Parametric Design and Analysis Framework with Integrated Dynamic Models

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Abstract: In the wake of uncompromising requirements on building performance and the current emphasis on sustainability, including building energy and indoor environment, designing buildings involves elements of expertise of multiple disciplines. However, building performance analyses, including those of building energy and indoor environment, are generally confined to late in the design process. Consequence based design is a framework intended for the early design stage. It involves interdisciplinary expertise that secures validity and quality assurance with a simulationist while sustaining autonomous control with the building designer. Consequence based design is defined by the specific use of integrated dynamic modeling, which includes the parametric capabilities of a scripting tool and building simulation features of a building performance simulation tool. The framework can lead to enhanced awareness of building performance in the early stages of building design, thus improving energy performance and many other quantifiable performance objectives.

Keywords: Integrated Dynamic Model, Consequence Based Design, Parametric Tool, Building Performance Simulation, Integrated Design.

Introduction

Nearly 80% of the design decisions that impact energy consumption are made during the first 20% of the design process (Theßeling *et al.* 2008). Regardless of the numerous attempts to structure the design process, and in so doing improve performance of buildings, no tangible multi-disciplinary structure is found in the design approaches in Danish building design practices today. One reason is the diverse and segregated cultural differences between those who design and those who calculate (Bleil de Souza 2012). Another reason is the absence of tools that meet the performance analysis needs of both architects and engineers in early design (Toth *et al.* 2011).

Many engineering consultancies offer architects building energy consulting expertise in the early stages of building design, but very few projects are fashioned within a true integrated design process[1]. This means only few projects today are designed by design teams consisting of experts in many disciplinary fields of the AEC industry.

Energy analysis (and other performance analyses and assistance) are for this reason either handled by the architects themselves or not considered at all. Engineers usually assist the architect with the aid of building performance simulation (BPS) tools in later stages, which often results in easy-fix solutions which are far from ideal in terms of performance, cost-efficiency and the overall holistic and human centered solutions.

Background

The analysis procedure when operating BPS tools requires a user with suitable knowledge of the tools and understanding of building physics as well as insight in regulatory building energy requirements. Of this reason BPS tools are often handled by experts (often associated with a simulationist or engineering analyst (de Souza 2009)). Nevertheless different software developers (e.g. IES (Integrated Environmental Solutions 2013), Autodesk (Autodesk 2013c)) have over the past few years produced simplified versions of their BPS products to accommodate building designers, thus making the process of energy simulation an accessible task for non-simulationists. The simpler tools have proved very powerful in improving energy performance from the earliest design stages which is demonstrated in previous studies e.g. Bambardekar & Poerschke (2009) and Doelling & Nasrollahi (2012). However non-simulation-experts may have difficulties establishing the required quality assurances (Hensen 2004) when handling the BPS environments, meaning non-simulationist often do not have the required competences to use and analyze BPS. The inclusion of a specialist in the early design stage is paramount to achieve a valid ground for informed design.

[1] Integrated design as defined by IEA task 23 (Löhnert *et al*. 2003)

The geometric modeling procedure when using BPS tools has been reduced dramatically due to better interoperability between BPS tools and design tools (often classified as CAD software). The technical foundation for model level collaboration has for this reason improved significantly. Yet many problems still exist when seeking to either unify or couple design tools and BPS tools (Negendahl 2013). One solution in coupling the design tool and the BPS tools is by introducing a middleware. A scripting tool can act both as middleware while it can enhance modeling prospects by integrating parametric variables into the model. In the past few years scripting tools have become more common amongst engineers and architects. Even though scripting tools (e.g. Grasshopper (Robert McNeel & Associates 2013a), GenerativeComponents (Bentley 2013), Dynamo (Autodesk 2013a) and Design Script (Autodesk 2014)) are used very differently by architects and engineers, the ecosystem of parametric tools and scripting environments are gradually changing the way architects and engineers cooperate. Toth *et al.* (2011) were the first to suggest the combined use of scripting tools and BPS tools in a collaborative environment. With the aid of a plug-in structure to link a design tool e.g. Rhino (Robert McNeel & Associates 2013b) or Revit (Autodesk 2013c) with a BPS tool it is possible for the building designer to maintain control of the geometric properties of a model and the BPS in the same unified modeling environment. Yet again the quality assurances mentioned by Hensen (2004) are still missing when using these parametric building performance simulation models.

