Interactive computational modelling in early-stage architectural design

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In the architectural design process, a given set of design requirements normally has to be fulfilled. In the early stages of the architectural design process, assessing the fulfilment of design requirements relies on the insight of the designer and focuses on a limited range of objectives e.g. functional or aesthetical. For other objectives, as for example engineering related aspects, the assessment is usually postponed to later stages in the design process, where a number of relevant aspects of the design may be unexplored, but already limited by earlier decisions concerning other objectives. It can also be the opposite, if the attention is only directed at the engineering aspects, functional and aesthetical design requirements may not be fulfilled.

Due to the nature of the early stage of the design process, the amount of time is very limited. From the engineer's standpoint a complete solution cannot be created in this limited time, attention should instead be directed on gaining an understanding of the overall structural behaviour and observing potential critical aspects of the design.

The absence of heuristic knowledge, such as experience, intuition, rules of thumb, and precedent examples that designs can be extrapolated from needs to be compensated by project-specific early stage information of the structural behaviour. This information is normally provided through employing Finite Element Analysis (FEA), however, the indeterminacy and rate of change in early stage design poses a risk to apply any effort into the creation of a complex analytical model early on, instead it is necessary to employ simpler and quicker models and methods.

During the last decades there has been an extraordinary development of computer-aided tools intended for presenting or communicating the results of architectural projects. But there has not been an equally successful progress in the development of tools intended to assist conceptual design studies to generate architectural forms, which in an easy and interactive way also consider engineering aspects. Modelling tools utilized in conceptual studies must be capable of interactively modifying existing models. This is a fundamental aspect in any design activity, where the designer is constantly moving forwards or backwards, re-elaborating some particular aspect of the model, or its general layout, or even to go back to a previous solution that had been temporarily abandoned. Supporting an interactive and iterative design process, requires new interaction models and numerical approaches in the tools used.

The goal of the research is to develop new efficient methods and procedures for supporting an interactive and iterative design process that includes engineering aspects and improves communication between engineers and architects by visualizing structural performance early in the design process. By integrating engineering knowledge and physical aspects in the developed tools, a more efficient and better-adapted design process can be obtained. This is in contrast to the traditional process where the engineering and physical aspects often are neglected in the tools used in the early design stage of a building, only considering traditional architectural requirements.

The area of computational analysis is well developed, and FEA is one of the most popular methods in use. Employing it in early design stage computer tools requires that user interfaces be adapted accordingly. There are several applications of this sort. One of these is an application that we developed here, which we term Sketch-a-Frame, is a 2D FEA iPad application for early stages of the design process that makes use of beam elements. FEA computations are performed in real-time, to respond to changes in geometry. Accordingly, when a node is moved, for example, the results are updated and visualized continuously. This gives the user a strong feeling of manipulating the model directly. Real-time visualization encourages the user to experiment with the model in an exploratory way. This helps the user gain an understanding of the structural behaviour involved. The multi-touch interface is important for the interactions that occur, it's making it possible for the interface to work as effectively as it does, giving the user the feeling of being able to manipulate directly the model that applies.

To achieve this feeling of directly manipulating the model in three dimensions, the authors have worked with a new device termed Leap Motion. The device enables gestures to be used in three dimensions by employing a sensor that track hands and fingers with high precision. This has been combined with the existing FEA software ObjectiveFrame (Lindemann, Dahlblom & Sandberg, 2001), which have been developed for studying the behaviour of structures in the early stage of the design process. This enables users to manipulate 3D FEA models using gestures. This has served to close the gap between the human being and the computer, giving the user a stronger feeling of manipulating the objects on the screen directly.

With the emergence of Isogeometric Analysis (IGA) researchers from the fields of computational analysis and computational geometry have been aiming at integrating analysis procedures into CAD, by using one, and only one geometric model which is utilized both for the design and analysis of a structure. IGA is an extension of FEA, and is applicable with most popular geometric representation methods such as NURBS, T-Splines, and Subdivision surfaces. Apart from removing the conversion process of a design model into an analysis model, IGA has the advantage of always representing the geometry exactly, making it attractive for many analysis cases e.g. buckling analysis of shells which are very sensitive to geometric imperfections. The authors are currently developing a plugin for Rhinoceros 3D to test the possibilities of working in an interactive and integrated design and analysis environment.

References

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