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CAD standardisation in the construction industry – a process view

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Abstract

There has been a demand for uniform CAD standards in the construction industry ever since the large-scale introduction of computer aided design systems in the late 1980s. While some standards have been widely adopted without much formal effort, other standards have failed to gain support even though considerable resources have been allocated for the purpose. Establishing a standard concerning building information modeling has been one particularly active area of industry development and scientific interest within recent years. In this paper, four different standards are discussed as cases: the IGES and DXF/DWG standards for representing the graphics in 2D drawings, the ISO 13567 standard for the structuring of building information on layers, and the IFC standard for building product models. Based on a literature study combined with two qualitative interview studies with domain experts, a process model is proposed to describe and interpret the contrasting histories of past CAD standardisation processes.

Keywords: standardisation process, computer aided design, building information modelling, industry foundation classes

1. Introduction

Standards provide an essential ingredient to the ubiquitous use of IT in everyday life and business. The fundamental Internet and web protocols provide a good example of established interoperability standards. Numerous formal and de facto standards enable the seamless communication between computers and software applications in a world-wide network. Standardisation processes have received relatively little attention within the research community despite the tremendous importance of standards in modern society. Only recently has IT
standardisation started to emerge as a research field of its own [1,2].

Standardisation has always played a crucial role in the construction industry. Examples include: technical standards which enable parts to fit together, classification standards which facilitate quantity takeoff, cost estimation, and the compilation of searchable information databases. Classification of functional building elements (e.g. doors, windows, slabs etc.) is a particularly interesting parallel because it illustrates the difficulty of international standardisation without even bringing IT into the mix; when slightly different national implementations have emerged they have ultimately resulted in lock-in situations when incompatible standards have clashed.

The recent widespread integration of IT in construction makes use of several already existing standards, as the ones described above, but has also created the need for new types of standards. This particularly concerns the description of a building in digital form. Human experts and even lay people can read drawings and interpret them, despite minor ambiguities. However, if software applications attempt to access data created by other applications, the data needs to be formatted according to common specifications in order to be of any use at all. For the transfer of graphical elements between different CAD systems, the neutral standard IGES was developed around 1980 [3], but in practice DWG, which is the native format of leading CAD vendor Autodesk, has become the de facto transfer standard when exporting and importing data from other CAD systems.

For earlier generations of building descriptions, or more precisely 2D CAD systems, the layering approach combined with standards for how graphics are exchanged greatly facilitated data sharing. During the late 1980s numerous layer standards evolved within CAD user groups, and in some cases, on national levels. An international standard for CAD layering, the ISO 13567, was defined in 1997 to harmonise the incompatible policies that had developed locally over time [4,5]. 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 [6].

Previously published articles have mostly been narrow in scope, focusing primarily on individual standards in-depth, or reporting individual cases of standard implementation [7,8,9]. This study attempts to build a process framework for standardisation, based on standardisation experiences within the construction industry by taking a closer look at the processes of several already established and emerging standards. Such a framework would probably be helpful for standardisation work within construction, but also other communities heavily dependent on standardisation of IT for increasing interoperability.

2. IT Standardisation

2.1 General theory and concepts

Terms regarding standards and standardisation have been used with some ambiguity in past literature, however, a firmer typology has gradually started to take form [10], which will also be used throughout this study.

The word ‘standard’ is defined as follows:

“A standard is an approved specification of a limited set of solutions to actual or potential matching problems, prepared for the benefits of the party or parties involved, balancing their needs, and intended and expected to be used repeatedly or continuously, during a certain period, by a substantial number of
the parties for whom they are meant.” (De Vries, 1999, p. 15) [11]

Compared to many other definitions to be found in the literature, this definition provides an appropriate level of freedom for what kind of standards can be defined by its description without making it non-descriptive [10]. Regarding scope and focus, this study deals with compatibility standards, which is often the case when IT standards are concerned. These types of standards are sometimes also referred to as functional standards [10]. Perhaps implicitly implied but certainly good to clarify is that standards in this category are usually international standards with network externalities.

