DESCRIBING THE CHANGES IN ARCHITECTURAL INFORMATION TECHNOLOGY TO UNDERSTAND DESIGN COMPLEXITY AND FREE-FORM ARCHITECTURAL EXPRESSION

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SUMMARY: *The key question arising in this paper, is how our currently ubiquitous and pervasive information and communication technologies (ICT) has throughout the years managed architectural design information and how has that affected architectural design, in which building geometry has mainly been studied. The evolution of computer-aided design (CAD) is used as the "backbone" for the assumptions made. The focus area of this paper is CAD and more widely digital ICT within the architecture, engineering and construction field (AEC), its development and available computer-aided design tools throughout the last 30 - 40 years. Architectural design is discussed in this paper from the viewpoint of complex design and construction projects and therefore the more complex information structures used in contemporary design and construction. Complexity has also resulted in a more complex, curved and "free" architectural building geometry, which has been enabled by modern CAD-tools. The main conclusion is, that information and communication technology has indeed enabled us to manage more complex building projects better and more comprehensively than earlier, and also more complex architectural expression can therefore be used in contemporary construction. Building product modelling (building information modelling, BIM) has been proposed to be a suitable method to manage all design and construction issues within current IT-oriented building projects and process environments. Product modelling is seen as a natural step in the evolution of ICT. Building product modelling is regarded in this paper to be a promising method to increase our ability to manage some more vague building and design criteria, such as design richness or even overall building quality. This paper is related to the authors' post-graduate studies on architectural design, environment changes and building product modelling in Helsinki University of Technology.*

KEYWORDS: *architecture, representation, CAD, complexity, product modelling, information modelling.*

1. FREE ARCHITECTURAL FORMS BEFORE THE ERA OF CAD

Free architectural forms and shapes are often regarded as personal or individual, due to the fact that they are rather uncommon in orthogonal western architecture. An unorthodox combination of architectural elements and freely designed forms are often regarded as good, but also expensive to realize. More standard, traditional, perpendicular architectural forms and shapes are therefore often regarded as normal or perhaps even dull, but they are also cheap to realize. A few examples of using free architectural forms are analyzed before the advent of CAD.

Conventional box-like, horizontal-vertical, flat-plate architecture has been very common in western architecture during the last 200 years. Freely-formed buildings on the other hand have been regarded as more unique and uncommon architectural examples and some of those have even been developed into iconic landmark buildings, either over time - such as Sagrada Familia in Barcelona - or on purpose, as later in the Guggenheim Museum in Bilbao.

Several early examples of architectural building designs which are based on free building forms, have been based on physical models or geometrical construction principles. The forms have in most cases been created with the aid of compasses, curved plastic aids (French curves), pens-tied-to-ropes and clay-models. The erection of these buildings has most often been based on the builders' superior craftsmanship and tight co-operation between the architect and craftsmen. On the other hand, the erection has surely also followed trial and error -methods; rebuilding the desired form many times until it satisfies the author. It is understandable, that building curved architecture has throughout the ages been rather expensive, and either it has been done on purpose in iconic buildings, or it has been necessary for the structure as in arched buildings, because of well-known and respected artist-architects.

Antonio Gaudi's works in Barcelona in the late 1800's and early 1900's are well-known examples to manage non-rectangular architectural forms. Gaudi developed his architectural expression, for instance in the church of Sagrada Familia with physical models, such as hanging structures with ropes, strings and weights.

In terms of design quality, free architectural forms in landmark buildings are often regarded as synonymous with the highest quality architecture ever. On the other hand, these architectural icons should perhaps not be compared with more common buildings, due to their very different original purpose, different meaning and often also different intended use.

FIG. 1: Casa Batllo by Antonio Gaudi in Barcelona 1904-06, is a good example of curved art-nouveau architecture. It is also a good example of how pervasive architecture of a building can become a piece of artwork.

Alvar Aalto's bending architectural shapes and materials, such as appeared in his furniture design or in the single-family house Villa Mairea, derive often from Finnish nature (Rinnekangas & Pallasmaa 2005). Aalto has used free wavy-forms (aalto = wave in finnish) very effectively; forms have been used just in some of the most essential targets, such as in doorhandles, in hand-rails or in the inner roof curvature. He has used free architectural motifs sparsely, not everywhere, to enrich the desired architectural effect. Aalto has also used the high-technology of his time when bending birch wood for his furniture. The furniture manufacturer Artek - art and technology - combined Aalto’s nature-based design visions, industrialized production methods and also modernistic values of the functionalistic age.

