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Modeling and energy analysis of buildings based on integrated CAD – models in tuition of CAAD

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The first implementation of the system MEA for building spatial and structural modeling and energy analysis using integrated graphical digital models in tuition of architecture students is being described. Working at different design stages and with various types of models the aim was to deliver the understanding of CAD tools as intelligent rather than pure technical ones.

Keywords: *3D modeling of buildings integrated digital graphical models, energy analysis, variant design.*

Introduction

The scientists, designers, the representatives and government of municipalities, the users of the building industry production in our country and in the Eastern Europe investigate the problems of energy saving in the buildings and try to find the ways and tools to solve them. National codes and regulations, books and articles prepared by the experts concerning the heating saving of newly designed buildings and buildings under renovation are being published in Lithuania. All that makes better the preconditions of the designing and renovation of the objects taking into account the energy factors.

On the other hand there is a lack of methods in our country for the energy analysis of architectural and structural solutions of buildings allowing to evaluate the projects especially using the systematic approach and make an energy related decisions.

The system MEA (modeling and energy analysis) is our attempt to create an automated system for effective modeling of buildings at different design stages, analyze and evaluate alternative projects.

One of the important reasons encouraging the development of the system MEA is that according to our new building regulations we are obligated to control not only the U-values (heat transmission coefficients) but also the specific heating energy loss index of building projects already at architectural design stage. The calculation of these indices could be labour demanding especially when investigating several design alternatives. Other circumstances relating the problem are that the U-values for different enclosing parts of the buildings are limited with two the lower and the upper ranges and the differences comparing various parts of the building are very distinctive. So as a rule we have to investigate several design solutions (both architectural and structural) at the same time keeping control over mentioned thermal indices.

That is the background of the research and the proposed academic course.

Objectives

New course related to building spatial and structural modeling and its energy analysis was developed and implemented for students of architecture in context of general curriculum of CAAD. Before that semester the students of the faculty have three semesters related to CAD methods and technologies (2D, 3D, program development, practically based on AutoCAD). The main aim of the new course is to push students from using computer as drawing board towards computer aided design, where computer is more than a pencil.

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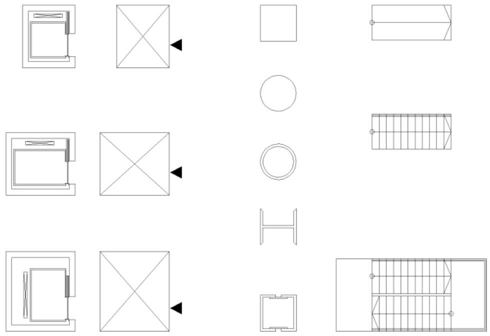

Figure 1. Elements in design vocabulary

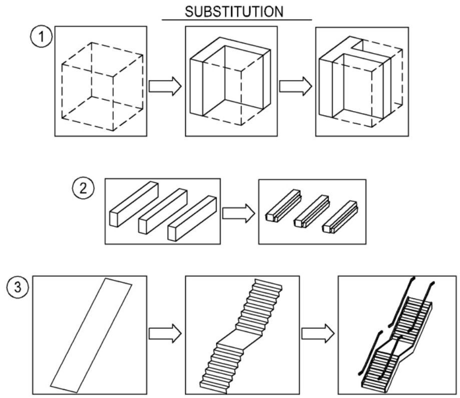

Figure 2. Substitution and level of detail

Requirements and concepts of the system MEA

We realize the process of the designing of new or renovation of existing architectural object as a process of the iterative and interactive searching which is implemented in practice by changing the model of the object and defining it more precisely, by removing it and returning again to the previous solution, by modifying it's geometry and possible re-building of initial forms of the model. This approach led us to main ideas that we implemented when designing the subsystem of spatial modeling of the system MEA:

- Quick and possibly unconstrained generating of the initial general building forms in the beginning using the orthogonal approximate geometry;
- Creating of the design vocabulary as a graphical digital database with the broad manipulating possibilities with its elements;
- Modifying of the form and dimensions of the forms as the elements of the graphical digital database and defining of the stages of editing;
- Description of the relations between various modeling stages and free exchange between the elements of the model and the elements of the database;
- Creating and support of hierarchical definitions;
- Ability to apply quickly the precise dimensions and other geometric constraints to the components of building model;
- The size of the model is the critical issue.

The modeling part of the system deals with the geometry of the whole buildings or the parts of them. In the viewpoint of methodology it is influenced on the known paradigm called "Types & Instances" and its main concepts (design vocabulary, substitution, level of detail, hierarchical structures) formulated William Mitchell (1990) and later also developed for architectural design by Gerhard Schmitt (1993).