Three major challenges in using BPS in building design are identified:

1) Building designers are rarely experts in building performance evaluations.
2) Expert knowledge in building performance is rarely part of the early design stages.
3) Integrated design methods in the early design stages are a rare phenomenon.

Introducing Consequence Based Design

Consequence Based Design is an interdisciplinary dynamic framework for improving building performance [2] in the early design stage. The framework can support any type of analytical performance metric and is able to provide consequence feedback of design changes to a building designer in any stage of the design process.

[2] Building performance is in this article refereeing to calculable, measurable performances such as energy consumption, temperature, cost, etc.

This article focuses on the use of consequence based design as a framework to improve building energy and indoor environment in the early design stage.

Consequence based design provides visual building performance simulation feedback in the building designer's native design tool (CAD) while maintaining the validity and accountability provided by a simulationist. The framework is defined by the use of three categories of tools operated by three categories of operators, together creating and employing an integrated dynamic model: 1) Design tool 2) VPL (visual programming language / scripting tool) and 3) BPS environment (Negendahl 2013).

Each of these tools is operated by a specialist, hence introducing a new role distribution challenging the classic separation of the architect and the engineer. This new role distribution is based on personal expertise rather than disciplinary background, focusing on three subjects 1) building (model) design 2) building model parameterization 3) building model analysis as shown in figure 1.

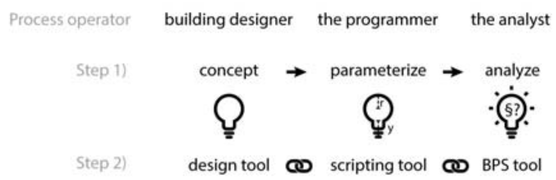

Figure 1. Consequence Based Design Framework. Step 1 – Creating and Defining an Integrated Dynamic Model. Step 2 – Operating the Integrated Dynamic Model.

The design process is defined by two steps: step 1 is defined by the creation and definition of an integrated dynamic model and step 2 is the operation of the integrated dynamic model. Step 1 is about forming the scope of the design while step 2 is about the exploration of the design.

Integration and Collaboration in the Early Design Stages

Integrated dynamic models can be operated by anyone (see figure 2), which is why such model can accommodate the building designer alone as characterized by the simplified standalone BPS tools such as Vasari (Autodesk 2013d) and Ecotect (Autodesk 2013b). The real difference from these standalone tools is the option to operate the integrated dynamic model in a collaborative and highly custom environment, of the simple reason that the tools defining an integrated dynamic model remain separated. Additionally, the ability for the user to customize the design environment to fit the special needs of the particular operators, is an exclusive characteristic of the integrated dynamic model (Negendahl 2013).

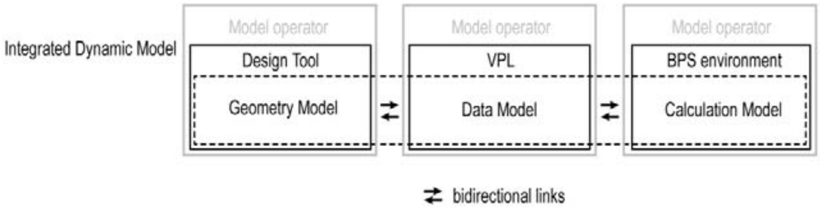

Figure 2. Integrated Dynamic Model: A Combination of: 1) Design Tool 2) VPL (Visual Programming Language – Scripting Tool) and 3) BPS Environment

The process of creating and using an integrated dynamic model is somewhat similar to the integrated design process as described by Löhnert *et al.* (2003) and utilized by e.g. Petersen (2011). The method detaches itself from the traditional integrated design process by being able to support changing criteria and multiple parallel concepts, using advanced parametrical operations and is defined by the integration of runtime linked BPS tools. When the model is created the method allows the building designer to work intuitively and uninterrupted with building performance feedbacks. The framework embraces the supremacy of "computer intellect" in terms of calculation, data analysis, and information retrieval while acknowledging the superiority of human intelligence when it comes to strategy of designing high performance buildings. The integrated dynamic model is introducing a whole new level of disciplinary independence that may open up for new creative solutions and more focus on the analytical part of design exploration.