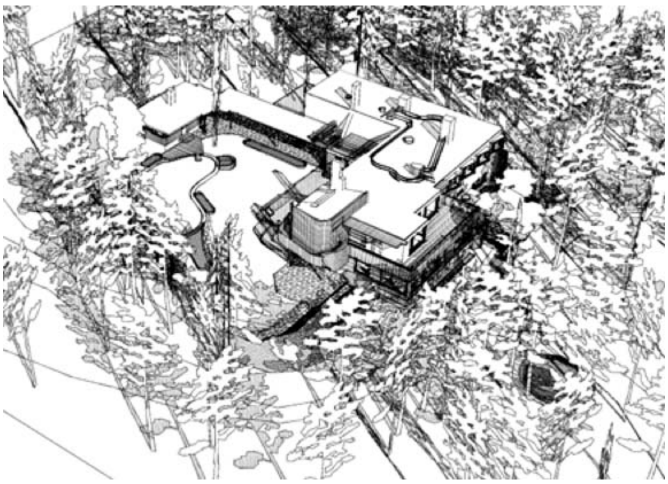


FIG. 2: (left). Stool 60 - chair by Alvar Aalto 1932-33 is an archetype of a simple modern chair, still in production by Artek. Fig 3 (right). Villa Mairea by Alvar Aalto 1938-39 fits to the site with its modestly bending walls and terraces. Aerial winter view from Lauri Melvasalo’s master’s thesis 2004.

Reima Pietilä's works from the 1960's represent also "pre-digital" individual architecture with unconventional and flexible shapes. Pietilä's personal organic-morphologic architecture and free architectural forms, mainly in ceilings and walls, are found for instance in the Dipoli student union house in Espoo and Metso-library in Tampere. It may sound almost like an anecdote, but Pietilä created a-not-so-traditional architectural model of Metso-library by baking it from wheat bread in the oven, to study the arch-shaped concrete roof forms; innovative use of unconventional but very contemporary modelling tools.

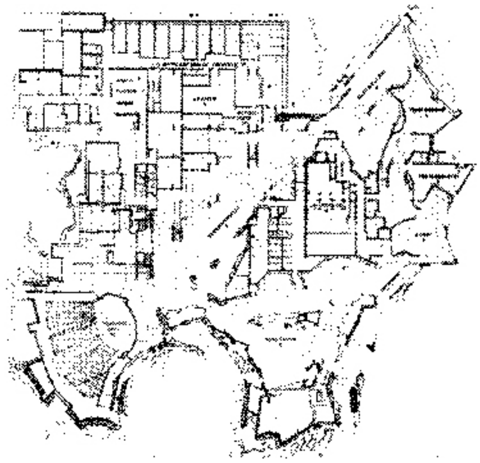


FIG. 4: (left). Dipoli student union house in Espoo by Reima Pietilä 1965-67 is curved both in plan, but also in the spatial dimensions, where organic curved concrete vaults are used. FIG. 5 (right).

FIG. 6: Tampere city library Metso by Reima Pietilä 1986 is strongly emphasized by the curved concrete beams and concrete elements in the roof structure. Metso (capercaillie, lat. Tetrao urogallus) which is a largish bird living deep in the forests, has given the shape to Pietilä's library.

2. THE BRIEF EVOLUTION OF ARCHITECTURAL CAD'S DIMENSIONS

Computer-aided design (CAD) with all of its aspects, has been in an evolution-like changing process since the advent of the concept in the 1960's. This evolution has mainly been based on technology leaps and new innovations in computing and software technology. During the 1980's - the "enlightenment" of computerized design - CAD started to appear more in architectural practice and it also became an acceptable design tool. Finally CAD strengthened its position to be the inevitable architectural tool in design practice during the 1990's.

The earliest and perhaps most widespread meaning of CAD concentrated on *2D draughting* in design. The spatial third dimension has also been well noticed already in the early days of drawing-based CAD, hence, *3D-modelling* has always been an essential part of the concept. While some CAD-pioneers used semi-spatial drawing-tools (2D-drawing + height) in the 1980's, CAD was also called 2 1/2 D.

Although the mainstream use of CAD in architectural practice during 1980's and 1990's focused a lot in transforming architectural documentation from hand-made drawings to digital, the early visionaries had very clearly noticed the wider variety of possibilities and promising alternatives in the digital architectural media

(Mitchell 1977, Negroponte 1970). Such topics as 3D-modelling, **visualization**, **simulation**, analysing design solutions and quality, and generative systems to produce new design solutions, were under keen discussion, and they were also tested in laboratories during the "pre-history" of CAD in the 1960s and 1970s with expensive main-frame and mini-computers. Computer technology and available tools were unfortunately not ready for cheap mass-distribution for architects yet.

The concept of *4D-modelling* meaning 3D plus the time factor, appeared in research discussion during the late 1990s showing that the CAD-systems had also been used by construction companies and builders. After 4D, a natural step to *5D-CAD* expanded the concept from a 3D-model + time + cost, was unavoidable. The evolution of CAD from 2D-drawing towards unnumbered n-dimensions has been noted in 2002 (Lee et al 2002).

