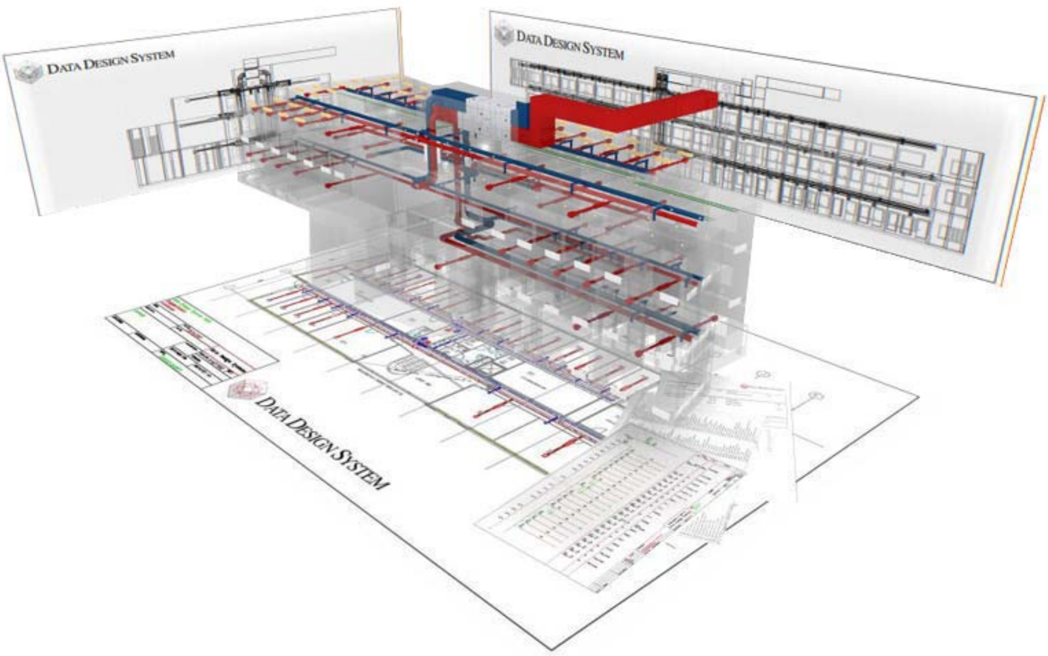
THE 4TH DIMENSION OF MODELLING

An Analysis of Energy Conservation Tools in Computer Aided Design and Modelling



Holger de Groot

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An Analysis of Energy Conservation Tools in Computer Aided Design and Modelling

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“We know that the white man does not understand our ways. He is a stranger who comes in the night and takes from the land whatever he needs. The earth is not his friend, but his enemy, and when he’s conquered it he moves on. He kidnaps the earth from his children. His appetite will devour the earth and leave behind a desert. If all the beasts were gone, we could die from a great loneliness of the spirit, for whatever happens to the beasts happens to us. All things are connected. Whatever befalls the Earth, befalls the children of the Earth."

American Indian Chief Seattle[1]

[1] James Wines, *Green architecture*. Köln, London: Taschen, 2000, p.35.

ABSTRACT

The Global warming effect is becoming the biggest challenge of the 21st century. In this context, it will be necessary to radically reduce the emission of green house gasses, by using technology, which already exists and will be developed further in the future. “Today’s problems come from yesterday’s solutions”,[1] choices of energy and material sources during the design process will be the key factor in bringing a higher responsibility to the Architects.

Today, “Computer Aided Design” (CAD) and modelling are the standard tools in architectural firms. Models are a visual aid in the presentation of buildings and projects to clients and making the construction understandable as a visual concept. However, the next evolution in architecture will not be the design field, but it will be the field of techniques and solutions that will be used to make a building future proof. Thermal insulation, solar energy, water catchment systems, recycled and renewable materials are only a few examples of these developments. This would become the 4th dimension of the 3D model and it will become possible that the effects of all these solutions can be viewed.

The aim of this research paper is to determine if it is possible to bring these new techniques of energy conservation into a CAD application. Would it be possible to translate these considerations into a computer based model to be viewed by clients or customers? It will be helpful to present problems and solutions in a construction model of a new building. This kind of model could present specific problems and effects, which may can meet the global warming effect.

This research paper explores a few examples of new software tools, like “Building Information Modelling” and “Life Cycle Assessment”. The report identifies how these tools can be helpful to make the right choice to the right time to save energy, material resources and to reduce the environmental impacts. The report proclaims the current problems for architectural firms and their staff members. It tries to show against the current view of several architects and architectural writers that these new programs and software tools are actually evolved enough to be implemented into a “Computer Aided Design” application. This research paper comes to the conclusion that architects and engineers can get a wide range of new possibilities through the potential of these new software tools. Finally, these possibilities can be used to reduce the wasting of energy and material resources.

1 Peter Senge, “Unhealthy energy conservation practices”, in *The green braid: towards an architecture of ecology, economy and equity*, ed. Kim Tanzer and Rafael Longoria, New York, NY, Routledge, 2007, p.153

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ABBREVIATIONS

AEC	Architecture, Engineering and Construction
AIA	American Institute of Architects
BIM	Building Information Modelling
CA	Cellular Automaton
CAAD	Computer Aided Architectural Design
CAD	Computer Aided Design
CAVE	Computer Assisted Virtual Environment
CIFE	Centre for Integrated Facility Engineering
DALYs	Disability Adjusted Life Years
GCs	General Contractors
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technology
InGaP	Indium-Gallium-Phosphide
ISO	International Organisation for Standardisation
LCA	Life Cycle Assessment
mc-Si	Multicrystalline Silicon
m/e/p	Mechanical, Electrical and Plumbing Systems
NBIMS	National Standard for Building Information Modelling
NIBS	National Institute of Building Sciences
PV	Photovoltaic
UCLA	University of California, Los Angeles
WDI	Walt Disney Imagineering

INTRODUCTION

A particular interest in the context of architecture and the climate changes being faced today have inspired this research into the development of new construction and design software in relation to global warming. If a new program and software tool would be implied into a CAD application, it can offer new possibilities to solve problems in this context. The scope and the goals of this research paper are to determine these possibilities to reduce the wasting of energy and material during a design and construction process. It needs to be asked, how it would be possible to translate these considerations into a computer based model that presents specific problems and effects, which may impact global warming, and can be viewed by clients or customers.

Architecture is one of the most powerful reflections of civilisation, but it seems that the societies lost contact to the earth in terms of green architecture during the last century. The opportunities for a reversal of this trend are given to the political expedience. Governments are starting to admit the bigness of environmental destruction, but it needs to be done more in this case as to think about the problems, it needs solutions.[1] Now, that global warming is confirmed fact and not just only a controversial theory, the international business and government communities are holding a series of urgent conferences to seek global remedies.

This research is focused on the use of computer programs in architecture, which are giving new possibilities in design and construction. During the last years, computers have come from a decentre position in design to take a central position in the process. In the beginning of 2002, computers have become essential to the communication of design and in the investigation and generation of structure, form and composition.[2] The rising number of possibilities in representation that software let the user manipulate offers the opportunity to take design to a higher level. For example, this higher level would be a result of the mergence of more than 3 dimensions in a construction and design process. This kind of a 4D model would include all physical information of a building or project. The essence of software is to represent problems abstractly through the use of variables, conditionals, iterations and

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[1] James Wines, *Green architecture*, Köln, London: Taschen, 2000, p.35.

[2] Mao-Lin Chiu, Jin-Yeu Tsou, Thomas Kvan, Mitsuo Morozumi and Tay-Sheng Jeng, *Digital design: research and practice: proceedings of the 10th International Conference on Computer Aided Architectural Design Futures*, Dordrecht, Boston, London, Kluwer Academic Publishers, 2003, p.ix.

procedures.[3] Computer programs and tools can help now to find new solutions and answers to match the global warming effect in the architectural design and construction field.

Research for this paper has been primarily archival. Literature, articles and records of several "International Computer Aided Architectural Design Conferences" are held at the library of the University of Auckland. Online media searches have also been successful, as personal discussions with self-employed architects of New Zealand and Germany. Secondary sources have provided information about products and techniques which are new on the market. The Referencing is achieved by using the "Vancouver Method", which is also known as the "Sequential Numbering Method".

The research paper itself is presented in three parts. Part one comprises one chapter which considers a literature review by looking at the history of simulation tool development, design methodology research and the practise of innovative firms.

Part two contains the analysis of new computer programs and tools in three chapters. Chapter one addresses "Building Information Modelling", or BIM, that is an object oriented digital representation of a building which describes the functional and physical aspects of a building and its components. Chapter two considers "Life Cycle Assessment", or LCA, that is a methodology to assess environmental performance of buildings. It focuses on potential, predicted contributions to regional and global impact categories and presents the result as impacts aggregated globally and over time.[4] Chapter three is about the education and the transfer of these new kinds of techniques and software tools in the daily practice of an architect and engineer.

Part three contains the over all conclusion which is presenting the final results, the facts and the outcome of this research report.

