Obstacles and New Opportunities for Integrated Design

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Abstract
Recent developments in integrated design in Civil Engineering are outlined by describing how projects can now be informed with engineering knowledge at a conceptual level. The well-defined methods of integrated design are challenged by young engineers and architects. The development of simulation programs has been massive and engineering educational programmes can no longer teach just one design method with its related programs, but must instead give room for a continuous experimental design laboratory.

Keywords:
Integrated Design in Civil Engineering, Digital Modelling, Energy Design, Architectural Engineering, Sustainable Design

1 INTRODUCTION

Design theory and design processes in civil engineering traditionally focus on the final stages – the documentation and certification phase of the design process. Architects in the building industry have had the privilege of working with the first conceptual stages. This pattern is changing and the following will describe recent developments where an architectural perspective is applied to civil engineering with a view to sharing information across the disciplinary boundaries.

The term ‘Integrated design’ captures this effort to integrate technical scientific knowledge from the conceptual design phases onwards. The result of an EU research project 10 years ago, Task 23, (integrated design in civil engineering in a Scandinavian context) is an approach based on a fully developed theory and the facilitating software to go with it [1]. Essentially, Task 23 suggests a method for structuring the design process as first defining a space of solutions and then a series of iterations where parameters are varied, which results in information for project decisions.

Research on Task 23 integrated design clearly showed that the greatest reductions in energy consumption are to be obtained in the earliest design phases. Operating buildings accounts for 40% of the energy consumption of European societies [2]. The most effective way to reduce this figure is to ensure that building design is informed from the start with the technical-scientific knowledge needed to construct potentially net-zero-energy buildings (an EU requirement for new publicly funded buildings from 2020).

Integrated design has now been widely implemented and is leading to a perception of the engineer as a member of a team in which the engineer contributes with his knowledge in parallel with other professionals right from the very earliest design stages.

A number of European countries (including Denmark) have the goal of being CO2 neutral from 2050, so a quantum leap is needed with regard to the information level of the design process, if this goal is to be reached.

There is consensus on the need for a more informed design process if the construction industry is to reach the goal of low-energy buildings and sustainability. However, there are obstacles to this process, as described in what follows.

1.1 Integrated design in Civil Engineering

For several years, design engineers educated at the DTU (Technical University of Denmark) Department of Civil Engineering have received teaching influenced by Task 23 Integrated Design Process, which as mentioned was originally conceived under the auspices of the EU. In the traditional design process, architects control the earliest design stages. The perspective of architects is to create coherence between the use and cultural qualities of a building. But the value of the building – for the owner and society – includes many other aspects.

In a traditional design process, the engineer contributes at the end of the design process by redesigning if necessary for safety and buildability. The documentation is another traditional task of the engineer in the final phases of the design process.

Integrated design, e.g. Task 23 and other well-developed methods, challenges this traditional consultancy process and proposes an engineering involvement in the design process from the earliest conceptual design phases, at which stage operating costs and other engineering aspects are (or should be) important design parameters.

In this model, the initial stage is an exploration of the needs and requirements of the various stakeholders of a building project.in order to define a space of solutions.

Freeware, Multi-criteria design method tools (MCDM-tools) were part of the Task 23 effort to facilitate a multidisciplinary team in defining the space of solutions.

The MCDM approach has not been further developed in Civil Engineering for final design phases, although it is described in other integrated design methods [3].

Software to facilitate the basic iteration and parameter variations was also developed as freeware in a further development attached to Task 23 (www.iDbuild.dk). iDbuild is fundamentally an approach, in which a room in a future building is modified (height, width, window orientation, u-values and g-values, window size, etc. are varied) and the effect on the energy balance is graphically illustrated as a deviation from a reference.

Subsequently, the early space of solutions as defined by the criteria and objectives is systematically scanned for solutions. Solutions are then provisionally calculated and compared with the criteria and aims. On this basis, it should be possible to make a design decision. In the original theory of integrated design Task 23, the iterations were to be facilitated by still more and more advanced and detail-focused software [4].

1.2 Integrated design – a creative tool or a just a checklist?

Most kinds of integrated design processes include an initial outline of a space of solutions. This is often perceived as a checklist: the achievement of certification, etc. But viewed in another way, it is a demarcation of design ideas, and in this sense should play an important role in creative idea generation.