Virtual reality VR has expanded computerized 3D-modelling and its visual characteristics from "how it looks" towards "how it feels and sounds" since the 1990's, when the concept started to appear more in research. Virtual reality is currently a wide topic and it has been one of the most used concepts within the area of CAD-related research, for example in the Cumincad-reference database (Cerovsek and Martens 2004). VR has also proved to offer valid tools for architects to present designs and also to communicate about the design issues with other project participants (Savioja et al 2003). The concept VR has recently continued to expand towards *augmented reality AR*, when even wider aspects of modelling, imaging, mobile technologies and active communication with the models and the real world are concerned (Kieferle and Wössner 2003, Kieferle and Wössner 2001, Wössner et al 2004).

3. EARLY PROTOTYPICAL CAD SYSTEMS HAVE DEVELOPED INTO STANDARD ARCHITECTURAL TOOLS

The earliest spatial 3D-design with computers in the 1960s had to be simulated with box-like parallel-pipeds due to limited computing capability. In the 1970s it was, though, possible to model also mathematically defined 3D-curved forms with CAD, but since it was done in research laboratories and universities with expensive mainframe machines, it should be noted, that CAD was not used in normal every-day architectural design, but in unique, specified, prototypal case studies and research examples.

When the meaning of early CAD is estimated in terms of design quality and built architecture quality, it might be acceptable to say, that early CAD or 3D-modelling did not affect the built architecture yet during the 1970s or 1980s. Nevertheless, the early research efforts in managing architectural geometry and forms with CAD, laid the basis for future tools, to develop and appear in the practice a few years later.

FIG. 7: One version of the main hall of Helsinki opera house (architects Hyvämäki - Karhunen - Parkkinen) modelled with Proj-program by Tapio Takala et al. 1978-84. An early example of free architectural forms expressed with CAD. Straight and curved lines could be modelled spatially in 3D, though yet without volume modelling.

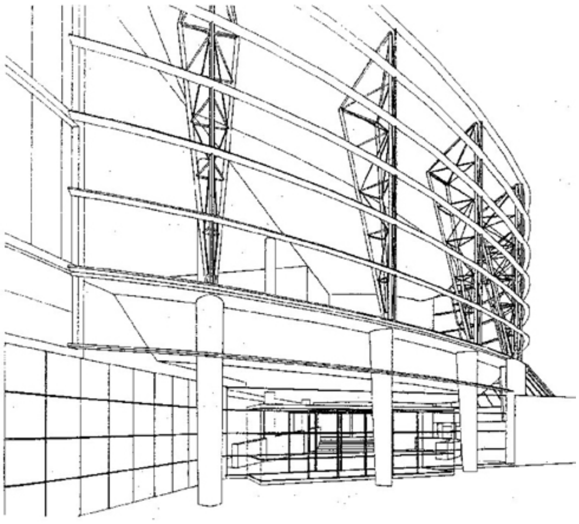


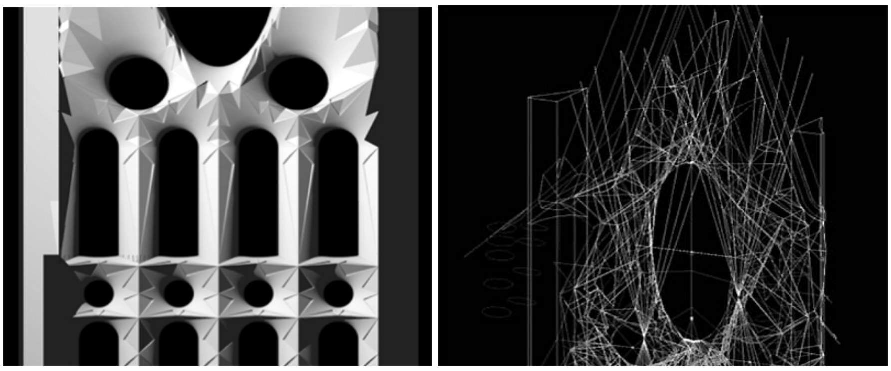
FIG. 8: 3D-spatial modelling example by architect Pekka Salminen 1992, who was one of the earliest Finnish pioneers in using CAD, has used 3D-modelling extensively in his architectural production.

Starting from the 1980s and finally during the last decade, CAD-systems have proved to be the most essential tools in architectural offices throughout the western world. This acceptance among architects has grown along with computing capability and added functional features in CAD-systems. The graphic and functional abilities of the majority of recently used CAD-systems, have developed until now, to handle also non-linear free forms, such as curves and curved surfaces. Current systems balance the needs within architectural design practice. CAD-tools to manage orthogonal architecture have been available since the 1960s, and tools to manage non-perpendicular architecture have also been available to match the needs of recent architectural expression. Technically speaking, the advent of B-spline curves and then NURBS-surfaces (non-uniform rational B-splines) in CAD-systems has in fact finally released our contemporary CAD-tools from the leash of perpendicular axial 3D-shapes (Chiarella 2004).