[3] Malcolm McCullough. "20 Years of Scripted Space", in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*, London, England: Wiley-Academy, 2006, pp.12-15

[4] Arjen Meijer, *Improvement of the life cycle assessment methodology for dwellings*, Delft, England: U Pr, NE, 2006, p.5

1. COMPUTER AIDED DESIGN AND MODELLING

This chapter includes background information on the history of computer tool and software development to date and explores the gaps of knowledge in this area. A second part of this chapter is a literature review that describes the main source of literature, which was important for the research process of this paper.

1.1. THE BEGINNING OF THE DESIGN SOFTWARE MARKET

Form is the physical formation of objects and spaces that they fit the function and the context of the design project. Yehuda E. Kalay, Professor of Architecture at the University of California, writes that the creation of form should be the ultimate objective of architectural design.[1] She explains that there is a direct causal relationship between software tool development and architectural possibilities, like Louis Sullivan's famous proclamation "form follows function". It needs to develop the function, which would be in this case, a new software tool or a program. If the "function" is available it provides the possibility to develop a new form, in terms of a new kind of building.

The first architects to use computers were interested primarily in maximising the efficiency of conventional modes of production. The Designers, who worked on the World's Fair in 1964, used a primitive calculating machine to build the Unisphere and around the same time Eero Saarinen engineered the complex reinforced concrete shells of his TWA terminal. During the 1980s, as computers became cheaper and more readily available, many architectural practices employed the first automated systems for drafting construction documents.[2]

Christopher Alexander, Emeritus Professor of Architecture at the University of California, is widely recognised as the father of the pattern language movement in computer science. His idea of a pattern language had an influence in the 1960s and 1970s on programming language design, modular programming, object-oriented programming, software engineering and other design methodologies where patterns have been used to document collective knowledge in the field. He was one of the authors, who published the book "*A Pattern Language: Towns, Buildings, Construction*" in 1977. His book describes a practical architectural system in a form that a computer scientist might call a generative grammar. This

[1] Yehuda E. Kalay, *Architecture's new media: Principles, theories, and methods of computer-aided design*, Cambridge, Mass, MIT Press, 2004, p.223.

[2] Mike Silver, "Towards a Programming Culture in the Design Arts", in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*. London, England: Wiley-Academy, 2006, pp.8-11.

generative grammar is able to generate a boundless number of strings from a bounded set of rules. This book inspired the design pattern movement in the software industry. In 1986, “AutoCAD” was the first of the Computer Aided Design programs to record command line sequences of its drawing operations.[3] Finally, it was a significant year in terms of today’s interest in scripting, because “Autodesk” took over the personal computer design software market.

1.2. COMPUTER AIDED DESIGN AND INFORMATION MODELLING

Computer aided design programs were the first type of programs, which architects could use to save time and to complete a project without drawing blueprints. “Computer Aided Architectural Design”, or CAAD, was developed as a special class of software after CAD could no longer offer all that kind of drawing tools, which architects needed to complete a project. “Computer Aided Design” and “Computer Aided Architectural Design” systems employ a database with geometric and other properties of objects. All of them are concerned with assembling designs from standard and non-standard pieces, but the main difference lies in the domain knowledge, which is embedded in the design software. “Computer Aided Architectural Design” has two different systems in its program. The first is surface structure, which offers graphics to represent three dimensional objects using two dimensional representations. The second system is deep structure, which means that the operations performed by the computer have natural limitations. Programs like “3D-Studio Max”, which are developed for the computer animation industry, are also used in architectural design and can be seen as an example. However, it is not always clear what belongs to CAAD proper. It is perhaps surprising that “Computer Aided Architectural Design”, or CAAD, still means “Computer Aided Design”, or CAD, too many, who are actually involved in architectural design and construction.[4]

“Computer Aided Architectural Design” is a particularly dynamic field that is developing through the actions of architects, software developers, researchers, technologists, and users. CAAD tools in the architectural office are no longer outsiders, but have become important tools for all professionals in the design field. At the same time, techniques and tools from other fields and uses are entering the field of architectural design. This is exemplified by the tendency to speak of “Information and Communication Technology”, or ICT, as a field in which “Computer Aided Architectural Design” is embedded. Exciting new combinations are

[3] Malcolm McCullough, “20 Years of Scripted Space”, in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*. London, England: Wiley-Academy, 2006, pp.12-15.

[4] Mark Burry, “Digitally Sponsored Convergence of Design Education Research and Practise”, in Bob Martens (ed.), André Brown (ed.), *Computer aided architectural design futures 2005: proceedings of the 11th International CAAD Futures Conference held at the Vienna University of Technology, Vienna, Austria, June 20-22, 2005*. Dordrecht: Springer, 2005, p.3.

still possible for those, who are familiar with architectural design and have a clear visions of the potential use of “Information and Communication Technology”.[5]

One of these new potential tools is “Building Information Modelling”. The term “Building Information Modelling”, or BIM, was coined by Autodesk to describe 3D and specific computer aided design software for “Architecture, Engineering and Construction”, or AEC. Building simulation itself started to stand out as a separate discipline in the late 1970s. It has since matured into a field that offers methods and software tools for building performance evaluation. It models the physical behaviour of as-designed, as-built and as-operated facilities. Over all, discussions are now no longer about software features, but on the use and integration of simulation in building life cycle processes. Realistic part solutions are proposed and tested as seen in the following chapters and paragraphs of this research paper.[6]

1.3. DETERMINE ENVIRONMENTAL IMPACTS DURING THE DESIGN PROCESS

A second potential tool is “Life Cycle Assessment”, or LCA. Life cycle assessment is a suitable technique to determine the environmental impact of the sub processes in production processes, even in an early stage of product development. When applying life cycle assessment to product development, the goal of the life cycle assessment can be twofold. The first goal is to determine whether it is useful to continue the further development from an environmental point of view. This will not be the case if the estimated environmental impact of the product that is under development is one or more orders of magnitude higher than that of competing existing products. In that case, it is improbable that at the end of the development of the new product, the environmental impacts of the competing products are in the same range, and the appropriate action would be to stop with the development of the product. The second goal of the life cycle assessment is to determine where in the production process the most important environmental impacts occur, in order to focus on the improvement of the sub processes involved.[7]

[5] Bob Martens and André Brown, *Computer aided architectural design futures 2005: proceedings of the 11th International CAAD Futures Conference held at the Vienna University of Technology, Vienna, Austria, June 20-22*, 2005. Dordrecht: Springer, 2005, p.xi.

[6] Ali Malkawi and Godfried Augenbroe, “Introduction and overview of field” in *Advanced building simulation*. London, New York: Spon, 2004, p1.

[7] Arjen Meijer, *Improvement of the life cycle assessment methodology for dwellings*. Delft, England: U Pr, NE, 2006, p.85.

1.4. NEW STANDARDS IN EDUCATION AND DRAWING

In 1989, Harvard introduced the first programming course required for all professional degree candidates in a leading school of architecture. The software basis for this initiative was a program that was called "TopDown" and was written mainly by the University of California, Los Angeles (UCLA), by Robin Liggett and William Mitchell. "TopDown" provided a visual and dynamic way to combine substitution and dimensional variations on a compositional subject. It involved in the order of 20 lines of Pascal code to make an artefact in the program.[8] Since this significant date, computers have dramatically changed the way of architectural design and construction, which gets a diverse mix of different materials. This process is often supplemented by hand, using both traditional and non-traditional materials. This problem is still plaguing the industry that many in this field are not sync with the current technology.[9] Architects and engineers have still to educate themselves to the issues as some state and local regulations have forced the use of new technologies.[10]

"*You write a few lines of code and suddenly life is better for a hundred million people.*"

Charles Simonyi, inventor of Microsoft Word [11]

In computer aided design intelligent tools, which forward the process of product design are getting more influence in these terms. CAD tools become more specialised and the knowledge about it is becoming an essential importance. The record of that knowledge in databases as application of these bases together with CAD systems enables intelligent aid in product design.[12] Generally available "Computer Aided Design Systems" are not able to integrate resources that are used by a designer and therefore there are concepts of aiding the process at that stage by using for example personalised integrated aiding programs integrated with interface with CAD systems. These systems allow each designer to gather their personal experience.[13] Programming in architecture becomes now a much more open process. This process is inspired by capacity to generate new and unprecedented modes of expression. For many architects coding is becoming the formal and operative focus of building itself and programming itself becomes the new drawing.[14]

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[8] Malcolm McCullough, 2006, p.14.

[9] Mike Silver, "Building Without Drawings: Automason Ver 1.0", in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*. London, England: Wiley-Academy, 2006, p.47.

[10] Russell Fortmeyer, "When less powers more", in *Architectural record*, v.194, n.12, 2006, p.166.

[11] Mike Silver, 2006, p.8.

[12] W. Skarka, "Integration of product life cycle knowledge in CAD" in Ziga Turk (ed.), Raimar Scherer (ed.), *eWork and eBusiness in architecture, engineering and construction: proceedings of the fourth European Conference on Product and Process Modelling in the Building and Related Industries Portoroz, Slovenia, 9-11 September 2002*. Lisse, Netherlands, A.A. Balkema, 2002, p.421.

[13] W. Skarka, 2002, p.421.

[14] Mike Silver, 2006, p.11.

