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# THE USE OF FINITE ELEMENT ANALYSIS APPLICATIONS IN ARCHITECTURAL EDUCATION

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## ABSTRACT

Architectural design is a complex process and architects are continuously required to draw and analyze resources from various disciplines in their design decision making processes. Architects commonly refer to "rules of thumb", originating from previous design experiences to deal with design issues involving engineering analysis, since the formulation and analysis of the engineering problem is usually quite rigorous. The problem with this approach is that these rules of thumb may not be appropriate to the design problem at hand. Recent advancements in computer aided design, finite element analysis software and building information modeling paved the way for "integrated design", where architects and engineers work simultaneously throughout the design process. This paper reports two case studies which use finite element analysis software (ANSYS) to enhance the architectural design process. This paper also investigates the ways this approach can be applied more extensively in architectural design education.

**Key Words:** Architectural Education, Finite Element Analysis Software, Integrated Design.

## INTRODUCTION

The developments in the computers and information technologies in the last 20 years had a profound effect on the profession of architecture. The idea of using computers and artificial intelligence in the architectural design however even precedes the advent of personal computers in the 1980s. Significant theoretical research has been conducted under the "Design Methods" movement since the early 1960s in order to adapt the developments in science, engineering and communications into the architectural design process []. Although there was considerable interest in the field of computer aided architectural design in academics, very few design offices could afford to use computers until mid 1990s and the use of computers was essentially limited to drafting and spreadsheet applications. Developments in the information technologies and the increasing affordability of the personal computers in the second half of 1990s led to the widespread use of computers in architectural design offices. The internet made it possible for design offices to collaborate with clients and design professionals around the globe. Design offices quickly adapted to the available general purpose computer aided design software for rapidly drafting 2D floor plans and production drawings. Rapid developments in computing capacities and the emergence of a new generation of CAD software tailored for architectural design eventually made it possible for architects to prepare 3D Model and deliver realistically rendered presentations of their designs. Working with 3D models especially facilitated the preparation of production drawings for complex structures such as the Guggenheim Museum at Bilbao (Kolarevic, 2003; Kolarevic and Klinger, 2008).

In the last decade, there has been a revolutionary shift on the way design models are created in the CAD environment. First generation of CAD tools mimicked the way architects prepared drafted their blueprints on paper. The designs created with these CAD tools essentially contained information design geometry, such as

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the coordinates, sets of lines, polygons and volumes. Design models using the Building Information Modeling (BIM) structure of the new generation of CAD software store non-geometric information as well as the geometric information of the design components. Element of time can also be incorporated into the BIM models to deal with construction management and maintenance issues.

Building information models provide the medium for interdisciplinary collaboration. BIM models provide the infrastructure for multiple parties, such as the engineers and project managers to work simultaneously with architects on the same project, thereby reducing the time spent on the preparation of the design project. In the conventional procedural way of architectural design, the architect prepares the architectural plans and forwards them to the engineers who design the structural, electrical, sanitary and air-conditioning components of the design project. If a problem arises during the engineering designs, the engineer reports the problem to the architect and the architect modifies the design and forwards the modified plans to the engineers. This iterative design process is very time-consuming especially for large and complex design projects. When multiple stakeholders work on the same model, the problems which may arise in the design phase can be fixed relatively easy and the time spent on the preparation of the design project can be significantly shortened.

## COMPUTER AIDED DESIGN AND THE ARCHITECTURAL DESIGN CURRICULUM

Computers and computer aided design technologies did not only have an impact on the construction practice but on the design education as well. At first, design schools computer literacy of their students by including introductory computing classes and computer aided drawing courses to their first year curriculums. Computing classes generally focused on working with the operation systems, programming and productivity tools such as word processors, spreadsheets, image manipulation and presentation applications. Computer aided drawing courses generally focused on teaching the working principles of computer aided drawing and the commonly used commands in general purpose computer aided drawing applications. As time progressed, introductory computing classes became redundant since the new generations of students were already used to working with computers, and many architectural design schools removed these courses from their curriculums. Computer aided drawing courses are still included in the architectural design curriculums but the focus has shifted from drafting 2D layouts and sections with general purpose CAD tools to constructing architectural design models using computer aided architectural design software. Although, students use computer aided architectural design software throughout their education, especially on design studios, this use is mostly limited to producing sections and floor layouts, and rendered images of their design models. However, this is a very limited use of the building information modeling technology which is used in the recent computer aided architectural design applications. There is a growing interest in the architecture profession to move towards a more integrated way of designing and architects may have to work simultaneously with other stakeholders throughout the design process in the near future. Therefore, there is a need to incorporate the practice of integrated design using building information models into the architectural design curriculum.