Theories of integrated design do not profoundly address how the initial ideas that start the iterations are generated or how the synthesis of options is made [5] but when students work with integrated design, new creative options arise that were not foreseen in the initial theory and methods of integrated design. Experienced design educators recognize a tendency for students to generate many more ideas in a tightly defined framework than when working in a mentally completely open space, and in this sense integrated design could actually focus the students' creativity.

Progressively more and more advanced software is involved in the iterations and used in yet new ways and in other design phases than it was originally designed for.

Based on the supervision of numerous projects made by students in DTU civil engineering in collaboration with architectural studios, this paper outlines the latest developments and current challenges in integrated design in Civil Engineering.

2 OBSTACLES AND NEW OPPORTUNITIES FOR INTEGRATED DESIGN

2.1 Simulations as an investigative and creative activity

Simulations are an important part of the informed design process. There are numerous simulation programs for almost every engineering discipline and many universities have developed their own simulation tools – also DTU.

This simulation software allows for the handling of enormous amounts of information and makes possible the quantum leap in the level of information in the design process that is needed to reach the goal of CO2 neutrality and low energy buildings.

The perspective is promising, especially with regard to building physics. Structures are calculated with respect to maximum impact, that is, fixed factors. Indoor climate and energy performance, however, are dynamic, because they vary under the influence of the outdoor climate on the building, changing by the hour and season. Simulation tools developed to inform an integrated design process have in this sense cleared the way for new architectural expressions seen in recent climate-dynamic architecture. The performance of climate-dynamic buildings is complex and can only be handled digitally. Since the energy crisis in 1973, the focus has been on the reduction of energy used for operating buildings. At first, this was done by reducing heat loss by using more insulation and reducing glazed areas. But by the 1990s, focus shifted to the building's potential energy gain from the outdoor climate. Optimizing the building's symbiotic relationship with the exterior climate is the essence of intelligent net-zero-energy buildings. Simulation programs are the admission card for non-traditional architecture to explore energy gains from the natural environment. In 2006, Danish legislation became based on a government-approved energy balance indoor climate simulation program developed by DTU and SBI: Be06 [6]. To obtain a building permit, a building's energy balance must now be documented using this program.

As mentioned above, it is in the initial conceptual design stages that the most important reductions in the energy consumption of a building can be obtained. Therefore it is decisive to have simulation software that can be used for informing this level of the design process. The early design phases are characterized by a wide search of the entire space of solutions. In other words, there is a need for both speed and precision, which creates a serious dilemma. Speed is necessary to inform an on-going creative design process. Precision is mandatory because inadequate simulations risk misinforming important design decisions.

There are two basic categories of energy-balance/indoor-climate programs suitable for early design processes. The first are simplified hour-based simulation programs limited to fragments of a building (simulations at room level). Adding rooms together to match the scale of the building gives an indication of how the entire building will perform. This is the principle behind e.g. iDbuild, developed at DTU Civil Engineering to facilitate the early, conceptual design processes [7].

In the second category, calculations are based on monthly values, which is the principle behind e.g. the official Danish BE06 program.

As described above, the theory of integrated design processes often prescribes the use of yet more advanced simulation software as the iterations develop. The software developers explicitly aim at different levels in the design process as described above, but there is a trend among engineering students to transcend the prescribed uses of the programs. Simulation programs developed for the final documentation phases are used by students in the early conceptual phases. Students of design engineering display a new equilibrist tendency to use the various simulation tools dynamically and freely depending on the specific design challenge in question. Students switch between different simulation programs according to what they believe will give the required information fast and precisely for the specific building and location in ways that the software developers and theorists of integrated design did not foresee.

For example, the advanced final-stage oriented daylight simulation program Radiance is used by DTU students for the conceptual design phase in urban scale projects. The concept of a future low-energy building in an urban plan is informed by a simulation of sun- and daylight conditions for an abstract volume with a specific location and orientation. This 'conceptual simulation' is made in the Radiance program because it can be arranged to simulate daylight impact on façades. This means it can be utilized for a design process that creates the best conditions for naturally lit and not overheated future buildings in an urban plan. Radiance is normally used for detailed calculations of daylight conditions for end-phase designs.

The same applies to the documentation software Be06, which was created to document the energy balance of finalized design projects. Its monthly-based calculations have proved fast and easily applied in an on-going design process. For instance, it can give information with regard to basic geometries – which generally accounts for a conceptual design level in building projects. The basic geometrical dispositions define the future energy consumption of a building. For example, Be06 can give information that suggests a reduction in south-facing façades, etc.