1.5. LITERATURE REVIEW

Mike Silver, studio instructor at Harvard's Graduate School of Design and faculty member at Pratt Institute, holds a master in building design from the University of Columbia. In the article "Towards a Programming Culture in the Design Arts" in *Programming cultures: art and architecture in the age of software* (2006), Silver characterises the flexible language of commands and logical procedures of computers. Silver explains that this creative potential has until now been undervalued in the range of architecture and that the focus on programming new code promises modes of expression.[15] In a second article "Without Drawings: Automason Ver 1.0" in *Programming cultures: art and architecture in the age of software* (2006), Silver shows that technological innovation in architecture has been focused around the intersection of computer aided design for the most part. He presents his own investigation into projects that employs a cellular automaton, or CA, program for conveying design data directly on site.[16]

Once visual modelling was only used by researchers and in niche industries. Tools like 3D and 4D computer aided design and virtual reality are now in widespread use in construction. Martin Fischer, John Haymaker and Kathleen Liston from the Stanford University in California (USA), have formed a research team that has tested the usefulness of visual 4D models in planning the construction of several projects. They published the results and findings in the report "Benefits of 3D and 4D models for facility managers and AEC service providers" in *4D CAD and visualization in construction: developments and applications* (2003).[17] Their paper presents an extensive list of benefits users of "Building Information Modelling", or BIM, which is given in chapter 2.4. That list illustrates how current business practices and project delivery approaches allow, or do not allow, facility owners to reap these benefits.

Joann Gonchar proclaims in her article "Transformative tools start to take hold", in *Architectural record* (2006), that one of the main challenges in "Building Information Modelling" is the lack of standards for the organisation and format of the data contained within models. Joann Gonchar is an editor from *Architectural record* and member of the "American Institute of Architects", or AIA. She claims that a critical mass of building information modelling projects demonstrates the technology benefits and its potential for redefining practise. She comes to the point that the building information modelling technology

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[15] Mike Silver, 2006, pp.46-51.
[16] Mike Silver, 2006, pp.5-11.
[17] Martin Fischer, John Haymaker, and Kathleen Liston, "Benefits of 3D and 4D models for facility managers and AEC service providers" in Raja R.A. Issa (ed.), Ian Flood (ed.), William J. O'Brien (ed.), *4D CAD and visualization in construction: developments and applications*. Lisse, Abingdon, Exton: A.A. Balkema, 2003, pp.1-32.

is redefining the culture, hierarchies and the work flow in architectural firms.[18] For architects and consultants, the most exciting aspects of building information modelling would be the technology's potential to collapse separate activities, such as design, analysis and documentation, into one.[19]

Another important reading in this context is an article from Malcolm McCullough in *Programming cultures: art and architecture in the age of software* (2006). McCullough was the first architecture product manager for Autodesk from 1985 to 1986 and is called the "Veteran of architectural programming". He asserts in the article "20 Years of Scripted Space", that "Once the design world has been set up, it still needs to be explored, played and mastered with finesse." This article gives a look through the history of "Computer Aided Design" in the beginning of the 1990s and makes up the point that the next logical development in architectural drawing and programming would be the mergence. With the visual interfaces of better software today and the right process mindset, the user does not know when he is coding. The trick would be to see patterns and to find the free play within the structures of them.[20]

Arjen Meijer from the University of Technology in Delft (Netherlands) takes a closer look in the thesis of his dissertation "*Improvement of the life cycle assessment methodology for dwellings*", (2006), on damage to the health of occupants caused by emissions from building materials and local traffic in the "Life Cycle Assessment", or LCA, methodology for dwellings. The study determined the effects of several options for improving the environmental performance, for example, of different types of solar panels, reduction of energy consumption or air quality impact of local traffic.[21] His publication was important for chapter 3 that explores life cycle assessment as an active tool to reduce the level of environmental impacts during the construction phase.

Gehry Technologies was founded in 2002 as an independent organisation dedicated to the business of technological innovation and the development of architectural software tools. During the research process of this paper, Gehry Technologies comes up in many articles and book chapters as an important example that represents a new organisational model in the spectrum of building practise. Dennis R. Shelden is currently the chief technology officer at Gehry Technologies and he discusses in the article "Tectonics, Economics and the Reconfiguration of Practice: The case of process change by digital means" (2006) in

[18] Joann Gonchar, "Transformative tools start to take hold", *Architectural record*, v.195, n.4, 2007, pp.155-158, p.160.
[19] Joann Gonchar, 2007, p.162.
[20] Malcolm McCullough, 2006. pp.12-15.
[21] Arjen Meijer, 2006.

Programming cultures: art and architecture in the age of software, the implications on technological tools and organisational processes for designers and the building business. Dennis R. Shelden explains the potential of process reconfiguration and the reposition of design in context to Gehry Technology as an example.[22] Gehry Technologies is taken as an example in chapter 4 of this research paper, to show how firms have invested in the training and education of staff members and in new technology and construction tools. The article by Dennis R. Shelden shows how important modelling and simulation skills really are, if these skills get involved enough in the building design and operation process today.

1.6. CONCLUSION

This chapter shows that new construction tools, like “Building Information Modelling” and “Life Cycle Assessment”, are focused on the developing of new possibilities in construction and design. These benefits and their potential for the whole architectural business are explored in the following chapters two and three.

In the field of education it is indicated that not many architectural firms have started to invest in the training and in new software tools. However, the potential of process reconfiguration itself is large[23] and it seems that software development becomes an integral part of the building design process.[24] This development is subject of chapter four.

The chapter shows that new construction tools and skills can be helpful to perform the usage of energy and material resources. These new software tools have a high potential that offers a long list off positive affects and possibilities to the user. These tools and skills are also forcing changes and offering to establish new possibilities in terms of construction and design to match the problem of global warming.

[22] Dennis R. Shelden, “Tectonics, Economics and the Reconfiguration of Practice: The Case of Process Change by Digital Means”, in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*. London, England: Wiley-Academy, 2006. pp.82-87.
[23] Dennis R. Shelden, 2006, p.87.
[24] Mike Silver, 2006, p.11.

2. BUILDING INFORMATION MODELLING

This chapter explores the consideration to “Building Information Modelling”, or BIM. Building information modelling is an object oriented digital representation of a building. It is a compilation of integrated and dynamic data that describes the functional and physical aspects of a building and its components. This model can include information such as the dimensions and structural characteristics of beams, the fire rating of partitions or the warranties of mechanical equipment.[1]

The aim of this chapter is to explore if “Building Information Modelling” would be a construction tool that has enough potential to be helpful to perform the usage of resources during the construction and design phase.

2.1. BUILDING SIMULATION TO PERFORM THE USE OF ENERGY, MATERIAL AND TIME

Models have been used for centuries to explain what is to be built. Today, computer technology offers the possibility to build models in a digital environmental. The digitally enabled revolution promises to transform design and construction.[2] Never before in history, has it been possible to virtually construct a bridge or building one piece at a time and link to each step to a corresponding step on schedule.[3]

Now, at the heart of the new process is “Building Information Modelling”. Building information modelling can be used to demonstrate the entire building lifecycle that includes the processes of construction and facility operation. Some architects and consultants are still using building information modelling only within their own offices and distribute 2D background documents to other members of the team. On other projects, 3D models are shared with fabrications and constructors. Some contractors create their own building information models from their designers’ traditional computer aided design drawings. There are still benefits, even when only one member of a project team is working in a building information modelling environment.[4] It is decreasing the errors, which are made by the design and construction team and it reduces the time that is normally required to complete a building construction.

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[1] Joann Gonchar, “Transformative tools start to take hold”, in *Architectural record*, v.195, n.4, 2007, p.155.
[2] Joann Gonchar, 2007, p.155.
[3] Matthew Phair, “Foreword” in Raja R.A. Issa (ed.), Ian Flood (ed.), William J. O’Brien (ed.), *4D CAD and visualization in construction: developments and applications*, Lisse, Abingdon, Exton, A.A. Balkema, 2003, p.vii.
[4] Joann Gonchar, 2007, p.155.

Some sources say that if the industry embraces building information modelling, it would streamline the delivery process, ensure well coordinated documents, providing a basis for more accurate fabrication and construction. Designs would be more closely tied to structural analysis and energy simulations, producing better performing and higher quality facilities. In the conclusion, it means that these would be built more quickly and at lower cost than previously. Fewer claims and happier clients could be another result. Today, building information model can be used to evaluate glassing options, to perform daylight studies and energy analysis, as coordinating the structural, mechanical, electrical, plumbing (m/e/p) and architectural systems early in the construction document phase.[5] Architects and Engineers can work now with building information models, which provide the possibility to produce energy simulations, materials quantity analysis and construction scheduling. Some firms try to sell energy modelling now with all of their projects. They do this as an add-on service but that should become an industry standard to get a better result of energy conversation in the future.[6]

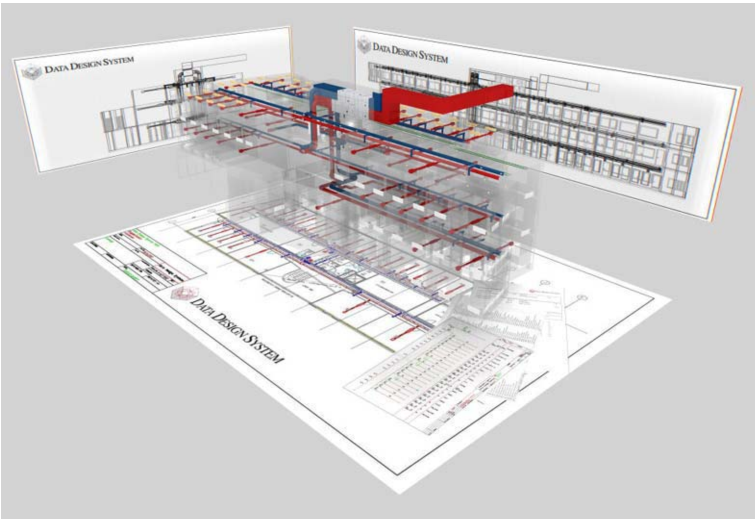

Plate 2.1
BIM model, which includes working drawings and technical building facilities