## FINITE ELEMENT APPLICATIONS

Finite element method is a numerical method commonly used to solve complex engineering problems, particularly in the fields of civil, mechanical and aeronautical engineering. In the finite element analysis the domain to be analyzed is discretized into a finite number of smaller subdomains called elements (Figure 1). Discretization scheme and the number of subdomains can significantly change the analysis time and the accuracy of the solution. Although, the theoretical development of the finite element method dates back to 1940s, the use of finite element programs was strictly limited to universities, research institutions and the aerospace industry until the late 1980s, as finite element analyses can be quite demanding in terms of required computing resources. Finite element analysis packages became available to a wider audience with the advances in the computing capacities of personal computers. Complex finite element analyses especially in the

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field of computational fluid dynamics still demand super computers and cloud computing, however, engineers widely use regular personal computers to run most of their finite element analyses.

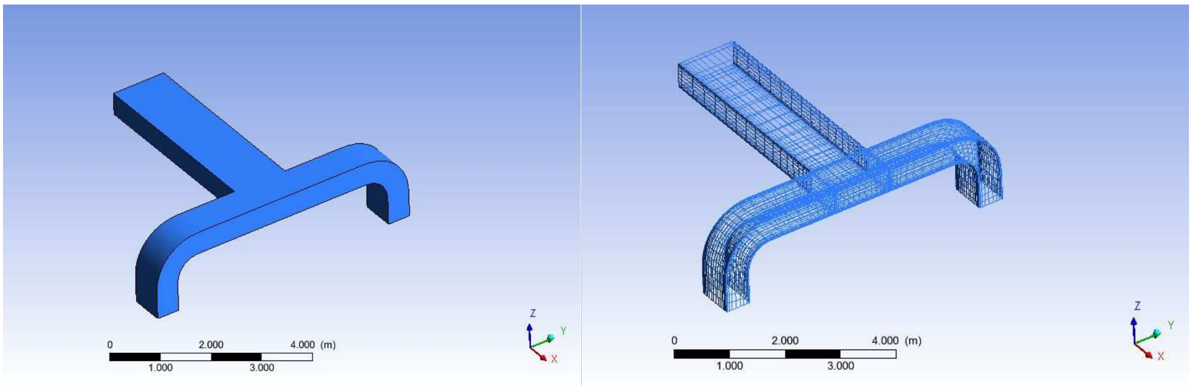


Figure 1: Finite Element Mesh of a Ventilation Duct

Until recently, the collaboration of finite element analysis tools with architectural design packages generally focused on the area of structural design and more than several computer aided architectural design packages today can forward information to structural analysis packages using the finite element method. However, the use of finite element analysis tools is also expanding to other areas such as building physics and energy efficient design within the field of architectural design. As the structures are becoming more and more complex today, it is becoming harder each day to use the “rule of thumb” approach which essentially depends on the previous experience of the architect with similar design problems. Therefore, there is a growing need to use finite element analysis simulations in the early design phase to spot possible design flaws or for experimenting with the design model to enhance certain design properties. Two examples of how Computational Fluid Dynamics (CFD) analysis with finite element packages can be used in architectural design process will be presented in the following text.

Architects are required to make design decisions within various scales throughout the design process. Mass models are widely used in architectural design to develop an understanding of the connections and relationships of the design with its surroundings. These models are also very useful in observing the implications of the design on its surroundings and facilitate the design decision making process in the macro scale for architects as well as urban designers. In the architectural design studios, students are generally required to carry out a detailed analysis of the project area and to build physical scaled mass models prior to making decisions in the micro scale.

Finite element analysis packages such as ANSYS FLUENT can be used to carry out complex Computational Fluid Dynamics analyses to understand the implications of the winds and other physical factors on the design as well as its surroundings. The effects of winds are not only essential to structural design but important for various other factors as well. Dikmen et al., have studied the effects of tall buildings on the pedestrian wind comfort In Istanbul and the effects of wind in the construction activities at highrise buildings (Dikmen et al., 2010,2011a,2011b,2012). Kolarevic presents various examples of how wind analyses can be used in architectural design (Kolarevic and Malkawi, 2005). These and other wind effects on the design can be evaluated by creating a finite element model of the project area and running CFD simulations based on the engineering data on the dominant winds. Variation of wind velocities and vorticities along wind streamlines and wind pressures acting on surfaces can be visualized through various plots such as Figure 2 and Figure3 generated through post processing of the finite element analysis results.