The elements of the design alphabet could be simple geometric forms (or types) identified with the building, parts of the building and its definite structural components. A rectangle box as a type (the building, the level of the building, the fragment of the wall, the column or the beam) will be defined as an instance with the particular geometric parameters (properties): length, width, height, etc. (Fig. 1).

The concept of the substitution according to G. Schmitt has three main meanings (Fig.2): first - the substitution of the alternative by another one according with the predefined constraints, that means the full substitution of the object by another one; second - the substitution of one class objects to appropriate objects of another class; third - the substitution of general representation of the objects to more complicated and more similar to real objects representation. The substitution as a procedure could be used during investigation of the design alternatives by repeating the condition "What if..." interactively.

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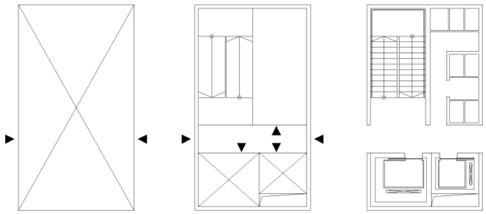

Figure 3. Level of detail in complex object

Thus the principle of the design vocabulary with the exchangeable building elements could be defined.

The definition of the degree or level of detail allows us to adjust the CAD model of the object to the design stage and to the degree of the object understanding. This tool enables us to overview different versions of the object represented in various degrees of detail. Main properties of the object like position, size, relations to other parts of the building remains the same, but the details of the form and the internal structure will be changed (Fig.3). In that way the elevations of buildings could be visualized with the ornamental details or much more abstract. Contemporary buildings having complicated internal structure because of the various engineering facilities could be represented also differently depending on the degree of detail of internal elements.

The idea of the hierarchical structures is well known and used often. The tool of the definition of hierarchical structures allows us to create more complicated structures of CAD models, to study alternative solutions effectively and enables to create new architectural quality.

Methods and structure of the system MEA

The core of the automated system are programme modules that enable to create integrated graphical digital spatial models actually represented by CAD database entities associated with different kind of structured information (mainly non-geometric physical, economical data) of the appropriate part of building: wall, roof, windows, etc. In other words, for our particular purposes we build integrated models on the basis of internal CAD database where different data is associated. In technological viewpoint the method proposed relies on open architecture of the basic CAD system allowing to customize standard programmes in wide extent and is based on module structure principle of programme development. The whole system includes various relatively independent programme modules for generating and analysis of the model and interaction between the system components. Some of these programmes using predefined data structures build an internal interface between the modules and external or user interface between the system and the user. The user manages MEA procedures and initiates definite modules using different menus or as alternative command line input. The version of MEA we are presenting here operates in MS WindowsXX / AutoCAD environment.

Generally modeling and energy analysis system of buildings MEA consists of these main parts:

- The subsystem of generalized (conceptual) geometric modeling of the building complex, building, or part of it;
- The subsystem of detailed geometric modeling of parts or structural components;
- The subsystem of geometry analysis of the model of building;
- The subsystem of energy analysis and evaluation of projects;
- The subsystem of review of indices and comparison of projects.

First subsystem enables the user to generate relatively quickly spatial surface building models and includes the ability to create different levels of detail of generalized compositions. Second subsystem lets create 2D graphical digital database of architectural/structural components by associating structured non-geometric data. In third subsystem are implemented the procedures of automated reassigning of 2D components' data to spatial model elements, filtering and analysis of internal CAD database in order to extract appropriate data required for calculating of resulting indices. Fourth subsystem is created for

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evaluating of project versions taking into account the resulting indices, registering/deleting of results in/out the memory, executing arithmetic operations with the indices and reviewing of results.

Modeling and energy analysis of an architectural object

We tested the system recently using various architectural objects in geometric and typological viewpoint. Here we present one of the examples of modeling and energy analysis of the renovation project of secondary school in Vilnius undertaken by the student and also supported by teachers.

This is a short description of the object: the school under renovation was initially built 1975 using typical project, built area was 2775.2 sq.m (dark grey), the area of additional new part is 1330 sq.m (light grey), number of levels is 2 or 3, common area of building is 6203 sq.m, the volume of building is 59356 cub.m (Fig. 4).

Existing main structures are: bearing structures – reinforced concrete frame, envelope structures – cellular concrete prefabricated 25 cm panels and 51 cm ceramic brickwork, flat bitumen paper roof, double-glazed windows, wooden doors.