2.2. CONSTRUCTION FEEDBACK BEFORE BUILDING THE PROJECT

Traditional construction planning tools, like bar charts and network diagrams do not effectively represent and communicate the spatial and temporal aspects of construction schedules. They do not allow project managers to create schedule alternatives fast to find the best solution to build a special design or construction.[7] For example, often trades closely follow each other on a construction site. If they are not scheduled in a good way or if the

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[5] Joann Gonchar, 2007, pp.155-156.
[6] Russell Fortmeyer, “When less powers more”, in *Architectural record*, v.194, n.12, 2006, pp.165-166.
[7] Martin Fischer, John Haymaker and Kathleen Liston, “Benefits of 3D and 4D models for facility managers and AEC service providers” in Raja R.A. Issa (ed.), Ian Flood (ed.), William J. O’Brien (ed.), *4D CAD and visualization in construction: developments and applications*. Lisse, Abingdon, Exton: A.A. Balkema, 2003, pp.1-2.

production slows, follow contractors can be kept waiting, which means that they cannot work and will be unproductive. This is a typical situation, which is called “start-stop” fashion. This leads to a condition known as “trade stacking” where multiple trades follow each other closely and, if one trade fails through the final inspection, all trades are affected, which is finally a result of mistakes in the management.[8]

Extending the traditional planning tools, building information modelling is a combination of 3D CAD models with construction activities to display the progression of construction over time. 3D computer aided design is often seen mainly as a design tool. It should also be seen as a construction tool, since a detailed 3D CAD model mirrors the completed project in the computer. It offers a project team the possibility to practice the construction of a unique artefact virtually before building it in reality.[9] A detailed and well coordinated building information model allows firms to prefabricate directly from the model and improves material management. In this case, building information models enable project managers to allocate and use material resources more efficiently. 4D models extend the usefulness of design information to the construction planning and construction phases. If building information models are built during the design phase, they can help to provide constructability feedback to the design team and they can also help to set priorities for design work. The result, information about necessary material procurement and crew planning for the construction are available before the management even ask for it. In this way, 4D computer aided design models help project managers to manage the flow of work and the allocation of crews and space on construction sites better then ever before.[10]

Before a project team is starting to use building information modelling, they need to decide what problems they want to resolve through the use of this tool. It is difficult for a designer to know to what level of detail he should model a particular part of a project. They often do not draw directly from accurately detailed 3D models, which clearly show what needs to be build. Subcontractors, which are hired by the “General Contractor” (GC) to perform a specific task as part of the overall project, are very interested in having accurate and well coordinated detailed design information. They can leverage that information in material procurement and management, planning and scheduling. Building a 3D computer aided design model in this case leaves accountability for the correctness of the information in the 3D model with the firms, who are best equipped to leverage the investment in building information models. A Designer remains in charge of the overall design concept and a subcontractor can focus on

[8] William J. O’Brien, “4D CAD and dynamic resource planning for subcontractors: case study and issues” in Raja R.A. Issa (ed.), Ian Flood (ed.), William J. O’Brien (ed.), *4D CAD and visualization in construction: developments and applications*. Lisse, Abingdon, Exton: A.A. Balkema, 2003, p.105.

[9] Martin Fischer, John Haymaker and Kathleen Liston, 2003, pp.1-2.

[10] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.3.

streamlining the production of their part of the project. Deciding the scope of the model is also important as it affects the future use of the model in the long term management of the building.[11] For example, once the building is in operation the model can be useful as an active part of the facility management system.

Effective use of 3D and a building information model as a detailed construction tool has implications on the project delivery process, the output or deliverables of various parties and the processes and organisation of projects. The 3D model is to mirror the real project in details and the same organisations that build the project should build the model as well. The reason is that they have the biggest stake in the accuracy of the information in the model. It is also unrealistic to expect that a group of designers and modellers has all the expertise about construction details necessary for a detailed 3D model. The experience of the 4D research group at the "Centre for Integrated Facility Engineering" (CIFE) at Stanford University shows that including key subcontractors as design build firms from the beginning of a project makes detailed 3D modelling more efficient and effective than including them later.[12]

2.3. A BREAKDOWN OF TRADITIONAL HIERARCHICAL ROLES

One challenge facing designers, contractors and other users of "Building Information Modelling" is the lack of standards for the organization and format of the data contained within models. As Joann Gonchar writes, "We still depend on standards that are a legacy of drafting in 2D".[13] Organisations such as the "National Institute of Building Sciences" or NIBS, which wrote the first "National Standard for Building Information Modelling" (NBIMS) and the "International Alliance for Interoperability" are pushing hard on the issue. A particular focus of the "National Institute of Building Sciences" effort is post construction accessibility of the building information model so that it could be used by a variety of stakeholders, including insurers, first responders or facility managers. Also the effort of this standard can be offered to the building's end users and to be valuable to designers. The true payback of building information modelling is in the building's facility management phase. It is the longest and typically runs 50 to 75 years.[14] For example, a building owner may find evidence of a leak in his building one day. Before he needs to explore the physical building, he could turn to his building information model and could see that a water valve is located in the suspect location. The owner could also have the specific valve size, manufacturer, part number and any other information, which ever researched in the past in the model. The "American

[11] Martin Fischer, John Haymaker and Kathleen Liston, 2003, pp.1-3.
[12] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.3.
[13] Joann Gonchar, 2007, p.158.
[14] Joann Gonchar, 2007, pp.158-160.

Institute of Architects" (AIA) has further defined building information modelling "a model-based technology linked with a database of project information", that reflects the general reliance on database technology as the foundation.

One of the main barriers to adoption of "Building Information Modelling" is not the technology itself. The barrier is more the implications for changes in the relationship of all members of a project team. Building information modelling allows architects, their consultants, owners and contractors to share information and expertise more easily and earlier in the life of a building project. Within architecture firms, the technology forces changes in culture and work flow that finally brings a breakdown of traditional hierarchical roles to a much more granular lever where all team members are important.[15] This development of the relation between new software tools and its user, as the re-coordination of the design and construction process will be explored closer in chapter four. The result is that those designers have a better grasp of scheduling and build ability issues facing contractors. Finally, when contractors are more involved earlier in the process, build ability issues will be dealt with on screen or on paper, instead of in situ.[16]

2.4. BENEFITS OF BUILDING INFORMATION MODELLING

The use of building information modelling software is changing the work flow and the organisation process of a project. The result would be that the potential of this new planning and design tool brings a high number of benefits to the designer, the owners and the builders. For example, during the design process, building information modelling can decrease errors which are made by team members, by allowing the use of conflict detection. Through detailed computer visualisation of each part of the building, the computer informs the team members about parts of the building in conflict or clashing. This reduction of errors is a great part of cost savings and gets realised by all members of a project. There are several benefits through the use of building information modelling for each member of the construction process. The report "Benefits of 3D and 4D models for facility managers and AEC service providers" by Martin Fischer, John Haymaker, and Kathleen Liston from the Stanford University in California (USA) that was published in *4D CAD and visualization in construction: developments and applications* (2003), presents these benefits for each specific member within the construction and design process as seen in the following paragraphs.

[15] Joann Gonchar, 2007, pp.160-162.
[16] Matthew Phair, 2003, p.viii.

2.4.1 FOR DESIGNERS

A design documented with a 3D computer aided design model will have fewer errors and coordination issues because the construction of the model is by multiple designers in 3D, and is faster than with 2D drawings. One reason is that reviewers can more quickly understand the scope and status of the design of the project. Workshops participants of a case study, who have been using 3D models for several years, reported that after an initial learning curve, the overall design effort and design time is less than with a process using 2D drawings. They use 3D models even when the client asks for 2D drawings because design revisions are faster and need to be done only once instead of updating plans, sections, elevations and details. A further benefit is the potential to eliminate construction documents. On many projects subcontractors complete a new set of shop drawings, and in some cases subcontractors fabricate parts directly from the building information model with numerically controlled machines. 2D construction documents and shop drawings appear to be rather useless on a project where the design is documented and shared with a detailed 3D computer aided design model. Designers who are involved in projects that used building information models from design through construction reported that they saw an increased coordination effort during the design phase of the project followed by fewer requests for information during construction.[17]

2.4.2 FOR OWNERS

Owners are the ultimate beneficiaries of better performance by designers and builders from the use of building information models. Workshop participants reported in a case study, that owners can use 3D and 4D simulation models themselves to speed up, improve decision making and to involve many more stakeholders than traditionally possible. For example, “Walt Disney Imagineering” (WDI) was able to get the input from about 400 stakeholders during the two month pre bid design and construction schedule review for the “Paradise Pier” portion of “Disney’s California Adventure”. They were holding meetings with groups of eight to ten people at a time in their “Computer Assisted Virtual Environment” (CAVE). The groups could interactively review the proposed design and construction schedule from any perspective and they quickly understood the design, the schedule and the corresponding constraints.[18]