Standardisation, which is the process of a specification becoming widely used and accepted for its purpose by its users, is ultimately achieved either through a formal, semi-formal, or de facto process [10]. Formal and semiformal standards are the result of committee work, often involving lengthy negotiations and compromises between the interests of different stakeholders. Examples of this type of standards include the building element classification systems in use in many countries and EDIFACT messages developed for electronic procurement of construction materials. The degree of formality involved depends on the status of the organisation defining the standard, ranging from the International Standards Organisation through national standardisation organisations to different sorts of industry consortia. De facto standards arise through a Darwinian selection process between competing standards on the market, gaining support by becoming the preferred choice of the users. A good example of a de facto standard is the widespread adoption of the PDF format for document exchange on the web; the platform-independent portable document format was launched by Adobe Systems in 1993 and was made an official ISO standard long after gaining its de facto status, in July 2008 [12]. Some formal standards have become very successful, but there are also numerous which have had no impact on the market. De facto standards are by definition successful. The labels for the different processes have therefore no relation to the actual success of the standard, they merely make it easier to compare and analyze the different means by which standards are developed and establish their position the marketplace.

Analysing the stages a standard goes through on its path to the marketplace is an important part of the IT standardisation literature. There have been some variations in the stages suggested so far, however, most of the stages are agreed upon by researchers [13]. Variations are mostly due to differences in purpose, typology, and properties of particular standards analysed. Generic stages in the progression of a standard have been identified, which include: requirements definition, development, agreement, marketing, deployment by vendors, and acceptance by end users. If any of these stages would happen to fail during the standardisation process, the whole process fails. Furthermore, a long incubation time for a standard may have harmful consequences on the marketing and deployment stages [14].

Some researchers have noted that analysing standardisation as a linear process omits important stages which heavily shape the final product. A linear model is not representative of how most standard setting organisations function due to the lack of a feedback and refinement mechanism. Through this development, different models for the life cycle of standards have emerged [13,14,15]. Eva Söderström (2004) [13] generalised seven published standard life cycle models into one core model in a recent literature review, of which the main result can be seen in Fig. 1.
Important to note is that the feedback mechanism, which is one of the main arguments for a cyclical process, should be enforced and implemented by the standard setting organisation. However, once a final version of a standard has been released, it should remain stable for a longer period. If new versions are released they should be compatible with earlier versions to avoid fragmenting and confusing the user base [16].

2.2 IT standardisation in the construction industry

IT standardisation is particularly relevant in the context of the construction industry; with expensive and tightly-scheduled individual projects spanning over multiple stakeholders, the demand for uniform tools, and policies for how to use them, is crucial if seamless collaboration is to be achieved. A new IT infrastructure is not something companies build up from scratch for each individual project that comes along, not only because of the massive investments in time and money involved, but also because there is uncertainty and risk present in such endeavours [17]. This strive towards interoperability is one reason why consortia and other cross-organisational collaboration activities are so prevalent concerning the development and standardisation of IT [16], and particularly within the construction industry where consortia have long been used for other forms of standardisation as well [18].

In order to properly understand standardisation efforts, it is important to be aware of the relationship between the development of a technology, and the definition of the standards necessary for its use. In most cases the technology is developed first, including several different technically working alternatives, after which the pressure for standardisation arises. Examples include rail widths for railroads, electrical current levels in power networks, computer operating systems, and video cassette recorders. A prerequisite for the success of video rental stores in the 1980s was the convergence of the market to one dominating technical format, in which struggle VHS emerged as a de facto standard. Similarly in the cell phone business, development of the technology and emergence of standards such as NMT and GSM has gone hand in hand [19].

This has also been the order of evolution for CAD software; the need for standardisation has grown stronger as both the number of users and uses for the software has increased [20]. Because of this retrospective relationship, the technical complexity of a standard is also something to consider when comparing different standardisation efforts. Many of the most successful standards are relatively simple, potentially leaving more resources available for marketing and deployment. To take a nearby example, the overall work input into the definition of the ISO CAD layer standard was in the order of one man year. For the IFCs, the standard in itself is highly complex with definition work still going on over ten years after the start of the standardisation effort [21]. One interesting question is if there is a point when a standard becomes so technically complex that the committee bargaining and decision-making processes to reach a decision become too cumbersome for a successful outcome [22]. In the case of

\[\text{Fig. 1 Generalised standards life cycle model (based on Söderström 2004) [13]}\]
building information modelling this is almost impossible to say since the standard has been influencing the development of the technology itself; distinguishing the standardisation efforts from general development and testing work of the software tools is very difficult.

One of the interesting aspects of standardisation is that seen as a project, a standardisation effort to a large part consists of voluntary work, taking place in committees and outside formal meetings, in a setting not controlled by formal contracts and budgets. Experts participating in standardisation efforts are often granted permission to work and funding from their companies, sometimes also helped by outside funders such as national or international research programmes. In many respects the process is comparable to how open source software development works [23]. Interestingly this way of working, to a degree, also resembles the functions of the scientific community. This has important implications for both the overall progress and final deliverable of the standard. Complex standards have many aspects to work on before even the first revision sees the light of day; choices concerning which aspects of the standard receive supplementary attention, and in which order, are usually guided by an explicit overall strategy. However, the actual working order and emphasis is also to a large extent steered by the participants themselves. Factors affecting the outcome include the individual working preferences of the participants, their possibilities to obtain external funding, and perhaps also their company’s blessing for participating.

