Architectural software tool for structural analysis (ATSA) intended for intuitive form-finding process

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Abstract.*This paper presents Architectural software Tool for Structural Analysis (ATSA) which is designed as a software bridge between architectural and structural software programmes. It has been developed at university in cooperation with architects and structural engineers, intended to make their interdisciplinary cooperation more efficient. ATSA is aimed to provide structural analysis of drafts created by an architetct in the early stages of design in order to enable the architect to understand the mechanical responses of the structure to loading, and thus optimise it creatively through an intuitive form-finding process.*
Keywords.*design tool development; interactive structuralanalysis; architectengineer collaboration; intuitive form-finding;generative design.*

INTRODUCTION

The early stages of design are the most creative phase of the architectural process. During this phase, the architect creates a large number of drafts to be considered for further development of his design, he develops an understanding of environmental characteristics, hedetermines the geometrical limitations of his design. The architectural software tool for structural analysis (ATSA), we have been developing, will supply architects with an insight into the structural behaviour of their drafts, providing information on strain, stress, displacement, rotation, reactions, forces, and moments. Using this information, architects can understand form and forces in a designed structure and intuitively react to any manipulation of the design.

This intuitive form-finding process is similar to the ESO (Evolutionary Structural Optimisation) optimisation method. However, this method uses an artificial intelligence algorithm to solve form changes, which allows it to fully automate the form-finding process.The similarity between these two processes, especially their synergy, has recently become the subject of several research projects (Holzer, 2005; Burry, 2005; Buelow, 2009). An examination of the synergy between the intuitive process of architectural designing and an artificial intelligence algorithm in the early stage of design is a long-term goal of our research. One step towards achieving this goal is the development of ATSA.

EXISTING ARCHITECTURAL SOFTWARE TOOLS FOR STRUCTURAL ANALYSIS

The existing architectural software offers different approaches to structural analysis. These software solutions mainly differ in their method of creating the structural analysis model, the related graphical user interface GUI, workflow and demands for calculation of structural analysis (time-consumption).

The Complex physical geometry of analytical models

The simplest and most common solution is the direct export of the architectural design model from the design modeller into an external structural analysis software programme usinga universal geometric file format (OBJ,IGS, etc.) However, when the complex physical geometry of the model form is exported using an ordinary geometric file format it does not contain enough information(such as boundary conditions, material properties, cross-section) necessary for structural analysis.

Therefore, it is necessarily to manually input addition information in the analysis software (in practice this is often the structural engineer's task), making it impossible to automate the analysis process. Furthermore creating a structural analysis model identical to the complex geometry of the design model is also more time demanding for calculation of the analysis. This method alike techniques used in our original interdepartmental collaboration, due to the time-consuming analysis is not suitable for verification of the large number of drafts produced in the early stage of design.

Dual geometry of design and analytical models

More sophisticated solutions are now available based on the creation of the dual geometry of both a design and analytical model, BIM tools being one such example (Revit, Archicad, Allplan, etc.). These tools dealing with interdisciplinary collaboration belong to often discussed issues nowadays. Thanks to the archetypal nature of the design model, during its creation it is possible to automatically generate a simplified, schematic geometry against the background, representing an analysis model, which decreasestime consumption.

Generated analysis model can contain all relevant information for structural analysis and therefore it can be analysed inexternal structural analysis software (Scia Engineer, Robot Structural Analysis, FEM-Design, etc.). The aim of BIM is to develop a standardized universal file format IFC [1],to ensure data compatibilitybetween architectural and structural software. According to currently available resources, we can assume that in this workflow the architect is not expected to provide his immediate response to structuralmechanical responses (strain, stress, displacement, etc.), because the IFC file format does not provide him with the necessary analysis feedback.

In BIM, apparently, it is the structural engineer who adjusts the design modelbased on structural analysis.The design model is a communication bridge between a structural engineer and architect. The architect receives the structural engineer´s response to analysis in the form of changes made in the design model. Then, the architect may choose to incorporate those changes or further changes into his model.

