Complex design strategies using building information models

Evaluation and interpretation of boundary conditions, supported by computer software

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The choice of a chord and its execution should be regarded as a must and not left to arbitrary wish or superficial speculation. (Johannes Itten, 1961)

The paper describes a modular concept for the IT-support of planning practice using BIM (Building Information Modelling) and a parameterized building model. The platform used is the modularized software concept for architectural planning in existing built contexts (prototype software FREAK). The current progress in the development of a reasoned support of planning tasks is described in this paper in more detail. The system consists of a series of software prototypes which are linked to the BIM, utilize the specific data within and demonstrate the value of a consistent and extendable CAD-model.
The "Colored Architecture" software prototype is one such design-support module of the software platform and enables the designer to experiment with the parameters colour, light and materials in architectural space. This module supports experimentation, assessment and realization of colours and materials in the architectural design process on a new quality. For instance, the integration of "live radiosity" light simulation allows a qualified and interactive assessment and evaluation of colours and materials in near-real lighting conditions.
The paper further elaborates on software prototypes, modules and concepts including building surveying and the design of self-supporting domed structures.

Keywords: *Design; Parameterized Building Information Modelling; Plausibility; Planning Support; Colour, Material and Light Design.*

Instruments – digital tools

The computer allows us to increase both the efficiency and quality of many aspects of planning. Better computer performance and hardware capabilities have made it possible to support increasingly complex tasks, e.g. visualisation, complex calculations and data management etc. However, increased computer performance in itself is not enough. To truly support the planning process, the designer must be provided with useful and relevant tools for a wide variety of purposes, e.g.

- providing knowledge,
- retrieving/storing relevant information,
- a consistent data model,
- comprehensive yet simple control,
- adaptability and extendibility,
- an integration with plausible and relevant design assistance, etc.

Digital support should complement the experience and expertise of the planner and be able to respond flexibly to the planners needs. In this way, efficient and qualitative support for many aspects of the design process can be provided. It also helps students and planners with less experience to better learn and understand planning tasks and how to approach those using planning tools.

A central research topic at the InfAR chair for Computer Science in Architecture at the Bauhaus-University Weimar is the conception and development of program-modules to assist the planner in developing plausible and reasoned design solutions. In this paper we describe the state of the art of current research initiatives, approaches and developments.

Data model and platform

The complexity of planning tasks necessitates a special data model architecture. The meanwhile well introduced term Building Information Model (BIM, 2006) as a basis for the continuing consistent development of a building model is the way ahead for CAD planning. Using the software platform prototype FREAK, developed as part of ongoing research (Thurow, 2004), a special building information model was defined, developed and realized as a prototype. Planning data can be created, edited and saved both centrally and decentrally. A planning task can therefore be undertaken as part of a networked team or traditionally in a single-user environment.

BIM as used for most commercially available planning systems supports tools and concepts primarily aimed at handling classic object-oriented geometric elements. Architectural design is, however, much more than this. The BIM concept still needs appropriate tools and forms of representation for competently supporting specific planning tasks. It has to be stated out very clearly, that the use of the BIM-concept for the classical and established workflow in the architectural planning praxis is not expedient and effective. BIM-technology demands integrated program modules for the simulation and evaluation of the digital design model. Only then the workload of preparing a computer building model is acceptable and logical. These areas have been the focus of research at the chair for Computer Science in Architecture in Weimar and a number of prototypes have been developed.

An important concept for CAD-planning is the use of associative parameters. Abstract geometric values such as length, height, distance, angle, area etc. can be related directly to the geometric model so that parameter and geometry can influence one another, forming a consistent building model. This technology increases the functionality and control one has over the building model. An example of this is the surveying system in FREAK (Thurow, 2004). It integrates the dynamic modelling management system MVS (Hauschild et al., 2000). Using MVS, the parameters of a model are generated dynamically and linked associatively with the building model so that they can influence one another. The parameters generated through MVS and the geometric parameters ascertained during the survey effect one another and for the geometric model are resolved using a computational adjustment algorithm integral to FREAK.