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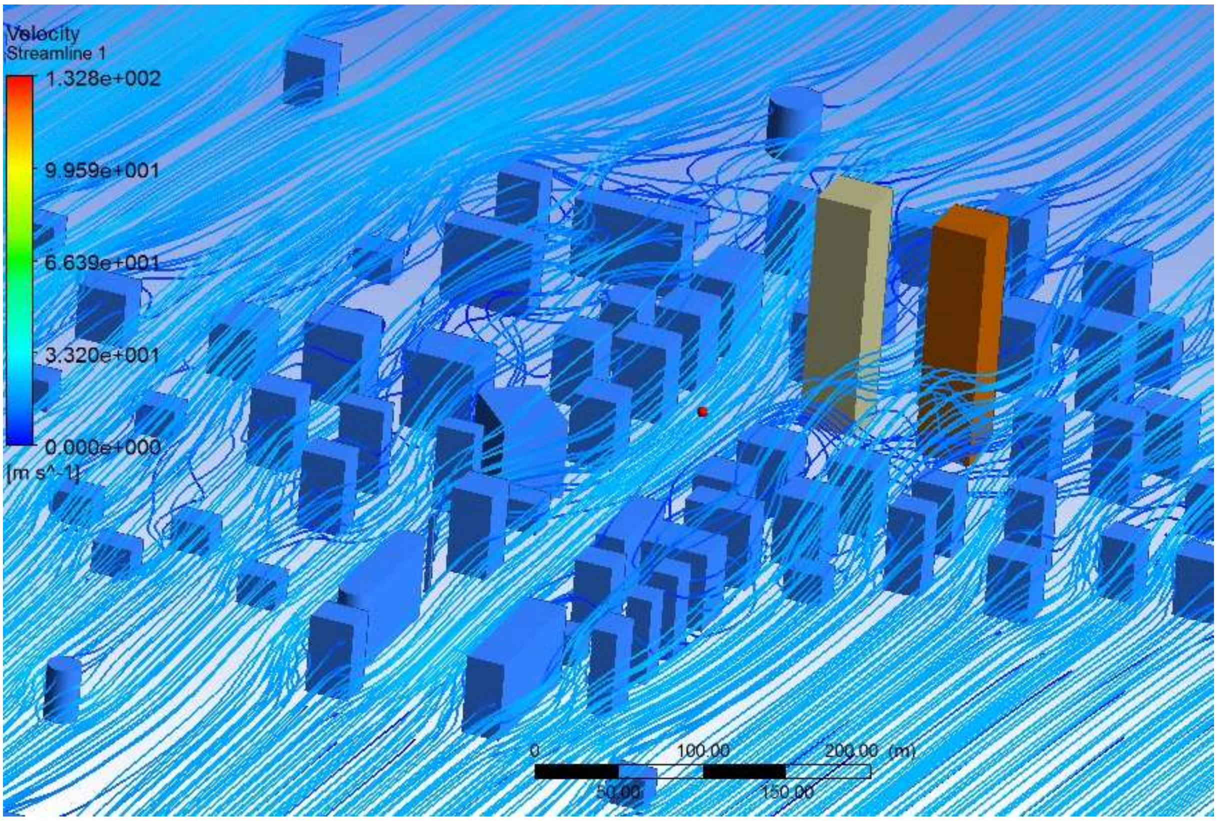


Figure 2: Streamlines of Wind Velocity Through an Urban Mass Model (Courtesy of Ümit Dikmen and Murat Aksel)