3. A process model in the context of CAD standardisation

As a result of the literature review presented in the previous section and lessons learned from interviews with domain experts [20, 24], a simple process model for standardisation was developed. The core objective was to combine concepts and frameworks used in the general IT standardisation literature with qualitative research results to improve our knowledge about this particular standardisation domain. The name of the overall model is “Develop, deploy and standardise CAD technology for construction”. Despite its name and particular application here, the process model is generic and not a priori restricted to CAD and product modelling technology.

The domain expert interviews concerned the standardisation processes of the international CAD layer standard ISO 13567 [20] and the IFCs [24]. Since detailed results of the two sets of interviews have been reported elsewhere in journal papers (referenced above), they will not be repeated in this paper. The method utilised in the previous studies was semi structured interviewing with a number of experts representing important stakeholder groups in the overall process of taking a standard into use; standardisation committee members, researchers, end user company IT experts, and software vendors. In these studies it was determined early on that a qualitative research approach was more suitable compared to a quantitative one with regard to the research questions which were of explorative nature.

The process model was developed using the graphical IDEF0 notation, which has frequently been used in construction IT research and also by experts involved in STEP/IAI work. The main concepts of the method are the activity and the flow. Activities are shown as rectangles and their names start by verbs. Flows are represented by arrows and the names are nouns. A flow can be either an input, output, control, or mechanism. An input represents something, which in an activity is consumed to produce an output. Typical
inputs could be raw materials, energy, human labour, but also information when the purpose of the activity is to transform the information. Outputs can be reused as inputs to further activities, and feedback loops are possible. The execution of activities is guided by controls. Outputs consisting of information can also be used as controls. Mechanisms, which point at activities from below, are usually persons, organisations, machines, or software, which carry out the activities. Presentation of IDEF0 diagrams is hierarchical [25].

The purpose of the model is to demonstrate the context of CAD standardisation work, in particular its relationship to actual use of the standard in construction projects and to the R&D work that precedes the definition of the standard and the development of the software technology supported by it. The model consists of 5 diagrams on 3 hierarchical levels. The diagrams are presented in descending order, which should aid readability.

The context diagram, seen in Fig. 2, explains the surroundings of the model. It places standardisation into a broader context, as just one part of a wide effort to develop and adopt a particular technology into widespread use. It introduces the actors and stakeholders affecting adoption of the technology. Resources are essential to development work at many stages of the standardisation process. It was mentioned in the previous sections that standardisation efforts have considerable differences in how resource-intensive they are, largely depending on the complexity and maturity of the applicable technology.
**Fig. 2** The context of the process model

**Fig. 3** The overall model
The overall model, seen in Fig. 3, splits the entire process into three parts: the development of the technology, the process of taking it into wide-spread use in practice (deployment) and the development of the standards needed to make the use of the technology cost-efficient. It is important to note that the order of activity boxes does not necessarily imply a temporal order of doing activities (in the way time-table charts imply). Thus standardisation can either happen before or after deployment, sometimes even prior to development of the technology. The importance of resources cannot be stressed enough, they have to be available during all stages of the process in order to enable a successful outcome. The input and influence of researchers and software developers is dominant in the development and definition stages, while construction process companies are mostly involved with deployment and definition of the standard.

The development diagram, seen in Fig. 4, splits up the development activity of CAD applications into several smaller phases. Development is based on research results gained by researchers, development of applications can either be instantly initiated, or alternatively, an anticipated need for standardisation might be discovered for future development. Applications can be developed in isolation, but at some point they might also be streamlined in order to be able to export and import data according to standards. The testing of applications is also a key phase, with an integrated feedback mechanism to the development phase for further refinement in accordance to collected feedback. Important to note is that vendors often like to claim standards compliancy for their products for marketing purposes, even though the particular functionality may not work in practice. This has been shown to be true with IFC data exchanges in several studies [6,26].
The deployment diagram, seen in Fig. 5, shows what happens after the standard has been incorporated into commercial software. It is then up to the individual companies to adopt the product and invest in training and integration to use the application as intended. The competing products, guidelines of client organisations, and decisions made by other construction process companies heavily affect the decisionmaking. Once applications are available from vendors they have to be taken into use inside single companies, and in project groups with several companies involved. Only use in real pilot projects can reveal some of the difficulties involved. De facto standards do not go through this process as they have already been accepted and adopted by the users.