The choice of structural system and materials can also be informed at a conceptual level by Be06. E.g. if the architectural expression consists of heavy, archaic structures with a lot of thermal mass, this can affect the energy balance positively or negatively. Information on such effects is important at the conceptual level.

These simplified, fast programs, however, risk missing good design solutions due to imprecision. For instance, a design with an innovative sun-shading device risks being turned down because a fast and superficial simulation shows inadequate daylight penetration, while a more advanced daylight simulation might show something else. There is a tendency in the early conceptual phases for students to create advanced hourly-based simulations based on luminance distribution on a realistic sky (e.g. Perez sky instead of CIE sky). This is a natural development connected to a germinating craftsmanship in digital modelling and simulation, and increases in computer power [8].

To inquire into the potential of new multidisciplinary collaboration in highly-informed early design phases, DTU Architectural Engineering and the Royal Academy of Art, School of Architecture organised joint workshops. At these, students have an informal platform for exploring the interface between design and digital modelling and simulation. In a similar way, final thesis projects become an Exploratorium. At DTU Architectural Engineering, they are often carried out in collaboration with architectural studios. It is clear that digital modelling and simulation integrated in a design process create new opportunities for architectural expression and slowly open up for climate-dynamic architecture.

But there are also obstacles to these developments. One lies in the way classical engineers are traditionally educated, where they have their first teaching in decision-making late, e.g. in relation to so-called capstone projects. An endless variation of parameters does not lead to design solutions and ideas. Integrated design informed by results from simulations is an engineering speciality. Simulation can be a waste of time if it does not match the immediate context of the design process.

In order for the engineer to perform an adequate simulation, he must have knowledge and experience of design processes; he must have tried to design on his own and in groups. Because of the many possible combinations of parameter variations, a qualified choice of concept as a guiding principle for the process is essential. These kinds of open-ended situations must be introduced early in the engineer's education to create an ambitious and constructive attitude with the motivation for learning being continuously to respond to open-ended challenges in projects. Moreover, engineers who have worked so much on design are able to perceive their engineering knowledge as concepts, e.g. the ability to synthesize extensive amounts of information on thermal behaviour into potential design concepts that can be matched with architectural concepts. The engineer specialist in integrated design also needs to know something about architecture in order to work in the interface between engineering concepts and architectural concepts.

One often overlooked part of integrated design is the graphical translation or communication of simulations. Some simulation programs already have good graphic features, but almost all simulation results still need extensive graphical reworking to parallel and match the architectural language of façades and plans (Figure 1).

2.2 Intuitive design methods and integrated design

During the early, conceptual phases, few architects design by systematically searching solutions within a multidisciplinary defined space of solutions.

This is not due to a lack of capacity, but is rooted in tradition and deliberate choices. In Denmark it constitutes an important standpoint because the intuitive design method is an explicit foundation for the pedagogical programme of the Royal Academy of Art, School of Architecture in Copenhagen [9].

The logically structured systems and methods meant to give an overview of design options based on scans of all relevant concepts is bypassed by intuition.

Architects educated in the intuitive design method are the main collaborators of civil engineering design engineers.

The Bauhaus School of Architecture in Dessau was one of the first schools of architecture to work explicitly with intuition, possibly inspired by modern psychological theories [10]. This was a revolutionary initiative which produced a quantum leap in form and design because it was a decisive break with the imitation-based design methods of the Beaux Arts Academies [11]. The Bauhaus impulse is, of course, still a source of inspiration.

The explicitly intuitive method is a well-defined tradition and indirectly takes a critical stand with regard to integrated design methods. It poses an important obstacle for the implementation of integrated design because transparency in the design process is necessary when working in multidisciplinary design teams. This transparency, expressed in decision charts etc., is of course a core in classic engineering design methods [12].

On the other hand, Task 23 presupposes some architectural ideas, but as mentioned their generation is not directly addressed. So the intuitive design method of the architects is a professional approach to the 'black holes' in the integrated design process and has value [13].

In the Copenhagen area, very few architectural studios work with integrated design. But intuitive design methods are challenged by requirements for documented and certifiably sustainable buildings.

Engineers have taken a completely opposite viewpoint to architects in recent decades. The development of indoor-climate and energy balance simulations can be construed as a popularization of advanced specialist knowledge, which means enhanced transparency.