Schematic geometry of analytical models

The method we propose is based on an architect´s direct response to the results of the structural analysis. The architect creates anschematic analysis model directly in the design modeller. Using ATSA

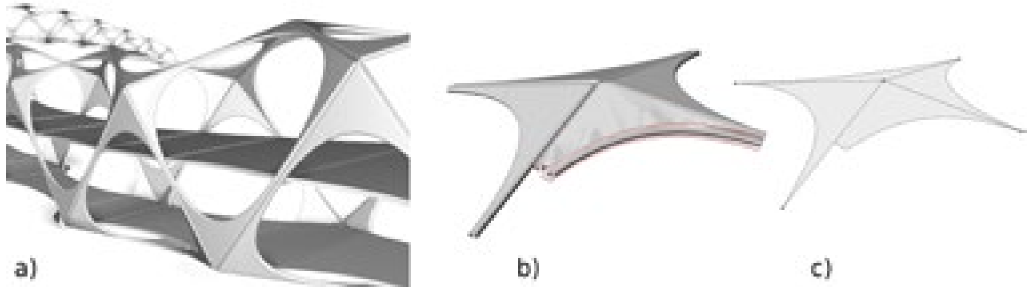
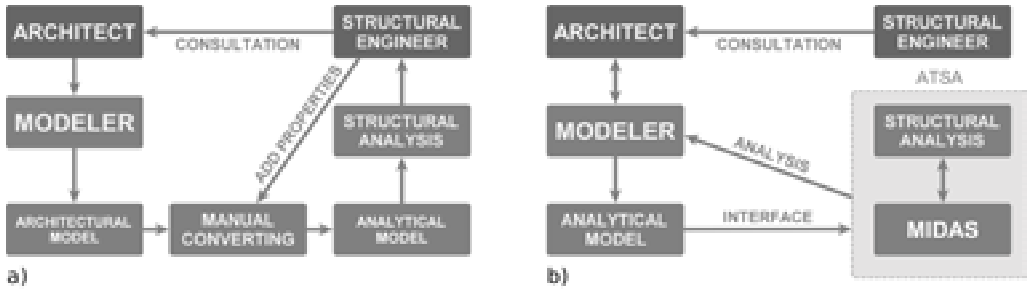


Figure 1
a) Architectural design model;
b) Structural design model;
c) Structural analysis model

Figure 2
a)Original workflow;
b) Proposed workflow



the model can be automatically analysed against the background andresults are displayed back in the modeller. With each change in the model, the process isrepeated automatically.

Creating an analysis model and inputtingthe necessary information is done in the design modeller interface using the plug-in. Direct creation of an analysis model provides better control and makes it easier to change drafts. Model analysis runs in an external programme, so the model is first exported into the adapted VTK file format [2]. After it is analysed the results are saved in it and the file is loaded into the modeller.

A very similar method of approach to structural analysis is the Karambaplug-in [3]. Unlike our solution, Karamba uses an internal library for analysis, and so it does not use any file format. The Karamba plug-in was released during the development of our ATSA and the similarity ofbothsoftwareconfirms that our development is moving in the right direction.

ARCHITECTURAL SOFTWARE TOOL FOR STRUCTURAL ANALYSIS (ATSA)

ATSA is designed as a software bridge between existing architectural software and structural software programmes being developed at university. It is intended for making interdisciplinary cooperation within the university more efficient. Our objective is also to apply ATSA in architectural practice.

Modules

The heart of the tool is the module MIDAS (Multi-functional Interface between Design And mechanical response Solve)[4] which ensures automation of the process of structural analysis on the structural engineer´s side. It is a pre/post-processor which receives, and based on parameters processes data between the architect and selected structural analysis software. This sophisticated data processing makes it easier for an architect to create an analysis model and facilitates the subsequent interpretation of the analysis results.

Currently there are two available options for structural analysis software: OOFEM[5] and SIFEL [6]. Both of them use Final Element Method (FEM). Both have been developed at the university under the GNU GPL license. As a part of our research OOFEM has been enhanced by adding some new elements and functions. The modularity of ATSA allows (if necessary) further structural analysis software to be added.

On the architect´s side, modules are being developed as plug-ins that extend existing architectural software. They make it possible to create an analysis model in the modellers which are preferred by architects. Modules extending architectural software can be added and thus enhance the variety of ways of to create architectural designs.

In designing this tool, we have focused on its adaptability and its future expandability. That is why the modules are being developed under GNU GPL v3licence. This will allow more experienced users to customize the tool to solve more specific problems. Adapting the tool helps to extend its functions.