CAD-systems' evolution has followed the needs of the designing community so well, that one might even claim, that CAD has not affected the design quality nor the architectural forms but, merely the architectural needs from design practice have strongly effected CAD-systems' evolution.

4. MANAGING FREE ARCHITECTURAL SHAPES AND FORMS WITH CAD SYSTEMS

Mark Burry from Australia has studied and published a lot of the issue to manage free Gaudian architectural forms and surfaces with modern CAD-tools and 3D-modelling techniques in several papers (Burry 2002). Burry has also discussed the important dialog between the designer and craftsmen, and lately the dialog between the CAD-modeller and talented craftsmen-builders, to underline the important meaning of spatial modelling to fulfil and accomplish finally the architects' artistic needs and architectural intentions.



FIGS. 9 and 10: A detail of Sagrada Familia's facade, modelled with Rhino3D by from Mark Burry (Burry et al 2001).

Robert Aish has also discussed about the CAD-system's ability to manage free forms and shapes, hence, giving the architect new possibilities to create more challenging but still generatively and parametrically controlled design. So called "associative geometry" where the designer can modify the modelling steps (modelling history) by altering parameters, hence, rework the modelling results, is a modern CAD-related example of an iterative design process, reminding of Gaudian-like traditional modelling processes, to finally reach the desired architectural expression by continuous redesign of the target.

The ability to model free, flexible, curved, sometimes even "liquid-like" shapes with CAD, has also strengthened the imaginary features in design. In virtual CAD-environments it is possible to create forms and structures that do not respect gravity nor real materials' characteristics, hence, from a pragmatic viewpoint it leads to non-realistic, non-buildable designs. The AEC-field of the western world, which is currently strongly economy-driven, does not usually value these kinds of experiences. Though, the studies and free form design efforts may still have highly regarded educational and artistic values for instance in architectural schools (Asanowicz 2004).

Free and unconventional digital experiments, such as imaginary design project proposals in competitions, sometimes also leads to "iconic" 3D-artifacts, which have artistic value even as themselves. Good modern examples of digital-deconstructivistic and fluid, free-form architecture of virtual projects are for example shown by the recent works of Greg Lynn and Kivi Sotamaa.

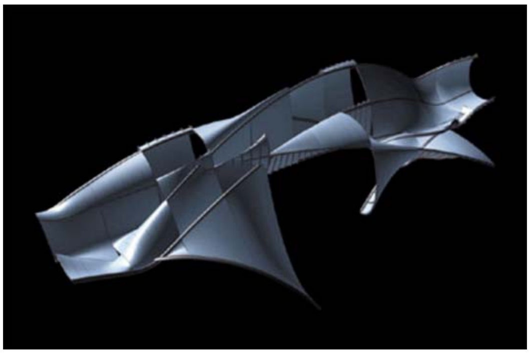
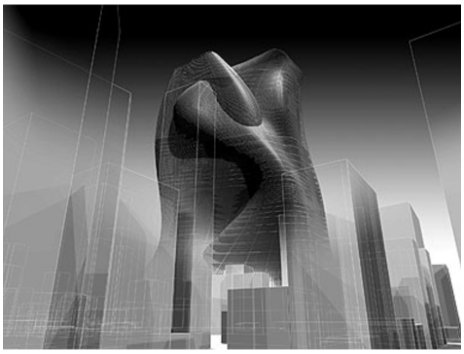



FIG. 11: (left). Projects from Greg Lynn Form and Kivi Sotamaa/Ocean-North. FIG. 12: (right).

5. EXTENSIVE AEC USE THROUGHOUT THE BUILDING LIFECYCLE

Flexible spatial geometry and shapes are currently easy to manage and design with 3D-CAD-system tools. In some of the most enhanced examples of the architectural free form modelling, the used CAD-tools are the same as the tools in automobile and aeroplane industries, which have obviously guided the development of some of these high-end tools, such as Catia. Other examples of similar kinds of 3D modelling tools are available in Maya, Rhino and Autodesk's 3ds Max and VIZ.

Frank Gehry's architectural career has bursted free and innovative use of flexible but still controlled architecture and forms, such as in the Walt Disney Los Angeles concert hall or Bilbao's Guggenheim museum. The use of high-end CAD-tools, but also product collaboration tools have been an essential part of Gehry's way of working.