In contrast to other goal seeking methods based on integrated design processes, the framework of consequence based design supports the experimenting nature of architecture in the early design stages and is highly adaptable in terms of BPS tools, consequence feedbacks as well as performance representation forms. The framework describes a data driven approach rather than a criteria driven approach, meaning the method is applicable outside the realms of structured design teams and role definitions often required in integrated design.

The framework of consequence based design is developed to improve the support of performance expertise in the early design stage by acknowledging the simple train of thought; conflicts between people in the early design stages lead to poor interdisciplinary collaboration, poor collaboration results in poorly designed buildings. When conflicts arises around the matter of who is in control and who is the decision maker when determining and crafting buildings, a design team is ineffective, since the conflicts may very well rise between the parties in the design team.

If a team of experts is to design high performance buildings in a collaborative environment, such an environment must be very attentive to cultural, ideological and basic human differences. Consequence based design is dealing with this delicate matter by utilizing the model as a medium to distribute knowledge.

The idea is to define custom integrated dynamic models aimed for the building designer, thus maintaining the building designer as the lead operator role in the early design stage. The model is created with the intent of experimentation. And as a fundamental part of an integrated dynamic model is the presence of parametric objects and variables. The consequence feedback from the linked BPS tool(s) is translated into direct visual input within the design tool, thus providing valid results in an integrated environment.

The consequence based design framework seeks to address the lack of operator expertise by defining a division of operator-to-tool solution, thus shifting the avertable interaction between people to an interaction through models. Bear in mind that when the model is created, the BPS tool is linked to the design tool through a scripting tool. This combination of tools gives the simulationist the option to define the necessary input requirements of a building performance simulation. Thus, in this framework embedded expertise (Kilian 2006) arises. Following embedded expertise, the building designer is less dependent on operator-to-operator interaction. This expands the autonomy of the designer, which many architects' request (Banke 2013; Hermund 2012). It is likely that an adequate amount of embedded expertise, when provided by a combination of a geometric model and results from a calculation model will deliver sufficient knowledge to make up for the lack of knowledge held by the practitioner. However, embedded expertise when provided from a computer simulation does not necessarily ensure sufficient analytical experience of the practitioner (Negendahl 2013). For this reason, the framework of consequence based design is sustaining the analytical responsibility with the simulationist. The role of the simulationist is to become all the things the simulation tool cannot be. By using integrated dynamic models the simulationist is able to automate rules of input variables, requirements of systems and even decision sequences, thus making the job of the simulationist less focused on performance simulations and more on performance analysis.

The Dynamics of the Design Process

Shaviv *et al*. (1992) described an ideal transition from heuristic knowledge into the use of various procedural precise calculation models (see the upper part of figure 3). The argument is that some BPS models are more suitable than others in supporting the building designer in the various decompositions of the design stages. This means that to better support the designer, the BPS tool has to follow the information level throughout the dynamics of the design process. While various standalone BPS tools can effectively be used to calculate the impact of design changes throughout the early design process, the very fact that multiple models have to be built in multiple environments may be a problem for the designer. Also the requirement of multiple tools further reduces performance quality assurances as mentioned by Hensen (2004). An integrated dynamic model support BPS tools at any scale and any information level, and the framework of consequence based design follows the idea of using procedural precise BPS tools throughout the design process. Figure 3 shows the use of various types of integrated dynamic models, where the linked BPS tools are replaced as the design decisions becomes more stable and more data has been collected. The figure also depicts the shifting control level of the integrated dynamic model. Every time a new type of analysis is required, the model must accommodate new input, new variables and parametric definitions. The model control peak points of the programmer are defined by the new implementation of parametric relationships and changes in the code. The model control spikes with the analyst are representing the necessary implementation of requirements to perform meaningful simulations with of the changing model. To make sure the new model works as intended, the building designer, the programmer and the analyst must collaborate. In figure 3, the peak points of collaboration at the model level can be seen when the three operators level of model control overlap. Ideally, collaboration between the programmer and analyst is initiated before a new model is taken into use by the building designer. In this way, many BPS tool specific requirements can be integrated before the model requirements and terms of experimentation from the building designer is implemented, leaving more time to implement the building designer's specific requests of the model. The collaboration between the programmer and the building designer is required to provide sufficient variability in the parametric definitions. Since the analytic knowledge (embedded expertise) of performance is distributed through and by the model, the contact between the building designer and the analyst is fully confined to the model. However, collaboration in the human interaction domain will always be beneficial for the process.