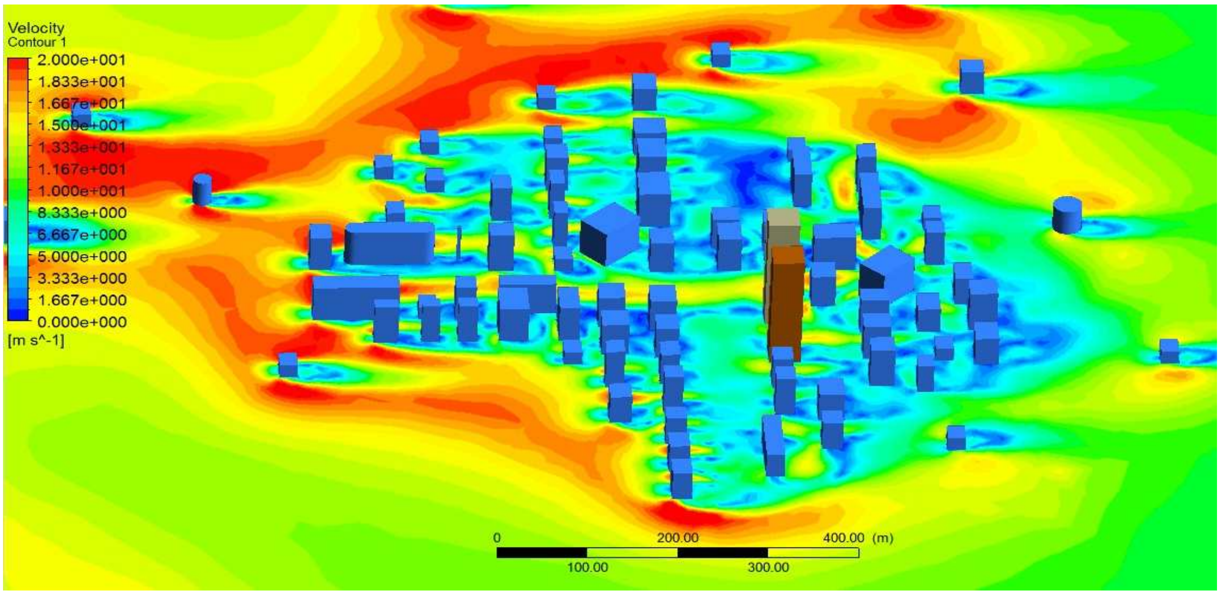


Figure 3: Contours of Wind Velocity Through an Urban Mass Model (Courtesy of Ümit Dikmen and Murat Aksel)

Computational Fluid Dynamics models can also facilitate design decision making process in the micro scale. The analysis of ventilation and heating is essential for energy efficient designs. In the following example, ANSYS FLUENT was used to obtain information on the performance of the HVAC system of a computer laboratory (Figure 4). (Figure 5) shows the variation of velocity of the air flow along the streamlines between the inlets and the outlet of the HVAC system. Similar analyses can also be conducted to check the effectiveness of natural ventilation.