The definition diagram, seen in Fig. 6, highlights the fact that a standardisation process is very a complex project in itself, involving several different stages, which all need to be successful for establishing a widely used standard. The need for standardisation originates from imminent market demand or anticipation for the need of standardisation for some emerging technology. Formal R&D programmes, client organisations, and construction process companies provide funding for standardisation work. These resources are then used to both develop a draft standard up until the point that agreement can be reached for a formal standard. Then it is up to software vendors, industry associations, and formal standardisation bodies to market and inform about the standard so that it becomes known to all stakeholders.
4. Discussion - standardisation cases

The process model presented in the previous section will be used as a backdrop to further highlight and discuss the differences in the standardisation process between the four standards selected for this study. Table 1 gives a brief overview of the origins, status and particular subdomain for the different standards.

4.1 IGES

In the case of the IGES (Initial Graphics Exchange Specification) standard the standardisation was carried out at a rather early stage; the basic CAD technology (2D and 3D geometric modelling) was developed during the 1970s and the first version of the IGES standard was published in 1980. Therefore it was almost an anticipatory standard. It should be noted that several big companies (i.e. Boeing, General Electric, Xerox) as well as the US department of defence were involved in its development. The first release, IGES 1.0, was published by the American National Standards Institute (ANSI) only one year after work had begun. Thus the standardisation process preceded the large-scale deployment of the CAD technology in the industry.
Fig. 7 Test file used to demonstrate IGES vendor interoperability in the 1980s

<table>
<thead>
<tr>
<th>Standard</th>
<th>Developed</th>
<th>Status</th>
<th>Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGES</td>
<td>1978 - 1980</td>
<td>Official, ANSI</td>
<td>CAD graphics</td>
</tr>
<tr>
<td>DWG</td>
<td>1982 - 1990</td>
<td>De facto</td>
<td>CAD graphics</td>
</tr>
<tr>
<td>ISO 13567</td>
<td>1993 - 1997</td>
<td>Official, ISO</td>
<td>CAD layering</td>
</tr>
<tr>
<td>IFCs</td>
<td>1994 -</td>
<td>Industry consortium</td>
<td>building information model</td>
</tr>
</tbody>
</table>

Table 1. The standards discussed in the study

4.2 DWG

DWG is the proprietary file format used by modelling software AutoCAD, its specifications have not been published by the vendor. To offer interoperability AutoCAD developed the open ASCII-based DXF (Drawing Interchange Format), to be used by other CAD vendors for importing and exporting CAD data. In the mid 1980s, DXF compliancy started to be more important than implementing support for IGES as the market share of AutoCAD steadily increased. Later, as third parties were able to reverse-engineer the closed DWG format and publish libraries for building translators, most other CAD-vendors started offering conversion tools to DWG rather than DXF. Considering the process model presented in this paper, DWG emerged by de facto standardisation after wide-scale deployment of CAD technology in industry. Due to the choices made by individual companies a de facto standard emerged, which forced other CAD vendors to develop the facility to import/export data in the AutoCAD format. The overall cycle was thus development of the CAD technology by different software vendors, industry deployment and rapid market penetration followed by the emergence of a de facto standard based on the proprietary format of the market leading system. In very rough terms, the basic software was developed in the 1970s, industry uptake took place in the 1980s, and the de facto standard was a reality around 1990.

4.3 ISO 13567

Basic layering emerged during the late 1970s, first mimicking a technique which already had been used in manual drafting. Support for detailed structuring of layers
was usually not embedded in basic CAD-software which resulted in a wide number of practices being developed on project and company levels. During the latter half of the 1980s, experiences from construction projects led to a wider demand for standards regulating the allocation of drawing elements on layers. Standardisation was attempted by CAD-system specific national user groups but also by national construction standardisation bodies. There was also consensus that something ought to be done on the international level to harmonise national standards. This led to the forming of a working group under ISO which delivered a standard in 1997 [27,28]. The full name of the standard is “Organization and naming of layers for CAD -- Part 2: Concepts, format and codes used in construction documentation”. The ISO standard was heavily influenced by already begun standardisation work in a number of member countries and the approach can be characterised as bottom-up.