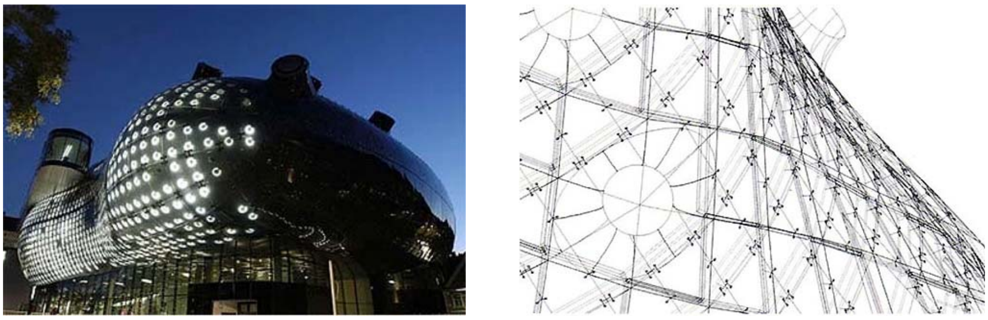
Since 2002 a high-tech consulting company and service provider Gehry Technologies has been distributing the developments done by Gehry for commercial platforms. Company's strategy has been the strong integration of design and manufacturing. They aim in bringing the co-operation proven in other, more high-tech oriented industries (aeroplane, automobile, naval) also to AEC-projects. The use and development of high-end ICT has been an essential part in the business strategy and networking principles of Gehry Technologies.

FIG. 13: Curved exterior walls of the Walt Disney concert hall in Los Angeles by Frank Gehry 2000.

6. SHORTENING THE PATH FROM DESIGN TO MANUFACTURING

Complex architectural forms and shapes make on-site building erection more complex, often unconventional, and surely innovative. Unfortunately it is also more expensive than erecting simple rectangular buildings. Design-CAD with computer-aided manufacturing tools has anyhow made it possible and much easier to produce free form geometrical architecture, as Branko Kolarevic states (Kolarevic 2001).

The high-end 3D-modelling and visualization used in complex-geometry construction projects has in its most enhanced cases had also a strong connection with current digital production technologies, such as building component prefabrication, the links from 3D-CAD-models to automated manufacturing (CAD/CAM) and computer-numerical-controlled production, CNC-tools. Kolarevic has also claimed, that digitally produced mass-customization and computerized production of building elements can even allow unique design objects to be produced almost as easily as mass-producing and duplicating similar objects.



FIGS. 14 and 15: Overall building shape and exterior detail from Graz arts house in Austria by Peter Cook & Colin Fournier 2003. Example of modern computer-presented architectural design, fluid free form "blobitecture". Images by Michael Rosenmann.

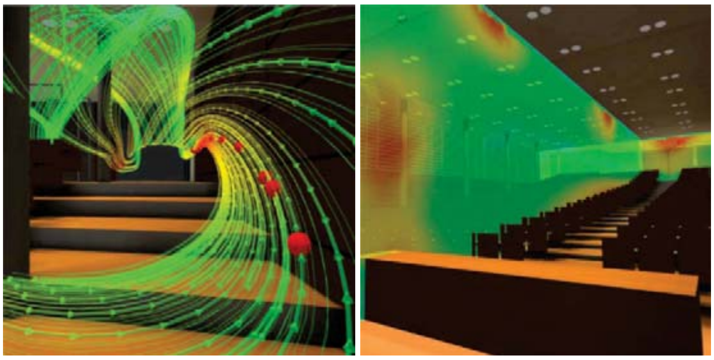
In several recent iconic architectural examples, such as those by Gehry, Lynn, Cook & Fournier, computerized design, form control and its close relation to the actual building production, has had a remarkable effect on architectural expression and final building appearance. It is quite obvious, that some of those mentioned landmark buildings could not even be possible to accomplish without the aid of relevant high-end CAD-tools' 3D-modelling features and modern digitized production technologies. On the other hand, this kind of free-form architectural expression may possibly not lead to mass-production nor wider distribution, due to its uniqueness, large amount of required design work and high degree of handwork in production, at least not during the coming decades.

7. COMPLEXITY OF THE DESIGN DOMAIN

When the factors of time and cost are connected to design and building information modelling, it has enabled the builders to manage on-site erection steps, simulate the building process and also analyzes the project's constructability better than before. Site activities have also gained from the latest evolution of modelling tools. For instance Graphisoft's new modelling and constructing tools enable the builders to model the building product and add resource-data to simulate the actual construction and also project economy.

In the Finnish ProIT-project the results of embedding product and production modelling on construction companies' on-site activities have been promising. The main advantages from 3...4...5D-modelling for the builders have been the increased accuracy in quantity take-offs, noticing the critical overlapping activities, a better general understanding of the project process and better visual control of the final designed and planned building product (Penttilä 2005).