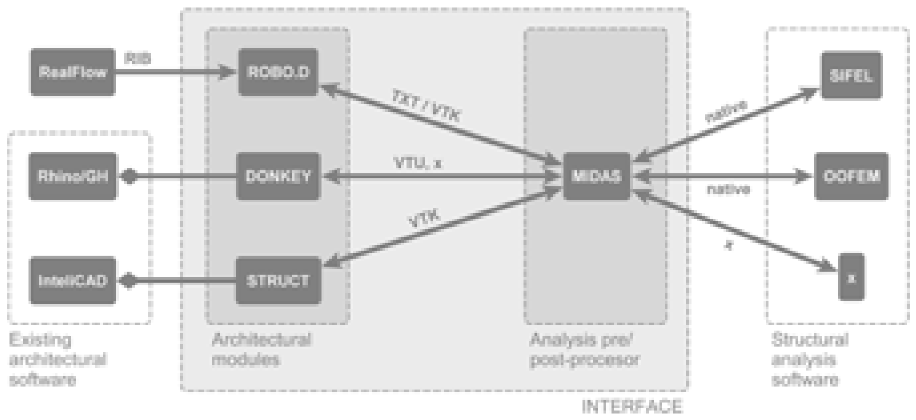


Figure 3 ATSA modules, functional scheme

Implementation

Communication among ATSA modules is performed via the VTK file format mentioned above. Its data structure is designed to work with MIDAS meeting structural calculations requirements as well as architectural requirements to represent analysis outcomes. Rules for file content and data structure are defined in the interface (OOP interface). This interface has to be implemented by each ATSA module to provide module cooperation. It is the only condition that has to be met when creating any new custom module. This interface is thus designed to be easy to implement and versatile. The chosen file format is easily readable and editable even for people (plain text file). But the ATSA interface is not necessarily dependent on a single file format. It is possible to implement new formats following the same rules or even to share data in computer memory. However communicating data via computer memory would not permit the possibility of analysis archiving or file sharing among different users.

ARCHITECTURAL ATSA MODULES

Each developed ATSA module represents a different approach to the architectural design process. It offers different possibilities and serves different goals. While the Struct module is mostly used for fast manual drafting of 2D schemes in AutoCAD®-like environments, Donkey is usually implemented in more complex and potentially more interesting generative design processes. A specific moduleto serve specific needs, Robo.dexemplifies a simple implementation of ATSA.

Robo.d

"Digital design is now fully assimilated into design practice, and we are moving
rapidly from an era of being aspiring expert users to one of being adept
digital toolmakers." (Burry, 2012).

Architects are creating innovative designs with custom created tools. With these custom tools they are able to accomplish better productivity and design control. Robo.d [7] is a specific tool which was developed in Java to design a fluid-form structure for the sculpture GDF-141 by Federico Díaz(Díaz, 2010). The whole sculpture was built from small plastic spheres, using automated robotic arms. In this project Robo.d generated simple text files for the MIDAS module which then passed geometry data to structural analysis software. Outputs were given in VTK file format, which could be inspected in the freely available VTK viewers (Paraview, MayaVi). Therefore it was not necessary to implement an analysis output display inside Robo.d. The shape of the sculpture was adjusted according to the resulting analysis, avoiding any critical tension inside the structure