The improved design of program interfaces and illustrating graphics potentially gives laymen opportunities for addressing this specialist knowledge. The German architect, Dietmar Eberle argues that in this respect engineers could be obsolete as partners in the design process because architects can get the information more freely and individually by means of computer programs [14]. This is a logical consequence of the development, but a first-hand encounter with energy simulation programs will demonstrate that it takes engineering knowledge to control and evaluate simulations. As mentioned above, a defective simulation will risk misinforming the design process, and wrong information can be worse than no information. However, simulation programs can form common ground for collaboration and integrated design when used by both architects and engineers. Similarly, drawing programs used by both architects and engineers, such as Google SketchUp, can be productive in a multidisciplinary design process.

2.3 BIM and Integrated Design in Civil Engineering

Drawing programs used in the early design phases by architects and engineers alike, and which can be imported in simulation programs, will entail a leap in the development of integrated design. It will mean new options for collaboration between architects and engineers if a special model does not need to be constructed for the simulation program. It will be a step towards the elimination of the dilemma of speed versus precision in the integrated design process, because it will be possible to test architectural ideas directly and continuously in the simulation program.

The integration of information from different simulation programs can also be revolutionized. Software developers create platforms for plug-ins from simulation tools from different engineering subject areas.

But because they were not thought out in the same way, it is still a demanding task to model and evaluate simulations.

The state of play of these promising visions was investigated in three afternoon workshops for engineering students at DTU. The students were all experienced users of energy simulation programs and various drawing programs, but had not worked with the option of importing drawings directly into the simulation program before. Two drawing programs and an energy simulation program were chosen.

IESVE contains a model tool called modelIT which can model basic geometries. There is also an option to import a gbXML file (Green Building XML) which is a common open source format created to exchange geometries between BIM programs (Revit, ArchiCAD, etc.) for simulation programs such as IESVE. IESVE has its own export tool, which functions directly in Revit. As a third and very new possibility, the import of geometries from Google SketchUp has been established. Google SketchUp Pro has a function which also allows import of CAD drawings.

The current situation (2010/2011) outlined by the reports and evaluations made by students at the three workshops is that it is possible to import a drawing into the simulation program with some difficulty. After the simulation, the information obtained must still be manually exported to the drawing program. Conclusions were that the process does not function ideally, but all students could see and experienced a great potential according to their reports and evaluations.

The traditional roles of architects and engineers are dissolving, opening up for new design processes. Apart from the changes caused by severe requirements for a high level of information in the design process due to sustainability issues, new project design tools are pushing developments as well.

Project designing with BIM (Building Information Modelling) has been legally mandatory for publicly funded large construction work in Denmark since 2009. BIM holds potential in relation to multidisciplinary integrated design because all groups can place information in different layers in the same digital model.

However, BIM also poses a line of obstacles to integrated design in the early design phases. BIM models do not work dynamically in that you cannot move freely from conceptual design to project engineering and back.

3 CONCLUSION

Theories and methods of integrated design are challenged by well-consolidated architectural design traditions. These traditions have quality and the potential for being developed in the context of integrated design. In Intuitive design methods there is a reservoir of tacit knowledge and experience in addressing the ‘black holes’ in the framework of integrated design. There is the challenge that decision charts do not unambiguously suggest solutions and the synthesis necessary for creating the actual form is not directly addressed.

But if work is made on the interface between architectural design and engineering simulations and attention is paid to the graphical communication of simulation programs, the goal of sustainable buildings is within reach. The use of simulation programs as common ground for architects and engineers can give the programs a new role in the design process. Informing the early design phases has become a creative engineering activity, in which increased computer power and student familiarity with a wide range of drawing programs and simulation programs change the prescribed methods of integrated design. The dilemma of speed versus precision in simulations used to inform an on-going design process is being solved by technical development. The effect of informing the early design phases is well-demonstrated with regard to reductions in energy consumption for operating buildings. The way in which the conceptual design phase is informed is changing rapidly and involves new ways of doing both engineering and architectural design. Integrated design is evolving in ways not foreseen in the theory behind the methods.

