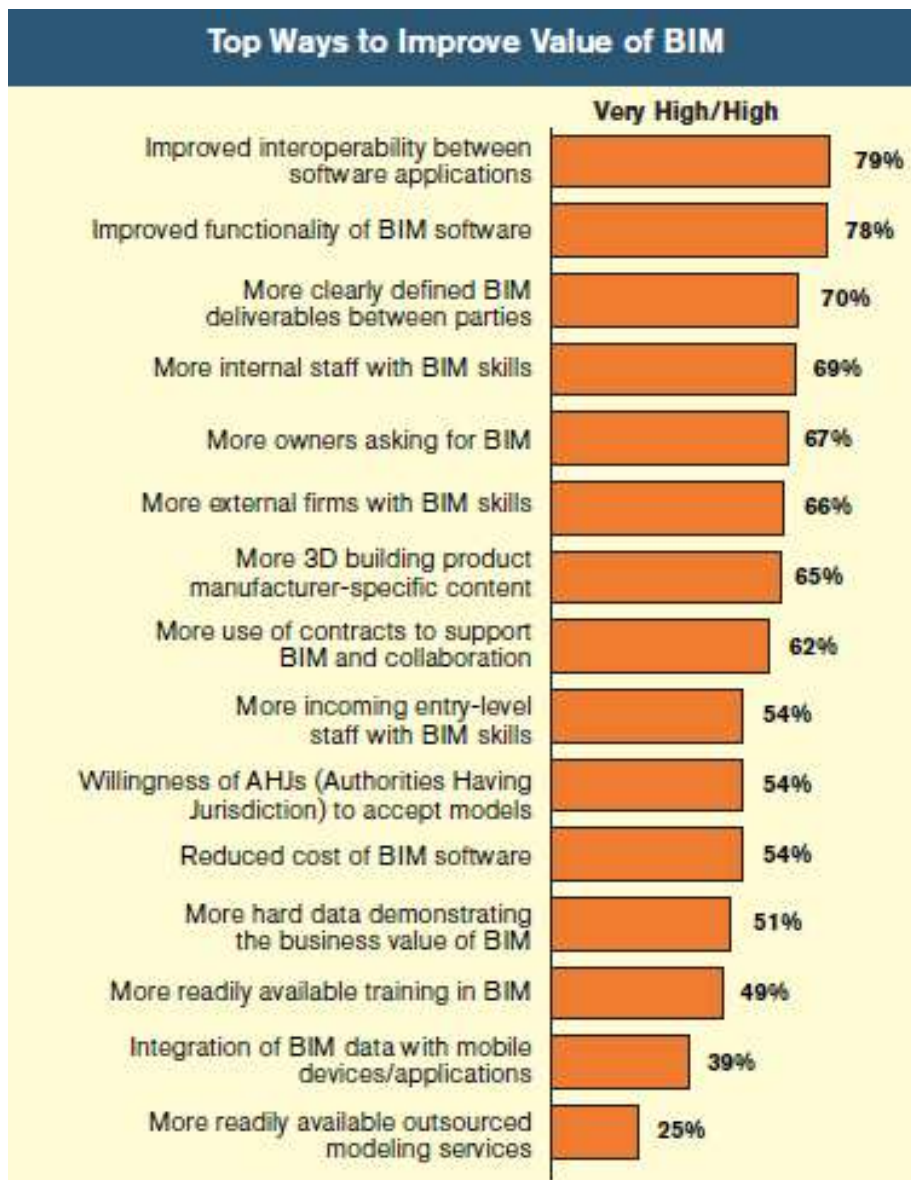
Top Ways to Improve Value of BIM

	Very High/High
Improved interoperability between software applications	79%
Improved functionality of BIM software	78%
More clearly defined BIM deliverables between parties	70%
More internal staff with BIM skills	69%
More owners asking for BIM	67%
More external firms with BIM skills	66%
More 3D building product manufacturer-specific content	65%
More use of contracts to support BIM and collaboration	62%
More incoming entry-level staff with BIM skills	54%
Willingness of AHJs (Authorities Having Jurisdiction) to accept models	54%
Reduced cost of BIM software	54%
More hard data demonstrating the business value of BIM	51%
More readily available training in BIM	49%
Integration of BIM data with mobile devices/applications	39%
More readily available outsourced modeling services	25%

Fig: 3.0   Top ways to Improve BIM

(Source: McGraw Hill Construction, Smart Market Report, Design and Construction Intelligence, 2009)

4.3.2   ISO

Several related industries, such as automotive and shipbuilding manufacturing have been relatively successful in integrating electronic product models into their operations but the building and construction industry, continues to lag behind in this development[d]. ISO STEP standardisation project which started in 1985, tried to solve the data exchange needs of a large number of manufacturing industries. Researchers, in their survey of domain experts and literature review[e] found that CAD layer standards based on ISO 13567 have been implemented, particularly   in

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[d] Frits P. Tolman, Product modelling standards for the building and construction industry: past, present and future TU-Delft Faculty of Civil

Engineering, and TNO Building and Construction Research, Delft, Netherlands

[e] R.Howard, B.C.Bjork, Use of Standards for CAD layers in building, Automation in Construction 16 (3) (2007) 290 – 297

European countries, but are not widely used due to lack of resources for marketing and implementing the standard as national variations, once it had been formally accepted.