Figure 4 GDF-141, structural analysis results

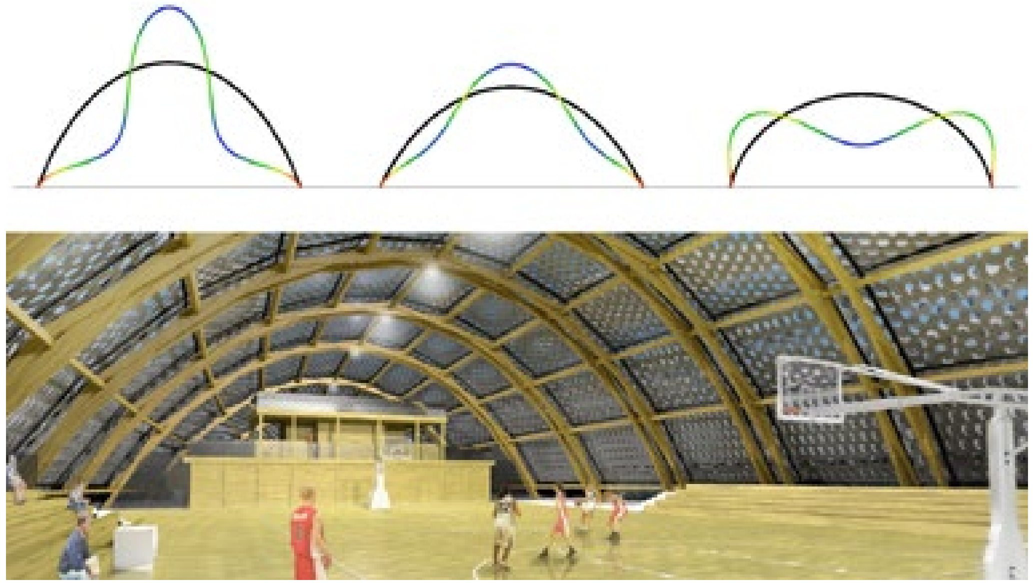
Struct

Struct is a macro written in LISP designed to work inside applications like AutoCAD® and its alternatives. Struct is being developed and tested mainly in 4MCAD which is based on IntelliCAD. Unlike other advanced ATSA modules Structis meant to be used by architects working manually in these conventional applications. They are thus able to receive outcomes of preliminary structural analysis inside the CAD environment where they are used to working every day.Simplified structure schemes are used as an analysis input and its outcomes are usually represented as a new geometry with exaggerated shift of construction nodes. In this way different design schemes can be quickly compared to each other.

Donkey

The Donkey [8] has beendeveloped for Rhinoceros® plug-in Grasshopper. Grasshoper is agenerative modelling software currently popular with architects. With Grasshopper architects can create complex parametric models of innovative constructions which can be structurally analysed using Donkey. Donkey is an interactive tool providing fast analysis feedback after the initial model has been changed. This interactivity is a great advantage mainly in the form-finding process. Donkey´s expandability allows developers to adopt specific construction solutions. An example is a student project by Martin Císař designing sports hall roof structure [9], which was inspired by Leonardo da Vinci's bridge design. Donkey was used to analyse the roof structure which helped the architect to find the optimum shape of the structure in its cross section. In the project we met the challenge to solve very special joint connections in the construction, which was solved by adding new feature to the Donkey module.

Figure 5 Sports hallroofing, form-finding process



DISCUSSION

While work ing either on real or academic projects, architects are usually not able to receive any feedback as to the quality or feasibility of construction in their drafts. Many design alternatives are quickly created and it would be very difficult or almost impossible for a structural engineer to evaluate them all. The main difficulty is incompatibility of interdisciplinarydesign data. This is usually handled by time-consuming manual model cleaning and adjustment. In consequence, structural engineers prefer to analyse only a few project alternatives. The development of ATSA solves the problem of data incompatibility and allows for the automation of the structural analysis process. The whole process becomes considerably less-time consuming, freeing a structural engineer from routine repetitive work and enabling him to devote himself to more efficient, hands-on consulting on designs. The architect obtains a degree of independence which helps him to design with more self-confidence and to create more daring and ingenious design alternatives. These design alternatives are also pre-optimised for later design stages. This does not mean that alternatives would be cut down to the simplest or cheapest options but it should help architects to back up and further develop their creative ideas.

CONCLUSION

In the digital toolmakers era we present our approach to the development of a universal interdisciplinary tool for structural analysis. We show how to ensure its interactivity, future expandability, and general versatility in other applications. Thanks to the ATSA tool architects receive information about the behaviour of structures, which can be used in their creative form-finding process. Our research concerns the natural process of form optimisation in student and professional projects, in order to better understand the needs of architects for structural analysis and representation of results. To meet architects' needs we plan to implement artificial intelligence algorithms (AI) into the ATSA tool and use them to eliminate routine repetitive work and to help with the interpretation of complicated analyses. We also intend to utilize the unique features of AI algorithms in the design process to increase its productivity and enhance its accuracy without disrupting creativity. Our aim is to satisfy demands for automation. However, we want to avoid fully automatic optimisation where the author loses control over the form-making process. The synergy between the intuitive process of architectural design and precision of artificial intelligence algorithms should enable one to produce works which represent the identity of their authors.

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