Modelling can currently be used for various visualization needs of the same complex domain. Some examples are the changing user needs in the future, or analyzing the complex functionality of the domain. Some invisible features of the domain have also been accessed through 3D-modelling, such as modelling and simulating the air movement in a room caused by the air conditioning system (Savioja et al 2003). Also virtual acoustics and sound rendering have been recent advanced extensions in modelling the building functionality, hence, augmenting the applicable areas of the design discipline (Lokki et al 2002). Visual modelling has also been used in enhancing the understanding of the complexity of the design task. When describing several viewpoints of the task, some unnoticed but still essential things can be revealed.



FIGS. 16 and 17: Particle paths and air flow analysis from virtual CAD-models, HUT Hall 600 –project (Savioja et al 2003).

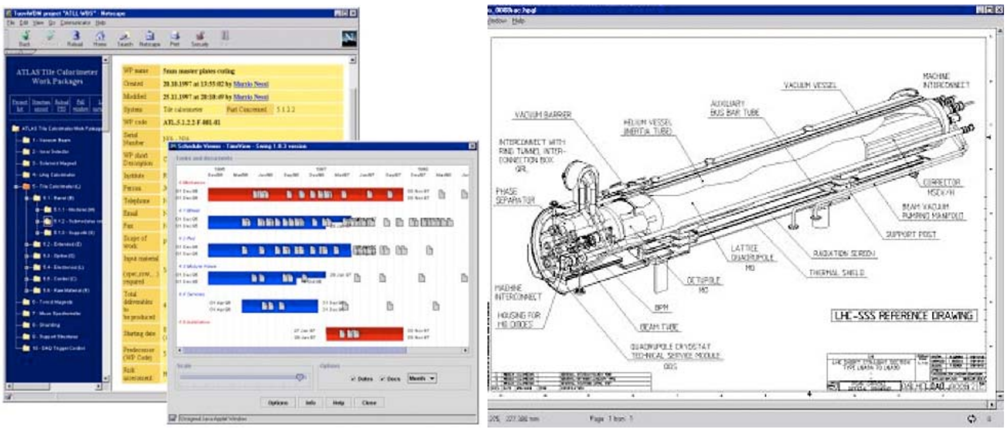
FIG. 18: Models to integrate visual and aural features. Pekka Salminen's Marienkirche concert hall renovation in Neubrandenburg, Germany 1996-2001. Visual combined with acoustic modelling, spatial characteristics can be simulated.

A CAD-systems' user interface has developed from early simple single-row menus to current complex and structured menu- and command combinations. Perhaps even too complex to be rational for novices and non-experienced CAD-users, insist some researchers (Stewczyk, Jakimowicz 2001). On the other hand the complex user interface of concurrent CAD-environments is also highly flexible. Current CAD-systems' functions, features and tools are often modifiable and even adaptable to various users' changing needs. The state of the art in high-end 3D-modelling has in some cases also lead to innovative new interface design issues. For instance voice and acoustics have become a noticeable feature of currently augmented reality interfaces (Lokki, Savioja, Väätäinen, Huopaniemi, Takala 2002) (Takala et al 1998).

8. FROM DRAWINGS TO INFORMATION MANAGEMENT

The tool aspect of CAD has always been strong within the context. CAD has developed from the earliest CAD-programs to current larger, more complex and naturally also more capable **CAD-systems,** or perhaps currently better called digital working environments. It has been proposed that the concept of CAD might even vanish, when it has been adopted by the majority of the designers. That era might be about now? Since CAD has often been regarded as a modern pen or "just a tool", those who underline this aspect, remind us wisely that the essential design wisdom will still be (mainly) in the designer’s brains, not in his hands nor in his computer.

Despite the limitations of our digital CAD-tools, users' abilities to manage architectural design information in a more complex and integrated way have been growing remarkably, thanks to CAD-tools' evolution. Concurrent CAD offers good methods to manage all the essential design data of a single designer, and also the integrated project data of the whole design team. The direction of the evolution has clearly been towards digital document management, sometimes also called *electronic document management (EDM)* or *project webs* (Björk & Hjelt 2006) (Liebich 2002) (Stouffs et al 2002) and building project banks which started to emerge in AEC during the late 1990s. Based on a Nordic barometer study, digital documents are currently the major method to store building information in digital form (Howard et al 2002). Since the architects have been using CAD to produce drawings since the 1980s, digital document management on a project scale is a natural step in the evolution of architectural ICT.



Figs 19 & 20. Views of a document management system (Kronodoc 2000), where project documentation is integrated with email-communication and project scheduling. CAD-drawings can be viewed with native software tools or Java applications.

9. BUILDING PRODUCT MODELLING

Building product modelling, product data modelling or *building information modelling* (BIM) is a methodology to manage the essential building design and project data in digital format throughout the building’s life-cycle. CAD-systems are elementary tools to create and manage building’s geometrical data in product models, but very essential to the methodology is, that there are also other better tools to analyze, operate and interfere with the common product model data. Lots of international efforts have been used lately to develop, test and adopt the IFC-data exchange format (industry foundation classes) to act as a common clever software-independent “data courier” between various AEC-field environments.