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**Fig. 8** The core concept of CAD layering

### 4.4 IFCs

While CAD systems facilitating the production of 2D drawings were being taken into widespread use, some researchers and system developers started to envisage more advanced object-oriented building representations. These advanced systems would enable solving some of the more demanding data sharing functions that purely graphics-oriented CAD systems could not manage [29]. Digital building descriptions using objects which belong to predefined classes have usually been called building product models, although some software vendors have recently coined the new term building information model (BIM) for essentially the same thing [30]. Research concerning such models started to gain momentum around 1985, when the ISO STEP standardisation project started.
STEP stands for Standard for the Exchange of Product Data and attempts to solve the data exchange needs for a large number of manufacturing industries. In the early 1990s there was some frustration that the building construction work within the STEP community lacked proper momentum and that the formal ISO rules for reaching agreements were too slow [22]. The need for standardisation was expressed early on by visionary researchers, industry experts and software developers which has driven the research and the development of the tools. As early as in 1985-86 the development of a building product model standard was defined as a high priority in the Finnish RATAS-programme [31]. Two influential high level models were proposed in parallel as a part of the STEP-standard. These were the GARM model [32] and the Building Systems model [33]. STEP is the ISO product modelling effort, which at the time also included an active subcommittee for building construction.

Fig. 9 IFC compliant BIM model

Independently from the efforts within STEP, twelve US companies using AutoCAD initiated co-operation in 1994 in order to make their software applications compatible with each other. After a demonstration at the AEC systems trade show, other companies expressed interest to join the effort and the co-operation was extended both to other countries and also to users of other CAD systems. In 1996 the International Alliance for Interoperability (IAI) was established based on a structure of regional chapters. The experts working on the IAI standard, which received the name Industry Foundation Classes, quickly understood that there was no need to reinvent the wheel. Consequently, important parts of their definitions were based on work done previously within STEP. This included the EXPRESS language and
a model called the Building Construction Core Model, which had received a lot of input from several EU funded projects. Among other benefits this entailed the possibility to reuse such entity definitions from STEP which deal with non construction specific items, such as basic geometry. The first version of the open standard, the Industry Foundation Classes (IFC), was issued in January 1997. Release 1.5 was the first to see commercial implementation in a CAD-application in July 1998. Release 2.0, issued in 1999 was much more comprehensive in scope. The latest available version is IFC2x3 [34]. Fortunately the quite frequent updates to the standard is something that the IAI has taken into account from the beginning ensuring backwards compatibility - as standards designed for evolving technologies should.

IFC work in many respects resembles an open source software project. The end result is publicly available on the web and free for anybody to implement and use - in contrast to ISO standards which have to be bought. And perhaps even more importantly, the work itself is partly self-organising, progress is tied to how the motivated and skilled experts can manage to get funding. The downside is the reliance on the changing business strategies of a number of involved software companies as well as on a number of time-limited R&D programmes (e.g. EC research funding, the VERA-programme in Finland).

Conclusions

De facto standardisation is rather uncomplicated to manage, because it happens if one particular software application gets a large enough market-share to put commercial pressure on the other vendors to provide conversion software to and from the format of the leading system. This is what happened in the case of geometrical primitives in CAD-systems with the DWG format. Consequently the effort which had been put into the development of the IGES standard became redundant, at least for CAD use in the building construction domain.

Other kinds of standardisation, ranging from industrial consortia standardisation to very formal standards published by the ISO, have in this context proven to be very difficult to manage. The ultimate success of the standard hinges on the success of every one of a number of different activities related to different life cycle stages of the standard. Key issues include:

- The timing of the definition of the standard to the general development and deployment of the underlying technology.
- The overall level of the resources made available for the standard definition, relative to the technical complexity of the standard.
- The management of the standardisation process, ranging from a top-driven traditional project, to an open source like collaborations based on voluntary contributions.
- The buy-in of software vendors for implementing the standard in applications
- The actions of key construction client organisations for promoting use of the standard.

To study a complicated international standardisation processes, particularly within construction IT, it would be beneficial to utilise a wide interdisciplinary perspective to enable thorough analysis of factors affecting the flow of the process. The model presented in this paper could function as the backbone for comprehensive case-studies; not only would this be fruitful for providing
structure to such an endeavor, but it would also help refine the proposed generic standardisation process model. In the particular case of IFC standardization, involvement with first-hand sources like software vendors, contractors and IAI consortia members would shed needed light on the whole situation by clarifying the effect these stakeholders have on the overall progress of IFC standardisation. It is hoped that the presented model can be of some help in structuring the discussion about standards, in particular the IFCs, which currently are the focus of much interest.

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