4 REFERENCES

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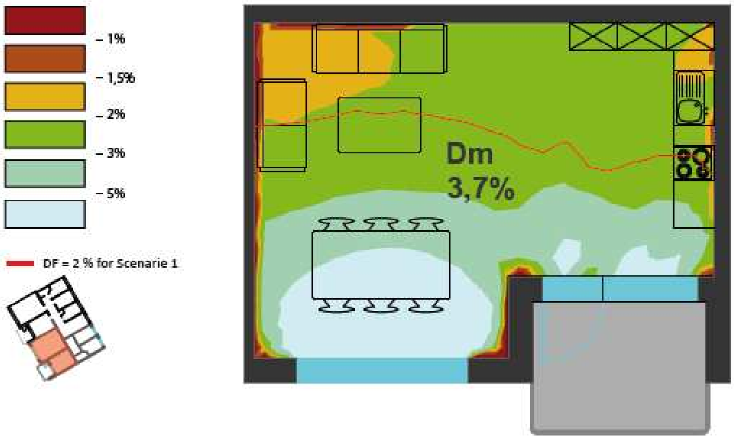
Scenarie 3 - SYDVEST

Altandør i altanbagvæg

Inddata

I Scenarie 3 er altandøren flyttet fra altanens sidevæg om i bagvæggen. Altandørens bredde øges til en M9 dør, og dette bevirker at vinduet bliver en smule smallere. Samlet betyder det at vinduesarealet øges fra 7,7 m² til knap 7,9 m².



Observationer

Effekten af at flytte altandøren er større end hvad der blev vundet ved at optimere på altanens flader. Det er nu kun i hjørnet af stuen at dagslysfaktoren er på under 2 %.

En ulempe ved løsningen er, at der efterlades et hul i altanens sidevæg, som vil være svær at lappe, så det falder ind med de oprindelige teglstensvægge.

Antallet af timer med overophedning stiger med 12 % for den sydvestlige del af lejligheden, som i forvejen døjer med overtemperaturer.

Overflade	Reflektans [%]
Væg, indvendig	77
Væg, udvendig	45
Loft	78
Gulv	58
Altanbrystning	90
Altanloft/gulv	50

SYDVEST	
Gulvareal	29,46 m²
Vinduesareal	***7,88 m²***
Vinduesandel	***27 %***

Parmetre der er forskellige fra referencescenariet er markeret med fed og kursiv.

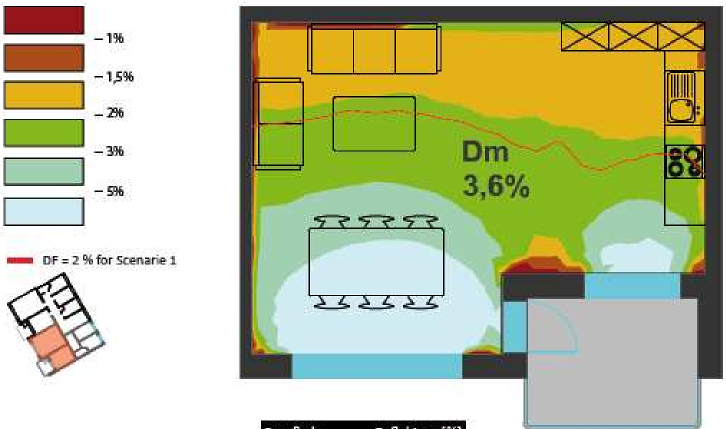
Zone	Reference over 27° C	Scenarie 3 over 27° C	Ændring ifht. reference
Klimaskærmen er efterisoleret på begge sider			
Sydvest	345	393	12 %
Nordøst	96	100	4 %

Scenarie 2 - SYDVEST

Optimeret altan

Inddata

I Scenarie 2 er der arbejdet med altanfladerne. Brystningen er erstattet af en glasbrystning, og væggene er filtset hvide.
Altanloftet har en høj reflektans som tilsvarer loftet i rummene, og gulvet har ligeledes samme reflektans som i rummene.



Observationer

Dagslysfaktoren bliver en smule bedre ved at optimere altanens reflektanser. Den røde linje indikrerer hvor Scenarie 1 havde en dagslysfaktor på 2 %. Det ses at lyset kastes lidt længere ind i rummet, men effekten er begrænset.

Der sker ikke ændringer i det termiske indeklima, da ingen af de ændrede parametre har væsentlig indflydelse på dette.

Overflade	Reflektans [%]
Væg, indvendig	77
Væg, udvendig	***77***
Loft	78
Gulv	58
Altanbrystning	***Glas (LT = 75 %)***
Altanloft	***78***
Altangulv	***58***

SYDVEST	
Gulvareal	29,46 m²
Vinduesareal	7,70 m²
Vinduesandel	26 %

Parmetre der er forskellige fra referencescenariet er markeret med fed og kursiv.

Figure 1: Example of graphical translation of results from a daylight and energy-balance simulation program. Seventh semester student project. The representations explain the changes caused by altering the design of the balcony.