[17] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.5
[18] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.5

2.4.3 FOR BUILDERS

Participants at a workshop, who have labour risk on site, said that detailed 3D and 4D models increase the productivity of crew and that they help to eliminate wasted materials and resources. Even if all the other project team members work with 2D drawings many subcontractors still want to have a 3D model for their scope of work and for the related scope of work. If all the information is available, they can build the 3D and 4D CAD models to verify that no interferences exist and that they have all the information and materials available for the construction. If the information is not available to build a detailed 3D CAD model it is far cheaper for an engineer in the office to find out what exactly needs to be built than for a crew on the site. The building information models support automated quantity takeoff for material procurement to ensure that each crew has the appropriate amounts and types of materials for a day or a whole week.[19]

General Contractors (GCs) and subcontractors benefit from smooth, safe and productive site operations. That contributes to the shortest and most economical construction period. If subcontractor and GC work on the same site, the schedules of a 4D model can help the construction team to coordinate the flow of work and the space use on site. Sometime, contractors produce phasing drawings for a project. Typically, these are only produced in 2D and for a few places on the site in time, which makes it more likely that a potential interference between trades gets overlooked. Combining 3D models with schedules can automatically produce 3D phasing drawings at the daily, weekly or monthly level. It only depends on the level of detail in the schedule and the building information model. Contractors can see who is working on which place, at which part of the construction and how the work proceeds over time and through the site. 3D phasing drawings automatically reflect schedule updates.[20] Over all, most builders who work with 4D models and communicate schedules find it much more effectively than the abstract bar charts, which are still used on most projects.

2.5. CONCLUSION

This chapter shows that “Building Information Modelling” is a construction tool that is helpful to perform the usage of energy and material during the construction and design phase. It has a potential that offers a long list off positive affects and possibilities. For example, this planning tool can bring the design process more closely tied to structural analysis and energy simulations, producing better performing and higher quality facilities. In this case, these facilities can be built more quickly and at lower costs, which results in fewer claims.

[19] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.6
[20] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.6

The report indicates that Building information modelling can be used to evaluate glassing options, to perform daylight studies and energy analysis, as well as coordinating the structural and architectural systems. That includes also energy simulations, materials quantity analysis and construction scheduling.[21] A building information model allows firms to prefabricate directly from the model and improves material management that enables to allocate and to use material resources much more efficiently.[22] After all and once the building is in operation, the model is useful as a part of the facility management system that is the longest phase in the life-time of a building and typically 50 to 75 years.[23]

This chapter considers that building information modelling also forces changes in culture and work flow, which brings a breakdown of traditional hierarchical roles to a much more granular lever.[24] The construction of the model by multiple designers in 3D is also faster than with 2D drawings. A further benefit in this context is the potential to eliminate construction documents, which results in lower costs.[25] After all, the owners themselves can use 3D and 4D models to speed up and improve decision making and to involve many more stakeholders. Finally, building information models greatly increase the productivity of a crew and help to eliminate wasted materials and resources.[26]

[21] Joann Gonchar, 2007, p.155.
[22] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.3.
[23] Joann Gonchar, 2007, pp.158-160.
[24] Joann Gonchar, 2007, pp.160-162.
[25] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.5
[26] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.6

3. LIFE CYCLE ASSESSMENT

This chapter looks at "Life Cycle Assessment", or LCA, as another example of a new tool development. Life cycle assessment is an assessment of the environmental impact of a given product or building throughout its life-time. The goal and the scope of a life cycle assessment is to compare the environmental performance of a product or a building, to be able to choose the way of production, which includes the lowest scale of environmental impact.

This chapter explores how life cycle assessment can help the architect to make the right choices of energy and material resources during the design and construction process. In this case it needs to be asked, if life cycle assessment software can help to reduce the environmental impacts in a regional as in a global category as well.

During the research process it came up that it is difficult to find a literature resource that provides facts and information, which are more than only an introduction to life cycle assessment. Finally, the main literature that is used at this research paper is *Improvement of the life cycle assessment methodology for dwellings* (2006) by Arjen Meijer.

3.1. REDUCING ENVIRONMENTAL IMPACT THROUGH LIFE CYCLE ASSESSMENT

Life cycle assessment is a possibility to assess environmental performance of buildings. LCA is taking all points of the production process into account. These points, or units, are the raw materials, the energy and water consumption, the production itself and the waste and pollution, like air emissions, water discharges and solid waste. It is adding together all the unit processes in the right proportions to assemble the inventory. However, the inventory does not provide the final answer and it needs more than that.[1]

According to ISO standardisation guidelines, a LCA study can be divided into four different steps: the goal and scope, the inventory analysis, the impact assessment and the interpretation. In the goal and scope definition, the aim and the subject of a life cycle assessment study are determined and a "functional unit" is defined. An example of a functional unit is "the production of 1000 litres of tea" with, for instance, the aim to compare the environmental impacts of different types of electric kettle. In the inventory analysis, for each of the product systems considered, data is gathered for all the relevant processes involved in the life cycle. A product system can be considered as a combination of processes

[1] Tom Davies, Nigel Howard, *Life Cycle Assessment: Design Series*. Australia, Branz, 2007, p.16.

needed for the functioning of a product or service. In general, many processes (>1000) are shaped in the inventory. The result of the inventory analysis is a list of all extractions of resources and emissions of substances caused by the functional unit for every product system considered.[2]

In the impact assessment, it is first determined which impacts categories will be taken into account and which extractions and emissions contribute to these impact categories. Impact categories correspond with environmental problems, such as acidification and global warming. There are two types of impact assessment methodologies. The first one determines the impact category indicators at an intermediate position of the source impact pathway. An example of these midpoint indicators is the decrease of ozone in the stratosphere due to emissions of ozone depleting chemicals, which ultimately causes damage to human health and to the ecosystem. The second one determines the impact category indicators at a level of actual damages to the environment. These endpoint indicators can easily be interpreted for further weighting, thus reducing the number of damage categories. An example of these endpoint indicators is damage to human health expressed as "Disability Adjusted Life Years" (DALYs).[3]

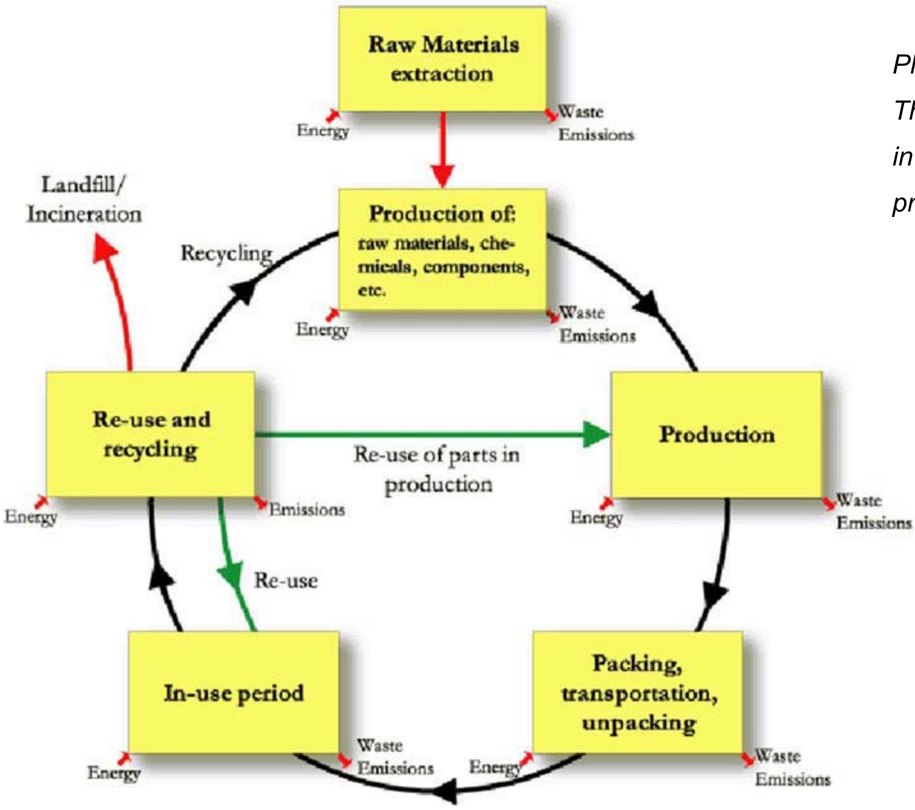

Plate 3.1
The environmental impacts in the different stages of a products life-cycle

[2] Arjen Meijer, "Environmental life cycle assessment" in Arjen Meijer (ed.), *Improvement of the life cycle assessment methodology for dwellings*. Delft, England: U Pr, NE, 2006, p.3.
[3] Arjen Meijer, 2006, p.3.