4.3.3 IFC

Leading software developers initiated the creation of an industry consortium called the International Alliance for Interoperability (IAI). The IAI is responsible for setting out a file format called IFC, which stands for Industry Foundation Classes and is based on an old interchange format called Standard for Exchange for Product Model Data (more commonly called STEP). Kam et al[6] report from their IFC implementation experiences that most of the shortcomings were caused by software and middleware that supported IFC 1.5.1.

The IFC has evolved a way around by removing the need to transfer geometry, and instead initiating the creation of the object within the receiving software product along with a list of industry agreed dimensions. This is a big advance over proprietary file formats and geometry dumps. Some progress has been made to create object definition standards for the transfer of these AEC object models but there is an enormous task in hand if all the current volume of AEC objects are to be translated through IFC. The first version of the IFC data model was released in 1997, and currently the latest release is IFC2x3. The IFC file format for transfer of complete building information models has endured one of the most lengthy standardisation processes within construction IT. However, it has still not managed to establish its place in industry practice outside small pilot projects[f]. Howard and Bjork in

their analysis of responses to their survey[7] question the real commitment of software vendors to implementing IFCs and other standards.

4.3.4 CIS/2

While project teams can look for best practices of collaboration outside the AECO industry, teams can shorten their learning times by understanding the adoption of IT within the structural steel industry. The CIM steel Integration Standard, Version 2 (CIS/2) is an industry-developed product model based on ISO-STEP technology that has been widely adopted within the steel construction industry. The broad use of this industry standard for both data exchange and improving productivity is an example of an early success story which Eastman et al[8] suggest, can provide as a valuable case study of successful deployment of advance IT applications within the AEC industry. Eastman et al[8] attribute some of the key factors behind this success to the strong inputs from the steel design, engineering and fabricating communities during the definition phase of the CIS/2 standard.

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[f] A.Kiviniemi, Ten years of IFC development, Why Are We Not There Yet? Keynote Presentation, Joint International Conference on Computing and Decision-Making in Civil and

Building Engineering, 14-16.6.2006, Montreal, Canada, 2006.

Standard	Developed	Status	Domain
IGES	1978–1980	Official, ANSI	CAD graphics
DWG	1982–1990	De facto	CAD graphics
ISO 13567	1993–1997	Official, ISO	CAD layering
IFCs	1994–	Industry consortium	Building information model

Fig 4.0: Various CAD standards[9]

4.4 Contractual Relationships

The construction industry is characterised by adversarial relationships where contractual arrangements encourage risk avoidance and risk shedding. Ande and Takayuki[g] report that the Japanese accounting law requires savings from projects through cost reduction / value engineering efforts to be returned to the Ministry of Treasury. This indirectly prevents contractors and designers from engaging in any efforts to minimize the life cycle cost. Sharing the savings from an investment in an integrated building information model among all stakeholders (including the contractor) will monetise the efforts and encourage the use of this approach. In the qualitative survey conducted in 2006[7] of engineers, architects, contractors and IT specialists from northern Europe, Hong Kong and the USA, analysis of responses reported that the distribution of any benefits from BIM will depend upon type of procurement and responsibility for operation of facilities

4.5 Functionality of Software

Howard and Bjork in the analysis of responses to their survey[7] explain that IFCs are rather oversold and their complexities should be hidden within simple-to-use

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[g] Andi and Takayuki Minato: Design documents quality in the Japanese construction industry: factors influencing and impacts on construction process, International Journal of Project Management Volume 21, Issue 7, October 2003, Pages 537-546

software. The McGraw Hill Smart Market Report 2009[5] also identifies improved functionality of BIM software among the top factors to improve the value of BIM. Architectural and structural software have been developed in advance of Mechanical, Electrical and Plumbing (MEP) software which proves to be a major shortcoming of the approach[10].

4.6 Multi disciplinary working Vs Inter disciplinary working

Analysis from responses to a web based survey[11] of various professionals in 2003 revealed that the working of various team members from diverse disciplines did not display a sophisticated level of integration. "It seemed to be more of multidisciplinary working and less interdisciplinary working". The findings of this survey[11] suggest that while computer supported collaborative working (CSCW) systems may improve project management and the exchange of information between team members, it has yet to significantly support activities that characterize integrated collaborative working between disparate specialists.