Elementary research on product modelling started in the late 1980s and the Finnish AEC industry is currently adopting the product modelling methodology into practice with accelerating speed (Fischer, Kam 2002). There has been a strong common national desire and 20 years of research efforts, first on the foundations of the product modelling methodology, and recently applied research to implement and test the product modelling methodology and finally adapt it into AEC-field practices (Penttila 2005).

When evaluating the current meaning of building product modelling, it is still a marginal phenomenon if measured in quantity and real project volume. Since the first product model pilot project *HUT Hall 600* in 2000-02 (Kam et al 2003), the number of “difficult” pilot projects, where product modelling and IFC-data exchange has been used and tested, can be estimated at 40 - 50 projects worldwide, 30 - 40 % of them carried out in Finland (Kiviniemi 2005b).

Company level commitment to product modelling is currently growing in Finland. One of the biggest builders Skanska aims to do 60 % of its own housing projects in 2006 with BIM, and their target is 100 % model-based in the own housing sector during 2007. Currently the personnel's capacity to learn new product modelling methods and skills, limits any quicker adoption of BIM, says Skanska. Another remarkable AEC player in Finland, originally the state-owned Senaatti Properties is the biggest public-sector contructor and FM-developer. Senaatti has also recently publicly announced its strategy to develop its processes towards building product modelling. As a property owner, their role as a trend-setter is very important for Finnish construction.

Based on membership of *IAI* (International Alliance of Interoperability, http://www.iai-international.org), the organization that develops and distributes information about building product modelling and also the IFC-standard, there has been a noticeable interest in BIM in the Nordic countries Finland, Norway and Denmark, Japan, Germany, France, UK, North-America, Australia, Singapore, Italy, and lately also China has showed growing interest in the area (Kiviniemi 2005b).

10. PRODUCT MODELLING AS AN ESSENTIAL PART OF BUSINESS STRATEGY

Several companies have taken advanced model-based technologies as an essential core for their business stategy. Of Finnish examples *Tekla* has developed product model based CAD-tools and technology for structural engineering (Tekla Structures) and also for the municipal sector. Also *Vertex/Argos* has distributed their integrated model-based CAD and product tools for years.

Another example of high-end tools and enhanced technology clearly as a part of the company's business stategy, is a Finnish building services design and facility management consultant *Granlund*. They offer services which cover the whole building's life-cycle, based on the core idea of building product modelling methodology. They also develop and sell a series of ICT-products based on the methodology, such as Ryhti - facility management tool and Riuska – thermal & energy simulation tool. Both "ryhti" and "riuska" are equivalents for firmness, solidness and "fair play" in Finnish. Granlund has developed BSPro-software together with some other US-based institutions (AEA Technology, National Institute of Standards and Technology NIST and Lawrence Berkeley National Laboratory LBNL) for combining several different CAD-models, visualization information, analysis and simulation with IFC-standard. Quite similar to BSPro-software is also another software tool *Solibri* Model Checker, which allows the user to combine several 3D-models, view their contents and analyze modelling on a product model basis.

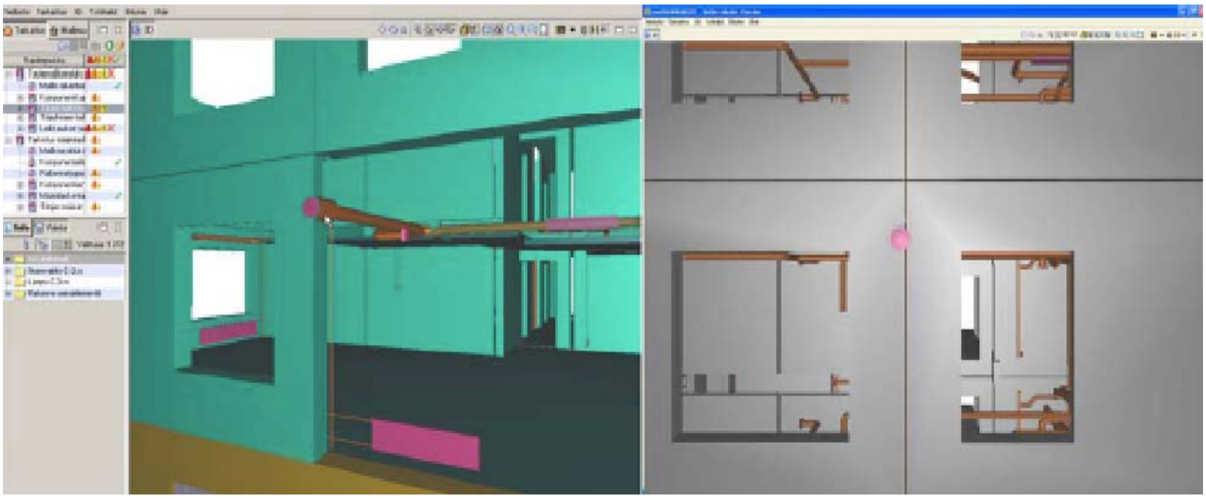


FIG. 21: Product model based concrete element and HVAC-models are combined with Solibri Model Checker. Rule-based cross-checking shows that ventilation ducts interfere with concrete element joints (Sulankivi 2005).