First we evaluated existing building in viewpoint of thermal insulation (Fig. 5)

The results of three project solutions chosen from the projects investigated using preliminary variant design procedures we present in the paper:

First solution – all the envelopes are insulated using the lowest U-values according to national building regulation (walls U=0.3 W/sq.m *K, pitched and flat roof U=0.2 W/sq.m *K, windows and doors U=0.526 W/sq.m *K).

Second solution – all the envelopes are insulated using the same U-values. Upper slab under pitched roof are insulated (U=0.2 W/sq.m *K) instead of slopes of pitched roof.

Third solution – is the same as the second one except the windows and doors have smaller U-value (U=0.67 W/sq.m *K) (Fig. 6).

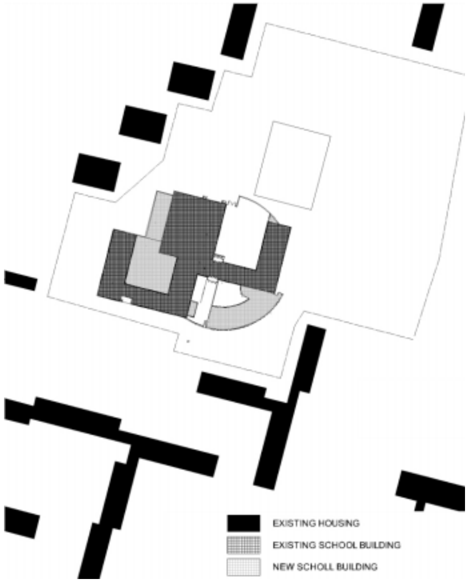

Figure 4 Scheme of the site plan

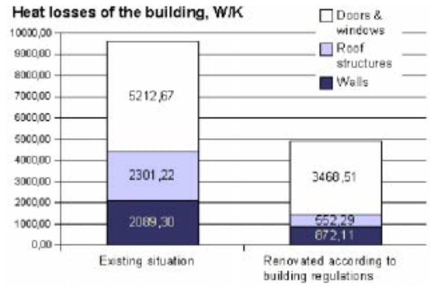

Figure 5. Specific heat losses of the old building envelop

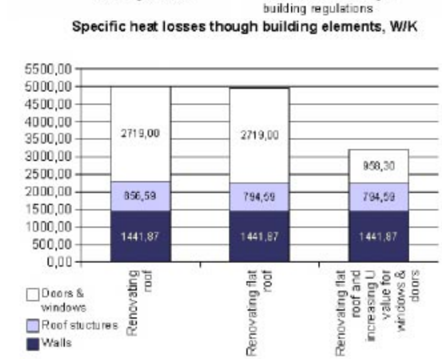

Figure 6. Specific heat losses through building envelops

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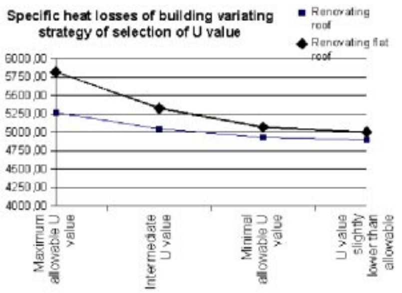

Figure 7. Specific heat losses for various U-values

The values of specific heat losses for the first and second solutions are not very distinctive because of the relatively small difference between roof envelope areas. The third solution could be a rational proposal for the client to invest by purchasing the windows with better U-value.

Finally we followed the dynamics of specific heat losses by changing U-value in the allowable range (Fig. 7)

Summary

Essential content of the system MEA for building spatial and structural modeling and energy analysis implemented for the first time in the CAAD course for students of architecture is described in the paper.

Some features of MEA were illustrated as the results of practical application of the system using academical project of school renovation.

Distinguishing features of MEA to our opinion are:

- It enables the user to generate easy and quickly conceptual spatial model representing design idea and allows the user to control and change quickly proportions, visual relations, forms etc. without applying dimensions to building parts;
- It enables the user to create and keep visual control over several versions of design and their detailed versions by tracking them in hierarchical descriptions;
- It enables the user easy to edit the abstract compositions by transforming them to building-like model (openings, roofs) and applying dimensions and other geometric constraints to parts of the model;
- It enables the user to convert the building model from pure geometric to intelligent one and keeps the model light in terms of size;
- It allows the user to control the values of evaluating indices in a graphical form during variant design procedures and helps to find the direction of rational searching of the solution;
- It allows the user to perform energy analysis procedures of building models where different types of entities and models of alternative CAD systems are used.

The students got the understanding about the proposed system as a set of tools for searching of rational architectural forms and structural solutions at different design stages.

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