4.7 Owner/Investor Interest

In a research conducted by surveying thousands of AEC participants, the McGraw Hill Smart Market Report 2009 "The Business Value of BIM"[5] reports "not enough demand from owners and clients" as the top reason for non adoption of BIM. In the study of BIM standardisation and industry

deployment[7], researchers conclude that while they have collected the experience of several well informed people in their attempts to try

It is evident that there are immense opportunities to involve property owners, developers and their advisors early in the planning and design process.

5.0   Successful Pilot Projects

The HUT-600 project in Finland[6], Heathrow T5 in the UK[7], Digital Construction Project in Denmark[h] and HITOS in Norway [i] are examples of successful pilot projects that have received the active support of owners/investors and/or governments from the very early stages of the project. It is imperative that initiatives by early adopters of technology have the support from the highest level of the organisation to keep the momentum of ongoing initiatives in CAD/BIM. Showcasing these success stories will only enhance the learning curve and prevent reinventing the wheel among non users.

6.0   Emerging Trends

The willingness to step up the efforts towards BIM standardisation is evident from the IAI/IFC linkage to geospatial information system (GIS) developments and the open geospatial consortium (OGC) Web Standard (OWS-4/5) specification which is looking at the relationship between GIS, BIM and CAD[j]. Recent research has embraced the service oriented architecture (SOA)/Web 2.0 approach on BIM[12] as it is technically viable to develop a BIM e-platform based on SOA and supported by a model-driven architecture (MDA). In surveys conducted in the

BIM solutions, very little has been known from property owners.

Canadian construction industry[13], the UK/Europe[14] and the UAE[15], almost half of the construction IT tools developed use web based systems as their implementation technology.

Radio Frequency IDentification (RFID) is a wireless sensor network (WSN) technology which the US National Institute of Standards and Technology[k] is currently exploring novel technologies for sensing in buildings. This will enable a building operator to place sensors without disrupting existing construction. It is evident that these technologies can be applied to the Facilities Management (FM) industry, for improving real-time decision-making processes during the operation and maintenance of built environments.

4D CAD and 5D CAD are other emerging trends in the AECO industry where construction schedules and costs are captured within the building information model to provide the time and cost dimensions of a project.

Internet based computer aided design (iCAD) has in addition to normal CAD, communication and collaboration tools. Application service provider (ASP) is the most comprehensive technology that supports collaboration and communication via the internet[16].

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[h] http://www.detdigitalebyggeri.dk

[i] F. Mohus, HITOS – The full scale IFC test

[j] A. Grilo, R. Jardim-Goncalves, Value proposition of interoperability on BIM and collaborative working environments, Automation in Construction, 2009

[k] National Institute of Standards and Technology (NIST), http:// www.bfrl.nist.gov/Wireless Sensor/ index.htm
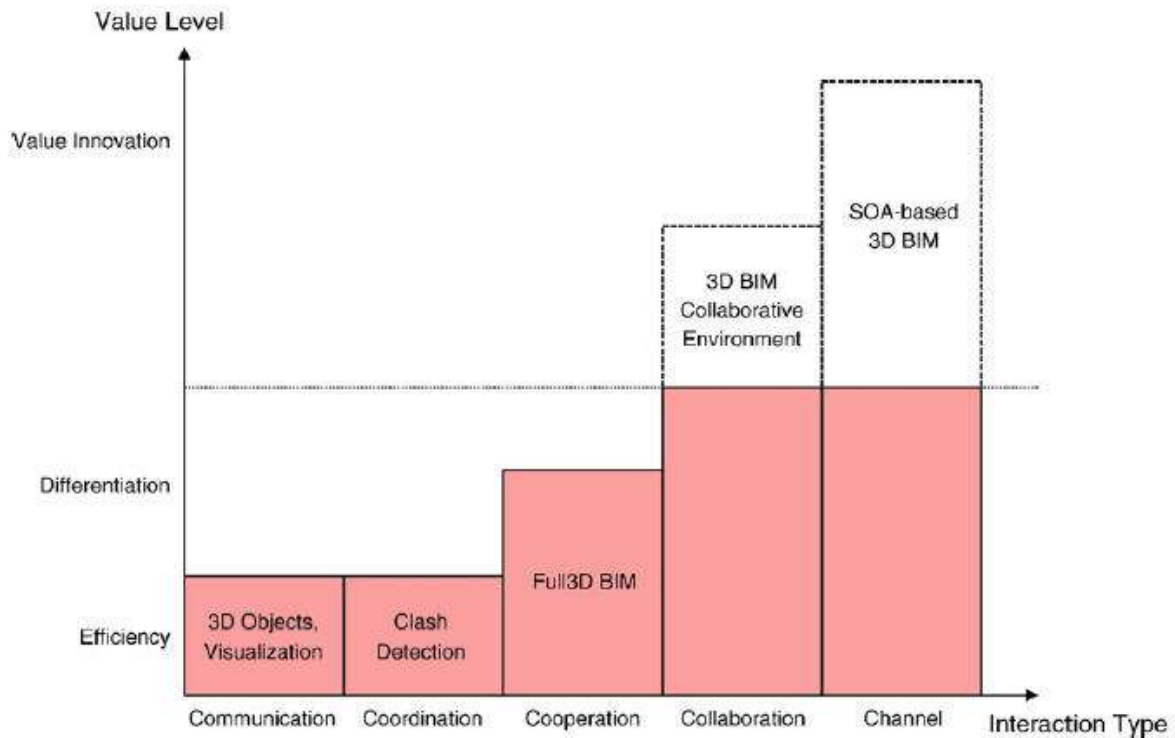
Fig 5.0 Value Level of Interoperability of BIM (Adapted from j)