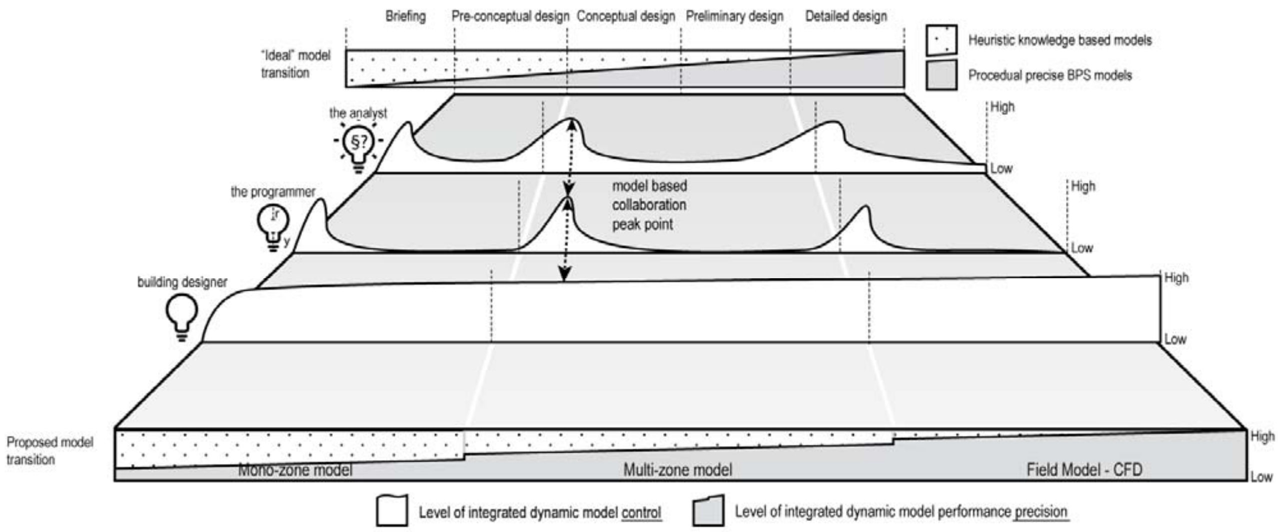

Figure 3. Consequence Based Design Framework. Integrated dynamic models are used throughout the design process and benefit from procedural precise calculation models, as described by Shaviv *et al.* (1992), here illustrated with three different types of runtime linked BPS tools. When transiting from one BPS tool to another, model control collaboration between the operators is required. These can be seen as model based collaboration points.

Compared to the integrated design methodology, the consequence based design framework only requires few peak points of collaborational interaction between the operators. The process of integrated design is often associated with parallel operators and team decision making in continuous iteration loops. The consequence based design framework does not require continuous human interaction. Once the integrated dynamic model is created, the programmer will only assist in using and modifying the model and the analyst will only monitor and provide feedback of the issues the model itself cannot handle, while the building designer has the actual model control. As seen in figure 3, the building designer remains in control of the model throughout the entire process. Even if fairly advanced simulation tools such as CFD are used, the building designer will never notice the difference in analysis complexity. The analyst remains in charge of providing valid input variables as well as managing important performance results back to the design tool. As Kaley *et al.* (via Shaviv *et al.* 1992) advocated with their procedural precise models, it is suggested to use simple mono-zone models in the earliest stages, transit into multi-zone-models and in the end, when assumptions are unnecessary, field models can be initiated.

The true value of using the consequence based design framework over the integrated design framework is the acknowledgement that building performance consists of more than a result from a BPS tool. The consequence based design handles unquantifiable parameters and objectives which are equally important as of those that are measurable and calculated. Consequence based design is about being aware of the consequences of design choices, since performance feedback is only one of many consequences the building designer should react upon. By integrating the performance feedback into the design tool, the designer has both the visual feedback of the geometry and the performance in the same place, thus aligning performance with composition, layout, aesthetics, social impact and many other unquantifiable characters of a building.

Discussion

Daniel *et al.* (2011) observed that if parametric modelling is to become central to the design process, then it will be necessary to deal with complexity and particularly in a collaborative environment. With the introduction of the operator, the programmer is removing the accountability of a coding-skilled building designer. However, a skilled building designer may very well take the role as the programmer, thus advancing the parametric possibilities of the framework even further.