Instruments and models for planning within existing built context

Today to design and to build in Europe means to work within the existing built context. Planning processes and methods have to be fitted on this situation. Today's CAAD-systems and BIM-proposals are not able and suitable to support the design in such existing environments. Basic deficits do exist, e.g.:

- the building parts in CAAD for new buildings are in conflict with surface models coming from the surveying process,
- free-form surfaces for ceilings and roofs in established buildings versus ashlars-shaped wall modelling in current CAAD and
- the different graduations for the level of detail for the modelling of existing buildings. Not all parts of existing buildings are intended to be changed on the same level of detail. Very often only a few parts are changed and detailed very much, while other parts stay unchanged. Considering that, we need a graduation between sketch and detailed construction models.

Surveying on site – the FREAK concept

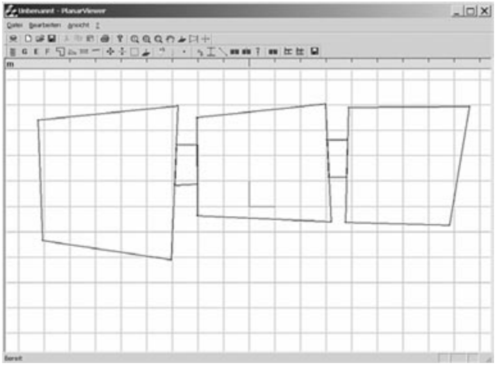
A building survey is an essential prerequisite for successful planning within existing built contexts. Currently available software solutions provide support for individual surveying methods and the manual construction of a building model out of these. To be cost and time efficient, building surveys need to be undertaken with a view to their further use in future planning phases. Digital techniques can potentially offer a variety of means of supporting this aim, although most existing systems fall far short of this. In most cases existing commercially-available software supports only certain aspects of the building survey, primarily the survey of geometric information: this is usually limited to a purely geometric representation and rarely takes into account the successive room-for-room process of the actual building survey. The combination of different measuring techniques is usually undertaken manually using fixed points common to two measuring systems. The surveyor is forced to develop the model manually from the measured data, rather than successively building a model as measurements are taken.

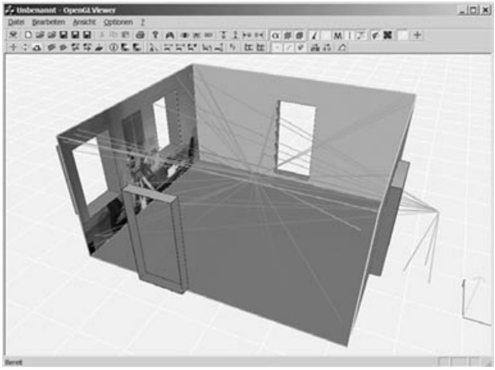
An approximate surface model

In the early phases of the building survey, the surveyor typically records the building surfaces and the presence of associated visible elements such as doors and windows, or columns and beams. The actual size of the building elements is typically obscured behind coverings such as plaster and wallpaper. The FREAK software platform supports the surveyor's working method. The surveyor moves from room to room making sketches of room surfaces and door/window elements (Figure 1). The result is an approximate surface model not to scale. The surfaces become part of the taxonomy of the building model.

Combining measuring techniques

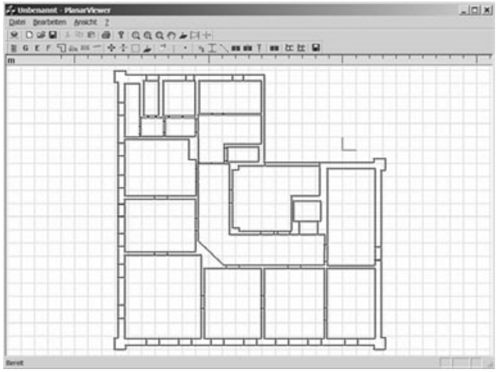
The actual taking of measurements begins in a second stage. Any number of different measurement techniques can be combined, whether manually-taken measurements or using tacheometry or photogrammetry (Figure 2). The surveyor measurements