11. CONCLUSIONS

When evaluating the CAD-systems' overall effects on architectural design, not only *design-CAD*, but the widest understanding of digital *information and communication technologies (ICT)* should be considered. CAD on its side, has expanded the architects' ability to control designed building geometry both in spatial dimensions throughout the building life cycle, but also in "flat" production drawings. Not only orthogonal slabs and walls, but also more freely expressed curved forms can be modelled with contemporary CAD-tools. CAD can be said to manage the overall control of the building geometry, in whatever architectural form it is expressed.

Along with the extensive use of CAD, the architect's ability to manage more design representations - drawings, schemas, diagrams, modelling techniques - at the same time has been enhanced (Achten, van Leeuwen 2001). Conceptually more complex architectural expressions can also be managed in current project environments.

Information and communication technologies have in general expanded, not only the designers but also the builders' possibilities to manage more complex design and construction projects, in terms of geometry, digital data, document and schedule management. Again, ICT has enabled, or at least made it possible, to achieve the overall control of both the design and construction processes.

The *changes* in ICT-tools, methods and also CAD-development can be analyzed from two different viewpoints: company and project. From a company-viewpoint ICT can, and has been used to rationalize the company's own information and data management internally. As shown, high-tech tools and modelling can also be a profitable strategic decision.

Despite the economy-driven needs in current construction, also free irrational and individual artistic experiences and non-conventional use of the contemporary technology & tools should be allowed and perhaps even promoted, to maintain and strengthen *design richness and creativity* in the future. The design flexibility and independence of any fixed design formalisms are important quidelines, which should be noticed in future development towards even more complex, but also architecturally richer buildings, built environments and better driven projects.

If and when CAD-systems and enhanced design data management is not used just for rationalizing the design process, but also architectural richness issues are regarded important, ICT can obviously also enhance the architectural design quality. If richness and complexity of the design can be connected with the designer's creativity, it may finally lead also to something called "better architectural quality". Not to forget that in good design, proper design management, wide understanding of the context and clear will to do things better, is always required – not just clever technical superiority or excellence or not just advanced or smart tools.

From a *project aspect* ICT has been used to rationalize and develop building processes and product data management. In Finland this has expanded from projects to even wider, national R&D-efforts (RATAS, Vera, ProIT). The (mega)trend where CAD-systems are seen developing from early designer's drawing tools towards current integrated and model based working environments, is an evolutionary process within AEC-field ICT towards more complex information and project structures.

Buildings of our current digital era are said to be more complex by information structure than buildings of industrial modernism, dating back to 1930 - 70's (Mitchell 2005). This gives us more requirements and sets new needs to manage all the building related information of our time. William Mitchell's proposal to measure and analyze the growing complexity for instance from design decisions made during the creative process may be promising. If some kind of "project complexity factor" could also be added to proposed architectural complexity, the analysis would have deeper coverage also in pragmatic building projects.

Building product modelling may well be one of the major trends to manage complex building projects in an integrated way in the near future. Since CAD-systems have been very essential tools to produce and maintain the geometry-based building data throughout this described evolution, the management of current building activity with concurrent design and engineering is not even possible without CAD-tools any more.

The domain of CAD has expanded from designers tables also to construction companies, actual building environments and (pre)manufacturing of building components. In integrated visions building information modelling aims at life-cycle data management. When CAD is flexibly integrated with BIM, it allows concurrent design & engineering, without losing coordination, hence, it leads to shortened project spans and savings (=less money). This may explain the current interest of construction companies on CAD, 3D-modelling and also product modelling.

In a building project it would be most efficient to clarify the client requirements for the building in the earliest design phases where the project owner usually collects and defines the most essential project facts and starting points together with an architect (Kiviniemi 2005a). Unfortunately it is usually not possible to connect these requirements to actual design solutions as the design process proceeds, as Kiviniemi says. Though, there is potential in our contemporary technologies to manage and maintain the original client needs through the design process and even include that in design documentation. There is development and application potential to map building information management and information modelling better to the client's and project owner's interests. High-end ICT and product modelling seems currently to offer valuable controlling features and analysis tools which are suitable for designers, builders, project managers, building owners and maintenance parties - not to forget rich architectural design content and it's values.

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