7.0   The Road Ahead for BIM

The American Institute of Architects (AIA) in conjunction with its Integrated Practice Conference released in 2007 the first draft[1] of its working definition of an Integrated Project Delivery (IPD) Model. One of the essential principles of the IPD is open and interoperable data exchanges based on a disciplined and transparent data structure which is essential to support an Integrated Project Delivery. The IPD working definition document [1] also defines BIM as "a digital representation of physical and functional characteristics of a facility… …. BIM is a shared digital representation founded on open standards for interoperability."

B. Succar[1] presents a linear view of BIM maturity in three stages in Fig 6.0 where IPD is shown as the long term goal of BIM. While

the ultimate goal of the IPD is to use clearly defined open standards, the AIA state that it is possible to achieve Integrated Project Delivery without BIM[1].

8.0   Recommendations and Conclusions

The author suggests a list of recommendations to ensure the continuing growth and integration of various multi disciplinary domains for the success of an Integrated Project Model.

The paradigm shift to an integrated project model should have the support of all stakeholders, including property owners, investors and particularly the government.

The author recommends an approach similar to what the Finnish have adopted nationally.

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[1] Integrated Project Delivery – A working definition – American Institute of Architects California Council, McGraw Hill Construction May 2007

Fig 6.0: BIM maturity is subdivided into three stages — linear view (adapted from [10])

TIEKE (The Finnish information Society Development Centre) plays a neutral and non profit networking role in public private partnerships and is a coordinating body for all Information, Communication and Technology (ICT) activities in Finland [m]. It has established cooperation agreements with international funding agencies all over the world to exchange information and launch joint calls for proposals or joint R&D programmes.

When introducing the publication "Developing and Implementing Knowledge Management in the Parliament of Finland", Japanese professor and knowledge management guru Ikujiro Nonaka crystallized his interest [n] in Finland as follows:

"You are the country where different decision making levels

have integrated their operations to be a national joint knowledge

management system with unique results".

The success of data exchanges between various design, drafting and analysis packages will ultimately depend on the seamless flow of data without loosing its richness and intelligence. As Grilo and Goncalves[17] explain, technical interoperability is feasible today but higher values of interoperability can be achieved through higher levels of interaction (Fig 5.0).

Well informed project teams agree the standards to be applied and software tools to be used prior to the start of a project. However, showcasing the potential benefits to the property owners and seeking their commitment will be a key success factor in deriving maximum benefits from such a deployment. The client team and their advisors could also select the best procurement route that can derive the optimum results from such a deployment.

With the shift of economic growth to Brazil, Russia, India and China (BRIC) economies [18], transferring the learning from the AECO industry in developed countries will help prevent BRIC economy AECO firms from reinventing the wheel. By embracing new technologies and processes, AECO firms in BRIC economies can catapult beyond technology adoption and legacy issues that plague many firms in the developed world today.

During the time of writing this paper in 2010, the economic recession has impacted both developed and developing countries. It is therefore necessary that organisations and project teams receive the support from governments and investors and not refrain from making investments in BIM, Product Modelling and 4D (PM4D) [6] and other emerging trends to continue the momentum in progressing towards an Integrated Project Delivery Model.

In Summary, this paper has briefly introduced the trends in computer aided

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[m] ICT Cluster – Finland Review 2009, TIEKE (The Finnish information Society Development Centre)

design, obstacles to an integrated project delivery ecosystem and the role expected of key stakeholders including software vendors and property owners to ensure a seamless integration of data, processes and technologies. It is evident that the concentration of this development and innovation is confined to a few pilot projects in Northern Europe, the UK and North America. However, the evolution of CAD as presented in this essay and pictorially through Fig 1.0, demonstrates that the AECO industry is very gradually but steadily expanding into an integrated and robust, IT technology

supported industry, by bringing together all the knowledge domains from the industry.

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