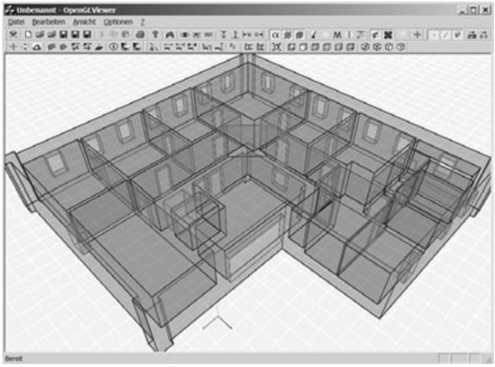




Figures 1 & 2
Sketch-based modelled approximate representations of three rooms. The room measured with the help of geometric abstractions, manually taken measurements, tacheometry and photogrammetry.

Figures 3 & 4
Plan view of a building survey. 3D-view of the geometric representation of the surveyed model.





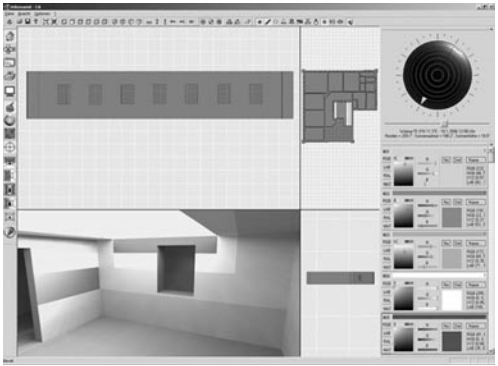
are added to the sketch model, e.g. the distance between two points on the sketch is measured and entered into the model. A computational adjustment algorithm is responsible for adjusting the geometric model based upon the measurements taken and for resolving inconsistencies between measurements taken.

To simplify the model and the survey, geometric abstractions (simplifications) can be defined for particular common kinds of relationships such as parallel walls, walls at right angles, horizontal or vertical surfaces etc. These can be controlled by the user.

This approach allows both precise and imprecise geometric information to exist alongside one-another in the same model. The surveyor can for instance sketch the floor plans in 2D and add the height later. Likewise, the inner geometry of rooms can be measured using tacheometry and the respective positions of the tacheometer later linked to one another. This overcomes physical obstructions such as doors between rooms which cannot be opened as the key has been lost.

A further important aspect in the computer-aided support of the building survey is the provision of tools to verify the accuracy of the geometric model. For instance a motorised tacheometer with laser beam can be driven by the model to point to and light up marked points within the actual room. The calculated position from the model can therefore be compared with the actual position in the room. The following figures 3 and 4 show the geometric image of a manual test survey.

The described building model is using the BIM concept for further planning steps: editing, extending, simulation and evaluation. A few proposals are discussed now.



Figures 5 & 6
Screenshot of "Colored Architecture" and a photo of the real room.

"Colored Architecture"

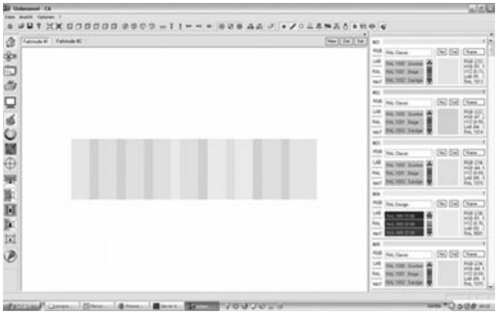
As described at the eCAADe 2004 in Copenhagen (Donath, 2004) we have focused the research activities upon different fields of simulation and evaluation, which are based on the BIM concept. Such a module of the software platform is a software concept called "Colored Architecture" (Donath et al., 2004; Tonn, 2005) which defines and examines the parameters of light, material and colour in architectural environments. Part of the research involved evaluating the concept prototype and its practical usefulness using a real design task with students.

The software prototype "Colored Architecture" supports digital planning with colour and materials from the initial design, through the planning phase to specification. It adapts existing strategies, instruments and representations, e.g. alternative variants, colour studies and colour relationships such as harmonies and contrasts. The assessment and evaluation of the design is undertaken using elevations and perspectives from the 3-D model. A further useful representation, particularly for editing, is the 'unfolded' 2D interior elevations of a room including floor and ceiling. To reliably assess and evaluate the results of colour and material choices, radiosity visualization is employed as it is able to represent interactions between different surfaces, e.g. reflections (Figures 5 & 6).