Next, the degree of the potential impact of individual substances within each impact category is determined. This is done by multiplying the inventory list of emissions to the environmental compartments air, water and soil and extractions with their corresponding characterisation factors. A characterisation factor represents the relative importance of the stressor to an impact category. The last phase in an LCA study is the interpretation of the results from the previous three steps, to draw conclusions and to formulate recommendations for somebody, who needs to make the decisions.[4]

3.2. INDOOR CLIMATE AND LIFE CYCLE ASSESSMENT

The general life cycle assessment methodology that standard assessments build on was developed by Udo de Haes and co-workers.[5] For buildings, there are several existing LCA tools for buildings environmental assessment, which are based on LCA available. However, these tools often do not, or poorly address, the indoor environment. “Indoor Climate Assessment” is addressed to these causes. It is a complete assessment of the use phase and the large time fraction that people spend inside buildings. It also implies that for measures to improve the indoor air quality, such as the application of balanced ventilation, the environmental impact due to increased material and energy consumption, should be reflected in the calculation. The beneficial effects of the measures on the occupants are not taken into account. [6]

Life cycle assessment focuses on potential, predicted contributions to regional and global impact categories, while indoor climate assessment focuses on actual health effects on a local indoor level. LCA presents the results as impacts aggregated globally and over time, while for example indoor climate assessment is specific or restrictive as to time and space. Furthermore, time dependent effects, such as decreasing emission rates from building materials, are difficult to implement in LCA. Therefore, only limited parts of indoor environmental issues can be addressed in building life cycle assessments.[7]

3.3. REDUCTION OF GLOBAL ENVIRONMENTAL IMPACTS

The use of conventional energy resources is still a major problem in terms of environmental damages. A wide range of alternatives, like passive and active solar hot water systems, the use of sustainable building materials and photovoltaic solar panels, are available and can actually reduce the environmental damage. The point is to find out, which one is the right choice for which project. Life cycle assessment can be a tool that helps to make the right

[4] Arjen Meijer, 2006, pp.3-4.
[5] Arjen Meijer, 2006, p.64.
[6] Arjen Meijer, 2006, pp.4-5.
[7] Arjen Meijer, 2006, pp.4-5.

decision in this case. For example, major environmental improvements can be realised by the introduction of photovoltaic (PV) cell technologies, but a lower environmental impact does not automatically imply, when the life cycle of a higher conversion efficiency of photovoltaic modules is taken into account. At the moment, the relatively high costs of current PV cell systems prevent large scale use of these technologies. New solar cell concepts have emerged recently, promising lower manufacturing costs and increased efficiency of the cell in the conversation of solar light into electricity. One example is the development of a high efficiency tandem solar cell consisting of a thin film indium-gallium-phosphide (InGaP) top cell mechanically stacked on a multicrystalline silicon (mc-Si) bottom cell. Although the intended efficiency of this tandem module ultimately is much higher (25%) than that of common mc-Si modules (<15%), this does not automatically imply that the application of InGaP/mc-SI tandem modules results in a lower energy consumption and a smaller environmental impact when production is included in the comparison. Environmental life cycle assessment is an appropriate way to assess the potential environmental impact of a product system. It evaluates product systems from "cradle-to-grave" and is relatively comprehensive in its coverage of environmental problems.[8] "Cradle-to-grave" itself describes the life cycle assessment of the materials which are used to produce the product, from the extraction of materials and energy to the return of the materials to earth, after the product is finally discarded.

Life cycle energy consumption is often used for the comparison of energy producing systems. A useful quantity to express this comparison is the energy payback time. In example, the amount of energy produced per year by that system. It may be noted that energy consumption contributes to abiotic resource depletion, one of the categories of the environmental impacts assessed by life cycle assessment. An additional advantage of studying energy payback times and environmental impacts using LCA is the possibility of identifying major contributors to energy consumption and negative environmental impacts. These can in turn be the objects of technological changes regarding production aimed at reduction of environmental impacts.[9] There are several disadvantages that must be kept in mind when applying life cycle assessment in a stage of the development process. As there is no experience with the production or the application of sub processes on an industrial scale, estimates based on expert judgement regarding material and energy consumption and production efficiency are necessary. Repeating the LCA during the further development process will result in an increased accuracy of the data.[10]

[8] Arjen Meijer, 2006, pp.81-82.
[9] Arjen Meijer, 2006, pp.81-82.
[10] Arjen Meijer, 2006, p.85.

3.4. CONCLUSION

The chapter shows that there is an operational availability of “Life Cycle Assessment” programs, which offer a high range of new possibilities through this software tool. In this case, it is disappointing to realise that there is actually not really a high quantity of literature available that gives more than an introduction on LCA-software. Over all, the publication by Arjen Meijer is the only literature recourse that has been found during the research process, which takes a closer look on life cycle assessment tools and describes the whole process of an LCA study.

In the conclusion it can be said that the environmental life cycle assessment is a possibility to assess the potential environmental impact of a product system or building process. Studying environmental impacts using life cycle assessment is the option to identify the major contributors to energy consumption and negative environmental impacts. These can be the objects of changes in the range of technologies regarding production aimed at reduction of environmental impacts.[11]

After all, life cycle assessment” is focused on potential, predicted contributions to regional and global impact categories and it presents the results as impacts aggregated globally and over time. There are several existing life cycle assessment” software tools for buildings environmental assessment available, which can be used to get the architect to make the right decisions at the time during the design and construction process.[12] Finally, these decisions make it possible to save energy and to eliminate the wasting of materials and resources during the design and construction process.

[11] Arjen Meijer, 2006, pp.81-82.
[12] Arjen Meijer, 2006, pp.4-5.

4. ARCHITECTURAL FIRMS AND CAD-TOOL DEVELOPMENT

This chapter shows the changes in using of technology tools and in the organisational processes for designers and the building business. Architects and engineers, whose knowledge depends on form, have started to adapt and extend generic software tools to their own specifics, but they do not use the new programs and tools to their full potential.[1]

The subject of this chapter is to discuss how firms have invested in the training and education of staff members, and in the range of new technology and construction tools to date. The scope is to show how important modelling and simulation skills really are in the building design and operation process today.

Chapter 4.2.1 and chapter 4.2.2 present "Gehry Technologies" as an example in context to architectural firms and CAD tool development. The background information for these chapters are based on the article "Tectonics, Economics and the Reconfiguration of Practice: The Case of Process Change by Digital Means" (2006) by Dennis R. Shelden in *Programming cultures: art and architecture in the age of software*. Shelden is currently the chief technology officer at Gehry Technologies.[2]

4.1. NOT EVOLVED ENOUGH TO USE THE TECHNOLOGY

While computers have dramatically changed the work of an architect, the design and construction process is still very much a diverse mix of different possibilities. It is often supplement by hand using both traditional and non-traditional materials. This problem is still plaguing the building and construction industry, that many in it are not in sync with the current technology.[3] A growing body of workers have a high knowledge in terms of computers, but they are beginners, at best, in the ways of construction. Side by side with a still significantly sized body of industry veterans that are have yet to embrace technology. Arguments can be made in support of delays to scattered adoption of "4D-Computer Aided Design" that the technology is not evolved enough for the architects and engineers, or that

[1] Malcolm McCullough, "20 Years of Scripted Space", in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*. London, England: Wiley-Academy, 2006, pp.12-15.

[2] Dennis R. Shelden, "Tectonics, Economics and the Reconfiguration of Practice: The Case of Process Change by Digital Means", in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*, London, England: Wiley-Academy, 2006, pp. 82-87.

[3] Mike Silver, "Building Without Drawings: Automason Ver 1.0", in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*. London, England: Wiley-Academy, 2006. p.47.

the architects and engineers are not evolved enough to use the technology.[4] Leon Glicksman, who is the director of the "Massachusetts Institute of Technology's Building Technology Program", describes this problem in education to perform the usage of energy:

"People usually fall back on what they did the last time, even if it's for a totally different climate. […] The Architect usually does his thing for a number of reasons, not including energy efficiency, and then throws the drawing over the transom to the engineer. Engineering shouldn't be the only thing that inspires design, but it should be toward the forefront."[5]

Those assertions are the continuing story of the architect's relationship with new computer software tools.[6] Architects and engineers have had to educate themselves to the issues as some state and local regulations have forced the use of new technologies. Not many firms itself have invested in the training and technology needed to efficiently implement energy modelling on projects. The result is that programs and software tools, which can help to perform energy models and the usage of energy, are not being used to their full potential.[7] As shown in plate 4.1, Leon Glicksman points out that buildings consume more energy than anything else, including automobile.