The real challenge in using the integrated dynamic models in integrated environments is how criteria and goal specification are understood by the design team. The way the team collectively handles the few collaboration points throughout design process (as seen in figure 3) is crucial to how well the integrated dynamic model is integrated into the design.

Undefined, inaccurately followed and misinterpreted performance requirements can in the worst case lead to a poorly performing building design. For this reason, when building performance is an important aspect of the building design, clear performance objectives are required. Following that statement, every requirement must be acknowledged by all operators of the model.

Bachman (2004) described his concern of the role as a building designer compromised by integration; if building designers still wish to control their design as a whole instead of purely becoming professional specifiers, the integration of requirements must be handled with care. Integration can be a dangerously all-inclusive term. Once the idea of integration is announced, any conversation on how to attain it can easily become unduly elaborate and all-encompassing. The problem is one of scope. Integration is about bringing all of the building components together in a sympathetic way and emphasizing the synergy of the parts without compromising the integrity of the pieces (Bachman 2004).

In this respect, the idea of consequence based design is simply emphasizing the consequences of design choices in terms of particular performance metrics. The integration is not about people, nor about requirements, but about knowledge and information. Performance feedback from an integrated dynamic model is itself a valuable piece of information that the building designer can chose to act upon. While the desire of the building designer in conforming to certain (performance) requirements is not explicitly necessary, the framework of consequence based design is defined by visualizing (or by other means provide) the performance consequences from the designer’s own choices. In this way, the building designer needs to behave towards the responsibilities following choices he or she makes.

Such behavior can lead to many interesting directions. The first reaction of the building designer may be experimentation of design solutions based on his or her intuition of performance. The intuition is then challenged by the hard data of the performance feedback. This process can change the perception and intuition of non-simulationists to require better understanding of the buildings they design. In this way consequence based design is a very un-intrusive framework to support performance based design, however it will never guarantee better building performance. Only the building designer's reactions to the consequences of their design choices can lead to better performing buildings.

Another use of the framework is the building designer acting as a problem solver. The problem solver will seek to minimize energy consumption, improve indoor environment, or whatever the scope is in terms of the provided performance feedback. In such cases, the quality of the integrated dynamic model is the only limiting factor to what extent the building performance can be optimized.

Consequence based design is defined by the explicit use of integrated dynamic models. This means that the BPS tool can cover any simulation tool, which may be runtime coupled with a scripting tool thus introducing multidisciplinary collaboration and true awareness of subjects which require expert knowledge, e.g. structural performance, life cycle cost, environmental and social impact. In any of these cases, a coordinated goal specification between the analyst and the building designer can lead to high performance buildings. This is, of course, optional, but the framework supports a much more objective focused design method if the team wishes so. With clear objectives, advanced automation features such as multi criteria optimization, shape grammar and agent based assistants can be incorporated into the integrated dynamic model without great difficulties (Negendahl 2013). The middleware, the scripting tool, is the sole reason for an easy model transition with these options. However, in such situations, the term "optimization" has to be redefined to accommodate the enhancement of both the quantifiable and the quality defined objectives which is yet to be resolved.

Conclusion

In the pursuit of improving building performance, the way experts from the various disciplines in the AEC industry are collaborating is redefined by the framework of consequence based design. While building designers rarely are experts in building performance evaluations, the parametric framework of consequence based design puts the building designer in charge of one or more BPS tools. Only through an integrated dynamic model is the validity and required expert knowledge present without continuous attendance of a simulationist. This gives the building designer a new level of freedom and autonomy to experiment with the building design, while relying on valid performance feedback. The framework gives the simulationist more time to analyze results and support the building designer in ways a BPS tool cannot, meaning the quality and depth of the building performance analysis can be greatly improved. Tedious tasks of reminding the building designer to adjust window-wall-ratios and using sufficient insulation are no longer necessary. However, with the actual presence of a simulationist acting as an expert analyst, knowledge in building performance has become a central part of the early design stages.

While consequence based design detaches itself from many procedural ideas in the integrated design process, the framework of consequence based design is capable of delivering the same end goals as described in IEA task 23 (Löhnert *et al.* 2003). However, consequence based design is not explicitly distinct by improving energy performance and indoor environment, since any simulated performance metric by a can be used. Treating quality defined and quantifiable objectives as equal is what makes consequence based design a framework superior in the integration of disciplinary expertise in the early design stage.

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