For the design task a building from the Bauhaus-University Weimar was taken as an object of study (Figure 11). By way of example, the design proposal involves the design of colour solar protection elements in the form of textile blinds behind the façade (Weinhardt, 2006). A series of different design proposals were evaluated using the "Colored Architecture" prototype tool.

Chosen planning methodology

At the outset of the design development, abstract colour variations were devised with the help of the colour design area of "Colored Architecture", which enables abstract colour combinations to be devised. In the main window of the colour design area a rectangle of freely-definable dimensions is drawn and then subdivided into surfaces using guides. This can be undertaken manually or automatically according to parameters given in a dialog-box. The individual sub surfaces can then be coloured and their interdependency with one another varied as means of



Figures 7, 8 & 9
Colour design study for one storey. POV-Ray Radiosity rendering of the design from inside. A photo from inside the analysed room.

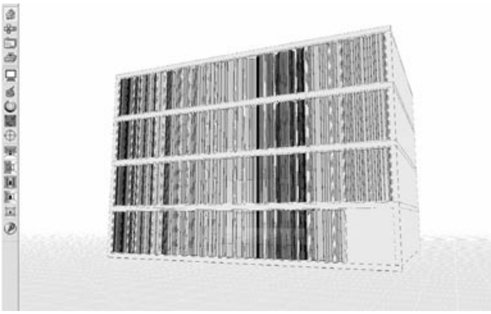
determining colour spectra. This abstract approach to designing colour combinations is a later addition to "Colored Architecture" and a direct result of trials undertaken as part of teaching. Despite, or perhaps because of its simplicity, it has become a much-used tool in the colour design process using "Colored Architecture".

Figure 7 shows a colour design study using a rectangle that approximately relates to the size of a storey. The subdivisions were defined manually by the designer. The modulation of the coloured surfaces is not arbitrary but the result of design intentions on the part of the designer. The screenshot in figure 10 shows one variant undertaken as part of the design study.

Identification and analysis of deficits

After the design study, a radiosity visualisation was undertaken both as a means of evaluating the colour design concept as well as for presenting the design. The freely available external renderer POV-Ray 3.6[1] was used (Figure 8 & 9).

An evaluation of the usage of "Colored Architecture" shows that the main deficits occur in connection with the visualisation. The visualisation does not provide a realistic view of the situation and hinders a reliable evaluation of the colour design study. The deficits could be a product of the export itself, possible insufficient colour and material definitions or a too simple representation of colours and materials in "Colored Architecture" itself, which derive from the early level of the implemented prototype.



Figures 10 & 11
3D-model with the designed and coloured textile blinds from outside. A photo of the object of planning and its environment with the glazed façade.

From "Colored Architecture" to "Colored and Materialized Architecture"

One approach to improving the deficits identified is to improve and extend the way in which colour and material parameters are given and their display within "Colored Architecture". In addition to colour itself, a number of further parameters are relevant for assessing the results:

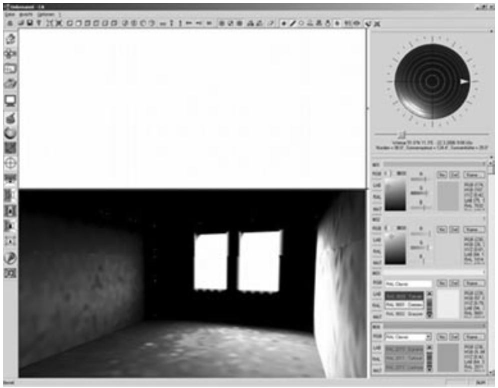
- Texture and structure
- Reflections
- Transparency
- Diffusion