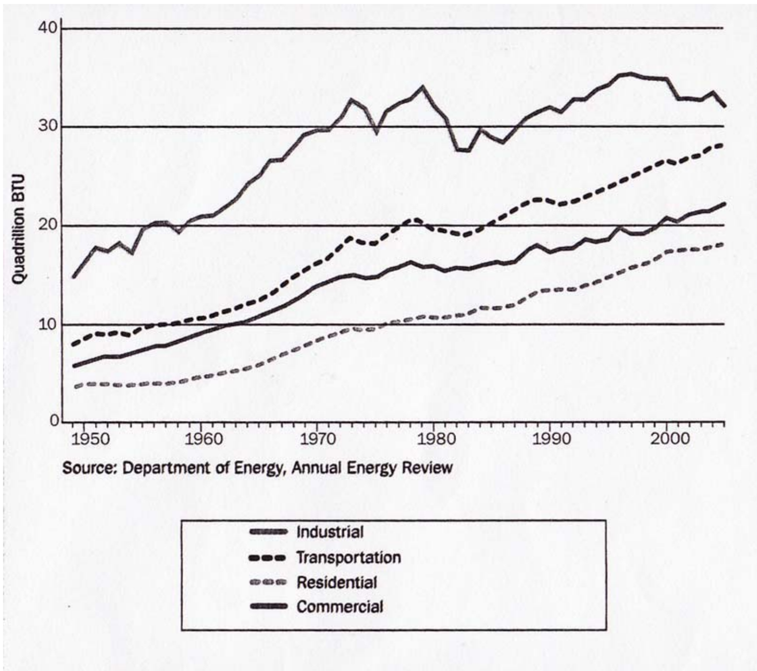

Plate 4.1
Energy consumption by sector; The Department of energy consumption reports illustrate how overall energy use continues to climb, even though on a per capita basis it has levelled off in progressive states like California and NY (BTU: British thermal unit)

[4] Matthew Phair, "Foreword" in Raja R.A. Issa (ed.), Ian Flood (ed.), William J. O'Brien (ed.) *4D CAD and visualization in construction: developments and applications*., Lisse, Abingdon, Exton: A.A. Balkema, 2003, p.vii.
[5] Russell Fortmeyer, "When less powers more", in *Architectural record*, v.194, n.12, 2006, p.166.
[6] Matthew Phair, 2003, p.vii.
[7] Russell Fortmeyer, 2006, p.166.

Glicksman tries to focus attention on building energy use among designers by developing free, simple tools to help architects make quick, informed decisions early in the design process. While, for example, the building energy use and cost analysis software “DOE2” costs nothing to download, designers proficient in both its use and the productive interpretation of its data are rare and expensive to employ. For the vast majority of buildings, owners seldom know how a building will perform and, since electrical engineers design around projected maximum power use, they do not know how much energy it will consume until the building opens. As it is written in chapter 2.1, some firms try to sell energy modelling now with all of their projects, but they do this as an add-on service. In this context, it should be an industry standard to get better results of energy conservation.[8]

4.2. A NEW KEY DISCIPLINE IN BUILDING DESIGN AND OPERATION PROCESS

Advancements in “Information Technology”, or IT, have accelerated the adoption of simulation tools due to the rapid decrease in hardware costs and advancements in software tool development environments. All these developments have contributed to the proliferation and recognition of simulation as a key discipline in the building design and operation process. Notwithstanding, the discipline has a relatively small membership and “simulationists” are regarded as exclusive members of a guild.[9] Architects, engineers, fabricators and any domain, whose knowledge depends on form, have begun to adapt and extend generic software tools to the specifics of their disciplines. It is no longer so rare for a design firm to have a few people who are writing codes. They do not need the kind of code that requires a degree in computer sciences to get right, but the kind that can be crafted one line at a frame on top of commercial software while still working on form.[10]

4.2.1 GEHRY TECHNOLOGIES - NEW ORGANISATIONAL MODEL IN BUILDING PRACTICE

A current example of these changes in architectural firms and their working process is “Gehry Technologies”. Building on 15 years of experience at Gehry and Partners, Gehry Technologies was founded in 2002 as an independent organisation dedicated to the business of technological innovation and the development of architectural software tools. This firm stands for the wider implications of a concentrated focus on technology tools and organisational processes for designers and the business of building.[11] Gehry Technologies is a relatively new organisation, which is representing a new organisational model in the spectrum of building practise. The problem is that the building practise has a history of a

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[8] Russell Fortmeyer, 2006, pp.165-166.

[9] Ali Malkawi and Godfried Augenbroe, “Introduction and overview of field” in *Advanced building simulation*, London, New York: Spon, 2004, p1.

[10] Malcolm McCullough, 2006, pp.12-15.

[11] Dennis R. Shelden, 2006, p.82.

hierarchically structured organisational model and supply chain. Other businesses have advanced their organisations in light of recent technology. While the heavy manufacturing industries have optimised around such hierarchical command and control structures, others have developed around more decentralisation. The business of building has to do this also. It has been noted that building teams are constructed as networked organisations, but are contractually restricted from functioning in this manner. The building process control has remained hierarchically structured. Conventional building delivery is structured hierarchically in terms of control and linear in time.[12] Digital tools are providing a catalyst for rethinking the structures of project delivery, presenting opportunities for firms to expand their roles, offer new services and change the sequencing of how and when design information is developed and consumed.[13] That is the point which needs to be changed, and is represented by Gehry Technologies.

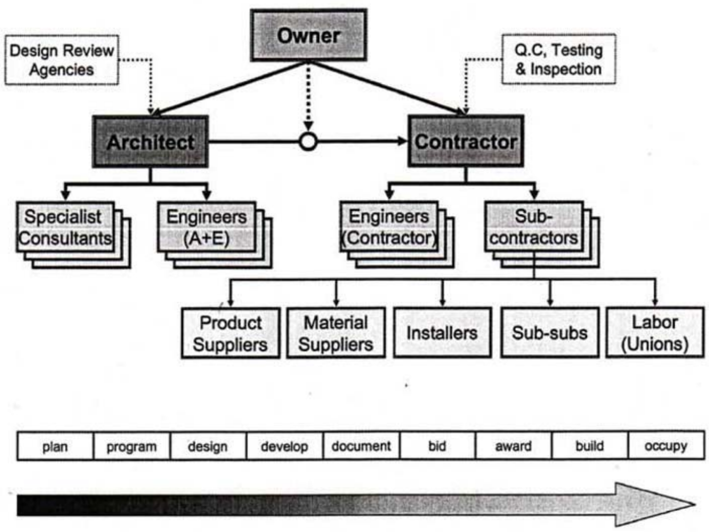

Plate 4.2
The conventional building process is structured hierarchically in terms of control and linear in time

The organisation pursues an enquiry into the process of building and emerging practices and roles suggested by technological advances. The impact of this focus on process translates into architectural form through tectonic aspects of design, and a view of building from the process of making back towards architectural design, rather than the prevailing view of making as design's outcome. There are several reasons for this focus on tectonics and process, not the least of which is that consideration of these aspects has been downplayed in the development of new software tools and methods in favour of the more obvious architectural drivers of schematic and planning level thinking about building. At Gehry Technologies, they perceive there to be a gap in the available tools sets and methodologies for these aspects of design, and great opportunity for the profession as it moves into these areas of interest. The opportunities and potential value of retooling contemporary building

[12] Dennis R. Shelden, 2006, p.82.
[13] Dennis R. Shelden, 2006, p.83.

practice are well documented, as are the potential pitfalls. There is great potential for building and construction design in expanding the set of forms available to architecture, along with a corresponding sense that the rules of engagement have to be different to realise this potential in built form.[14]

4.2.2 IN THE POSITION OF A TOOL MAKER

Gehry Technologies is actually in an unusual position in the spectrum of emerging building practice. They have found themselves in the position of tool makers, in order to fill tactical gaps necessary for new models of practice. Their experience suggests that there is a viable role for practitioners to engage directly in the business of technology innovation. The availability of computationally sophisticated talent in practice, and the increasing number of firms, both small and large, whose work is pushing the envelope of "conventional practice" through digital means, suggests that other firms have much to contribute, and much to gain, in advancing the common pool of technology available to practice. To date, this course of action has been limited by the high barriers to entry into the technology and innovation market. This limitation represents a leak of intellectual property and technological differentiation to competitors. In a short form, the business case that wills incentives firms to share innovation with the wider community is missing, and this situation thwart the development of new technologies and processes. The ambitions of Gehry Technologies for the near future include developing business models for the production and distribution of technologies that lower these barriers to entry and incentives a wider range of firms to contribute to the network of available software technologies.[15]

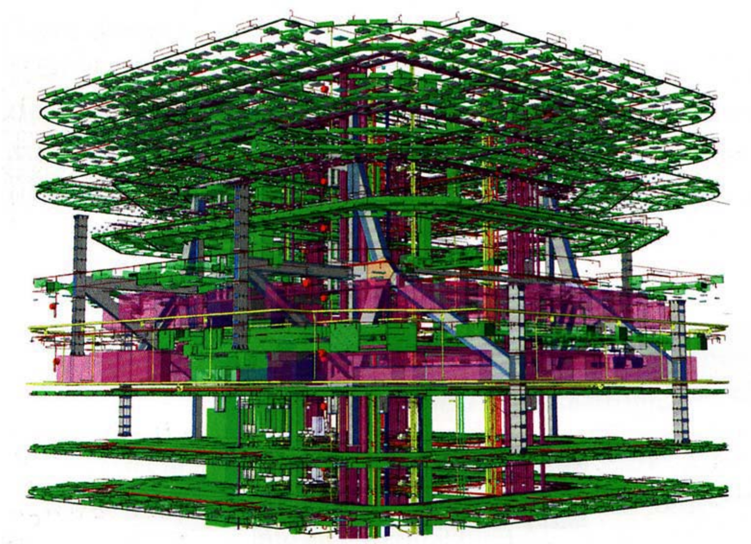

Plate 4.3
A section of a BIM model by Gehry Technologies and the structural engineers Arup, the drawing shows several floors of a mechanical zone, HVAC systems are green, plumbing and electrical are purple and blue, and steel is gray

[14] Dennis R. Shelden, 2006, p.82.
[15] Dennis R. Shelden, 2006, p.87.