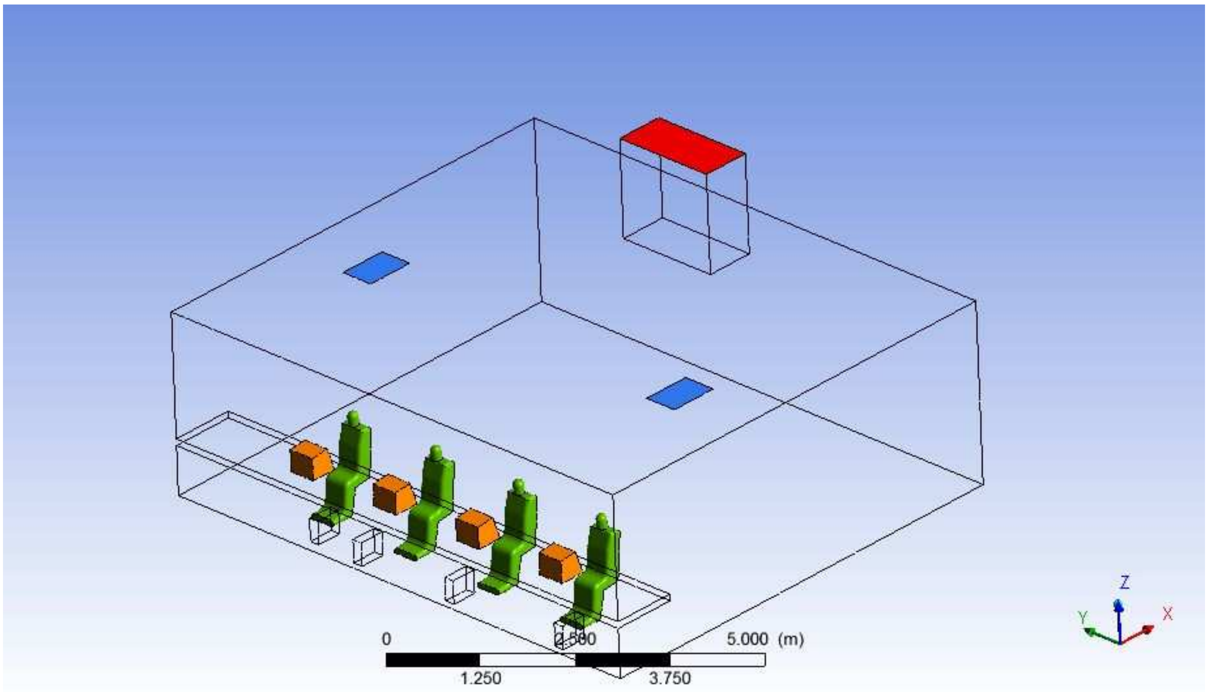


Figure 4: HVAC Model of a Computer Laboratory

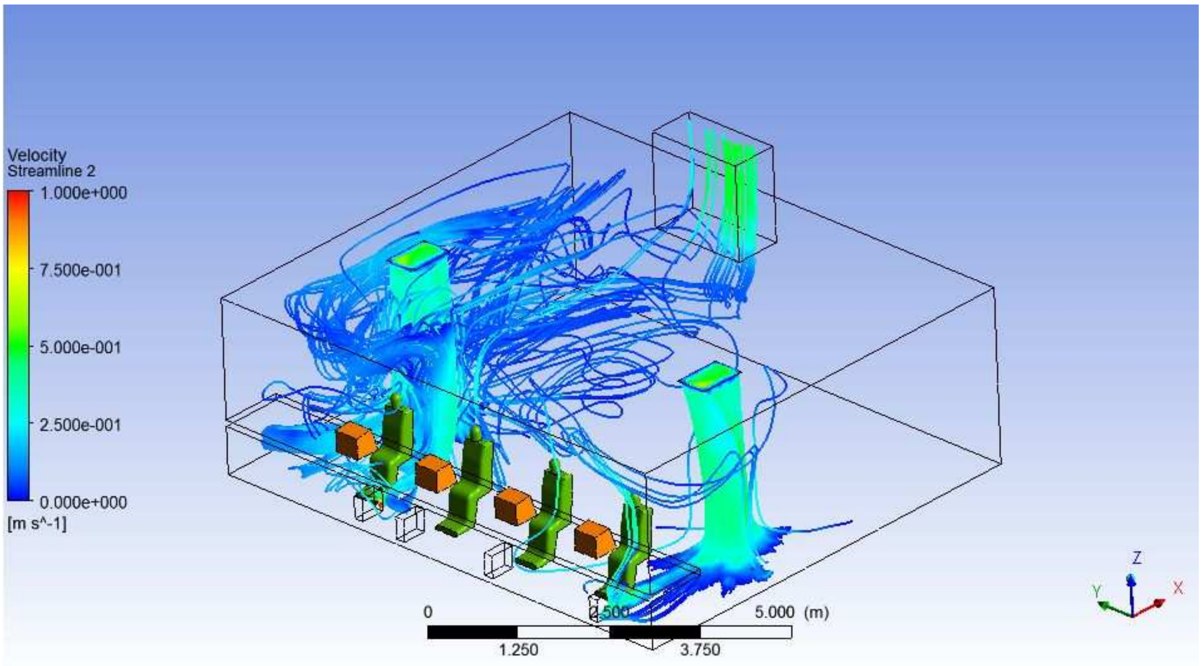


Figure 5: Variation of the Velocity of the Air Flow Along Streamlines Between the Inlets and the Outlet

## CONCLUSIONS

Architectural design is a complex process and architects are continuously required to draw and analyze resources from various disciplines in their design decision making processes. Architects commonly refer to “rules of thumb”, originating from previous design experiences to deal with design issues involving engineering analysis, since the formulation and analysis of the engineering problem is usually quite rigorous. The problem with this approach is that these rules of thumb may not be appropriate to the design problem at hand. Recent advancements in computer aided design, finite element analysis software and building information modeling paved the way for “integrated design”, where architects and engineers work simultaneously throughout the design process. Integrating the advances in finite element modeling and computer aided design tools can be used to facilitate the understanding of the implication of design decisions.

This paper reports two examples which use finite element analysis software (ANSYS) to enhance the architectural design process. Although, both examples focused on the possible uses of CFD analysis, finite analysis packages can also be used to evaluate the efficiency of other aspects of the design such as building acoustics. However, these programs require significant amount knowledge of the finite element theory and the features of the finite element software. Therefore, the user of the finite element package should have sufficient information on the nature of the design problem in order to check the validity of the results.

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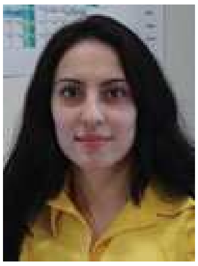

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