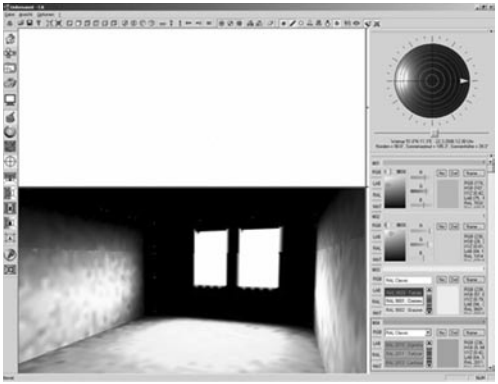
It quickly became apparent that the assessment of colours and materials is most effectively undertaken using radiosity light visualisations to show colours and materials in the context of the utilisation in the building. They appear very differently to the simple colours and materials shown on colour swatches or material catalogues. The attributes hue, saturation and lightness for materials vary depending upon the light, itself a factor of the position of the sun, cloud cover, atmospherics and artificial light as well as on the colours of nearby surfaces. Radiosity visualisations help simulate the effects of such interdependencies.

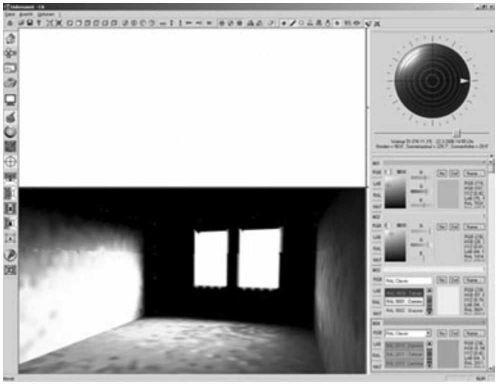
As a result of the evaluation, a "live radiosity" light simulation capability has been developed which enables the interactive and qualitative selec-

[1] Persistence of Vision Raytracer Pty. Ltd., 2006

tion and assessment of colours and materials under near-real environment conditions (Tonn et al., 2006). The process exploits hardware-accelerated techniques in current graphic cards (pixel and vertex shaders). First tests and studies using 'live radiosity' show great potential and we expect to see further exciting developments for "Colored Architecture" in future (Figures 12, 13 & 14).







Figures 12, 13 & 14
The "coarse" direct illumination of a room without reflections and light diffusion for early morning, midday and evening using the CIE-sky illumination model (Preetham et al., 1999; Darula et al., 2002).

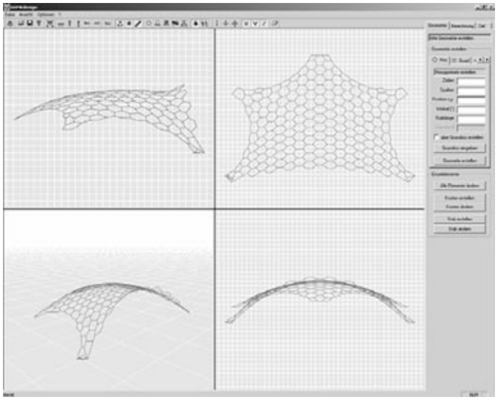
DOMEdesign – the formal shaping of shell structures

While "Colored Architecture" helps the architect to define, combine and evaluate the colours in the architectural design, the secondly discussed example "DOMEdesign" is placed in the field of structural design. Complex shell structures used in architecturally ambitious constructions remain as appealing as ever in the public realm. The support for design and planning of such structures was conceived and developed together with the chair for structural engineering at the Bauhaus-University Weimar, Prof. J. Ruth (Tonn, 2003). Developed as an advanced module based upon the platform and model of the FREAK concept (Thurow, 2004), the DOMEdesign software prototype helps in determining the design form of affine self-weight topologies for shell structures with particular emphasis on the early design phases.

The software tool DOMEdesign supports the formal design process of lattice and grid shell structures based upon the laws of physics. The computer-aided simulation of suspension models is used to derive structurally favourable forms for domes and arches subject to compression load, based upon the input of simple architectonic parameters. The planner need not concern himself with complex material properties at this early stage of planning. Instead the form determination takes into account geometric criteria such as span, dome height and plan dimensions of the area to be roofed over. Likewise the topography of roofs or landscape can be defined and the points at which the dome construction may rest. The main concepts, which support the digital design with DOMEdesign, are:

- the design-oriented approach to generate net structures

Figures 15 & 16
Dome shell of the open-air theatre. Final formal design using DOMEdesign.