4.3. SOFTWARE DEVELOPMENT BECOMES PART OF BUILDING DESIGN PROCESS

The forces of technology and economics have been universally favourable to architecture as a profession, not necessarily to builders, owners or consumers of design. There is a resurgence of interest in design as an economic differentiator, which has unfolded parallel to the evolution of design technologies that appears as a counterforce to the ongoing commoditisation of both tools and practice. The question of reach, opportunity and responsibility for participants that engage around projects is very much in play, and the economic pressures of differentiation and efficiency are sounding a mandate for innovation that digital methods are available to serve. The potential of process reconfiguration to reposition design as again central to building is large, and the opportunity for designers is taking on this challenge squarely seems open ended.[16] Software technology and technology itself is now perceived as the best thing as long as it cuts our energy bills.[17] As the chapter of this paper suggest, it is only a question of time before software development becomes an integral part of the building design process.[18]

4.4. CONCLUSION

It is a fact that not many architectural firms themselves have started to invest in the training and new computer software technology. These programs and tools are not being used to their full potential, and architects and engineers have had to educate themselves to the issues as some state and local regulations have forced the use of new technologies. Some firms are starting to sell energy modelling now with all of their projects.[19] Over all, new simulation tools and their high potential got recognised through proliferation as a key discipline in the building design and operation process, and there is a high resurgence of interest in design as an economic differentiator.[20]

It might be that this course of action has been limited by the high barriers to entry into the technology and innovation market, combined with a perception that opening a firm's internally developed expertise to larger audience represents a leak of intellectual property and technological differentiation to competitors. Finally, the potential of process reconfiguration itself is large, and the opportunity for designers is taking on this challenge squarely seems open ended.[21]

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[16] Dennis R. Shelden, 2006, p.87.
[17] Russell Fortmeyer, 2006, p.168.
[18] Mike Silver, 2006, p.11.
[19] Russell Fortmeyer, 2006, pp.165-166.
[20] Ali Malkawi and Godfried Augenbroe, "Introduction and overview of field" in *Advanced building simulation*, London, New York: Spon, 2004, p1.
[21] Dennis R. Shelden, 2006, p.87.

5. CONCLUSION

This research report explores a few examples of new software tools, like “Building Information Modelling” and “Life Cycle Assessment”. The report identifies how these tools can be helpful to make the right choice at the right time to save energy, material resources and to reduce the environmental impacts. The report proclaims the current problems for architectural firms and their staff members. This paper shows against the current view of several architects and architectural writers that these new programs and software tools are actually evolved enough to be implemented into a “Computer Aided Design” application. This research paper arrives at the conclusion that through the use of the full potential of these new software tools, architects and engineers can get a high range of new possibilities, which can be used to reduce the wasting of energy and material. Furthermore the author Russel Fortmeyer requires in his article[1], that these tools should be an industry standard. In reverse of this paper, it needs to be asked why the output of these new programs and software tools still get sold as an add-on service to the clients and does is not a part of the industry standard to reduce the wasting of resources during the design and construction process, as Fortmeyer requires.

During the research process of this paper it pointed out, and Matthew Phair describes this situation in his article[2] that arguments can be made in support of delays to widespread adoption of 4D “Computer Aided Design” that the technology is not evolved enough for the architects and engineers. In the result, it cannot offer the possibility to reduce the wasting of energy and material yet. Contrariwise, Mike Silver describes the situation in his writing[3] that computers have dramatically changed the way, but architects design and construction is still very much a diverse mix of different processes. These are often supplementing by hand using both traditional tools and non-traditional materials. The argument that the architects, engineers and other users are not evolved enough to use the new technology, is not the same problem and both viewpoints definitely cannot be valid in their message as Matthew Phair proclaims in his article.

For example, chapter 2 explores that “Building Information Modelling”, or BIM, is a new construction tool, which is evolved enough to bring the design process of an architect more

[1] Russell Fortmeyer, “When less powers more”, in *Architectural record*, v.194, n.12, 2006, p.165.

[2] Matthew Phair, “Foreword” in Raja R.A. Issa (ed.), Ian Flood (ed.), William J. O’Brien (ed.) *4D CAD and visualization in construction: developments and applications.*, Lisse, Abingdon, Exton: A.A. Balkema, 2003, p.vii.

[3] Mike Silver, “Building Without Drawings: Automason Ver 1.0”, in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*. London, England: Wiley-Academy, 2006. p.47.

closely tied to structural analysis and energy simulations, and is producing better performing. BIM allows firms to prefabricate directly from the model and improves material management, which enable to allocate and use material resources more efficiently. Also BIM greatly increase the productivity of a crew and, again, it needs to be said, in this case that it helps to eliminate wasted materials and resources. [4] Once the building is in operation the model is useful as a part of the facility management system, which is the longest phase in the life-time of a building, typically running 50 to 75 years.[5] Also chapter 3 indicates that "Life Cycle Assessment", or LCA, software is evolved enough to assess the potential environmental impact of a product system or building process. Its purpose is to identify the major contributors to energy consumption and negative environmental impacts.[6] LCA is focused on potential, predicted contributions to regional and global impact categories and it presents the results as impacts aggregated globally and over time. There are several existing LCA software tools and programs for buildings environmental assessment [7] and BIM software available. These software tools are getting used and are definitely evolved enough now to save energy, to eliminate wasted materials and resources during the design and construction process.

After all, the research paper comes to the point of view that the key factor needs to be others, which avoid getting these tools as a standard in the design and construction process. As said in the beginning, these new software tools have a high potential, which offers a long list off positive affects and possibilities to the user. This report approved a limiting factor in that case that an architectural firm needs to invest in the training and the new technology first, before they can get the benefits of these tools. It also might be that this course of action has been limited by the high barriers to entry into the technology and innovation market, combined with a perception that opening a firm's internally developed expertise to larger audience represents a leak of intellectual property and technological differentiation to competitors. Architects and engineers have had to educate themselves and this research report agrees with Russell Fortmeyer that programs and software tools, which can help to perform energy models and the usage of energy, are not being used to their full potential.[8] It still needs to have a progress of developing to get things better achieved and those

[4] Martin Fischer, John Haymaker and Kathleen Liston, "Benefits of 3D and 4D models for facility managers and AEC service providers" in Raja R.A. Issa (ed.), Ian Flood (ed.), William J. O'Brien (ed.), *4D CAD and visualization in construction: developments and applications*. Lisse, Abingdon, Exton: A.A. Balkema, 2003, p.3.

[5] Joann Gonchar, "Transformative tools start to take hold", in *Architectural record*, v.195, n.4, 2007, pp.158-160.

[6] Arjen Meijer, "Environmental life cycle assessment" in Arjen Meijer (ed.), *Improvement of the life cycle assessment methodology for dwellings*. Delft, England: U Pr, NE, 2006, pp.81-82.

[7] Arjen Meijer, 2006, pp.4-5.

[8] Russell Fortmeyer, 2006, p.166.

assertions are the continuing story of architect's relationship with new computer software tools, as Matthew Phair proclaimed.[9]

Another problem that is discussed in chapter 4 of this research report in that case is the history of the building practise itself. Building practise has a history of hierarchically structured organisational model and supply chain. Other businesses have advanced their organisations in light of recent technology. The business of building has yet to reach the next step in the development of construction and design. Building teams are constructed as networked organisations, but are contractually restricted from functioning in this manner. The process of building has remained hierarchically structured in control.[10] Joann Gonchar proclaims in her article that new technology and software tools are finally redefining the culture, hierarchies, and work flow in architectural firms. She has claimed that a critical mass of building information modelling projects, demonstrates the technology benefits and its potential for redefining practise as well, which brings a breakdown of traditional hierarchical roles to a much more granular lever.[11] The research paper agrees with her argument that the construction of the model by multiple designers in 3D is faster than with 2D drawings and it has the potential to eliminate construction documents which results in lower costs.[12] Finally, chapter 4 comes to the same result as Dennis R. Shelden in his article that the potential of process reconfiguration itself is large, and the opportunity for designers is taking on this challenge squarely seems open ended.[13]

Over all, architectural firms are starting to sell energy modelling now with all of their projects.[14] The new software tools, like building information modelling and life cycle assessment, and their high potential got recognised through proliferation as a key discipline in the building design and operation process.[15] Finally, there is a high resurgence of interest in design as an economic differentiator. Interest can be the main key factor to establish these new solutions. This is resulting in the reduction of wasting energy and materials and to match the problem of global warming during the design and construction process.

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[9] Matthew Phair, 2003, p.vii.

[10] Dennis R. Shelden, "Tectonics, Economics and the Reconfiguration of Practice: The Case of Process Change by Digital Means", in Helen Castle (ed.), *Programming cultures: art and architecture in the age of software*, London, England: Wiley-Academy, 2006, p.82.

[11] Joann Gonchar, 2007, pp.160-162.

[12] Martin Fischer, John Haymaker and Kathleen Liston, 2003, p.5

[13] Dennis R. Shelden, 2006, p.87.

[14] Russell Fortmeyer, 2006, pp.165-166.

[15] Ali Malkawi and Godfried Augenbroe, "Introduction and overview of field" in *Advanced building simulation*, London, New York: Spon, 2004, p1.

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