- the use of three dimensional topographies as bearing surface and
- the handling and adjustment of design parameters during the calculation process.

A recent example of the use of DOMEdesign in practice and in teaching is R. Kramer's diploma project entitled "The structural design of net structures using the example of the open-air theatre in Grötzingen" (Kramer, 2005). Figure 15 shows the open-air theatre built in 1977 in Grötzingen and designed by H. Isler and M. Balz. The concrete shell structure covers an area of 600 m^2 and measures 28 x 42 metres. After determining the appropriate form in DOMEdesign (Figure 16), the model can be used for realising the design. The shell structure derived by R. Kramer is shown in Figure 17. The different coloured lines represent structural members with different cross-sections. Figure 19 shows a photo of the model constructed with the help of a support model cut using a CNC-cutter (see figure 18). The support model was machine-generated using digital planning data resulting from data originally generated in DOMEdesign.

DOMEdesign has been made available online for free for some time (Tonn, 2003) and has been downloaded hundreds of times by users from all over the world.

More BIM more fun?

All of the planning prototypes described in this paper address the support of particular planning tasks and are integrated as modules in the software platform and model FREAK. Accordingly they access and contribute to the BIM and demonstrate the advantage of a consistent central and flexible CAAD model.

By using research results in a testing environment we are able to evaluate research concepts in practice-oriented studies, to identify deficits and gain not only valuable feedback but also new impulses for further development. The modules discussed help speed up decision-making in the design process and also help make design decisions more reasoned and therefore plausible. The parameterised approach to the building models enables the planner to work with a BIM within a CAAD model and to continually develop the model further. Many further digital tools can be developed to support other specific planning tasks using the same platform. It is a step in the right direction: a single complete model that can respond to the complex demands of architectural design and building.

Acknowledgements

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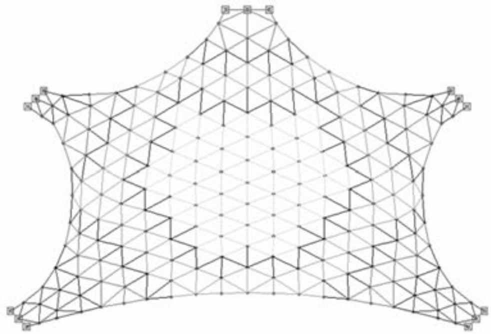
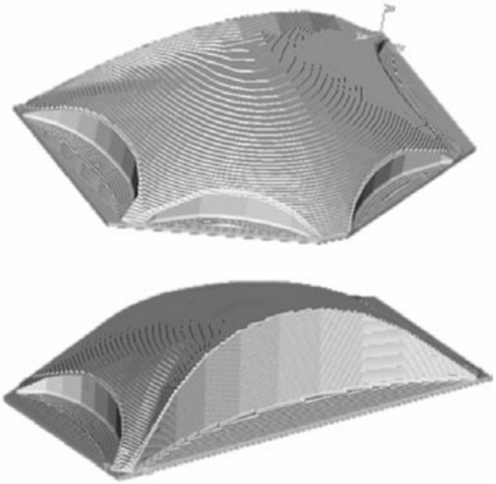
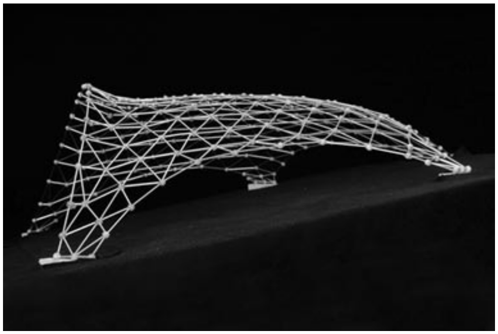
tural engineering at the Bauhaus-University Weimar, Prof. J. Ruth.







Figures 17, 18 & 19
The derived structural net of the shell (Kramer, 2005). The 3D-model of the support model for the CNC-cutter. Photo of the final model.

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