Parametric Natural Ventilation Simulation with Real-time Geometric Feedback (Nat-Vent)

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ABSTRACT

Nat-Vent is a modeling system to parametrically simulate natural ventilation of buildings in early stages of design. The Nat-Vent approach comprehends a set of architecture design tools that were connected to an equation solver through a Model Based System Engineering tool (SysML). SysML, which is a general purpose modeling language for systems engineering, is able to mathematically interoperate between architects and engineers while keeping model consistency between them. This implementation enhances the architectural side of design by offering a simple ventilation tool that can be used by architects and engineers, and also delivers geometric feedback from ventilation performance-based decisions.

KEYWORDS: parametric modeling; building technology; natural ventilation simulation; interoperability in building design; Model Based System Engineering.

Introduction

Since it is a healthy and energy-efficient means of supplying fresh air, natural ventilation is generally the preferred ventilation option in the architecture field. However, in building design, this has not been given proper relevance for three main reasons: the lack of effective natural ventilation tools during early stages of building design; the lack of familiarity of architects with natural ventilation analysis that favors collaborative design environments; and the lack of visualization of the geometric impact of decisions taken in the ventilation performance analysis domain. In order to improve these drawbacks, the aim of this research is to develop a model visualization system (Nat-Vent) to simulate natural ventilation, in early stages of design, using parametric data from CAD geometry of a building. Nat-Vent project is a simulation platform that consists of a group of well-known applications of the architecture domain, which have been connected to engineering applications that are able to solve the set of equations required for calculating natural ventilation. In order to easily associate applications and users of both architecture and engineering, the applications of the Nat-Vent system are interconnected by means of

System Modeling Language (SysMl), which is a general purpose modeling language for systems engineering applications (Friedenthal , Moore, and Steiner, 2008). SysML scope goes through a wide range of systems, or systems of systems, including hardware, software, processes, facilities, etc. Considering this capability of managing heterogeneous information from different domains, it is important to generate experiences that favor Interoperability of the SysML tool with other applications. The Interoperability experience trough SysML will be created using the following applications:

1. Sys Ml Modeler: Magic Draw 17.0

2. 3D Geometric Modeler: Rhinoceros 4.0 (scripting in Visual Basic Language)

3. Parametric Plugin for 3D Modeler: Grasshopper (scripting in Visual Basic Language)

4. Collecting data Software: Microsoft Excel

5. Functions Solver: ModelCenter

The present report will explicate the functions of each of these tools and also will provide a case study where the approach has been tested.
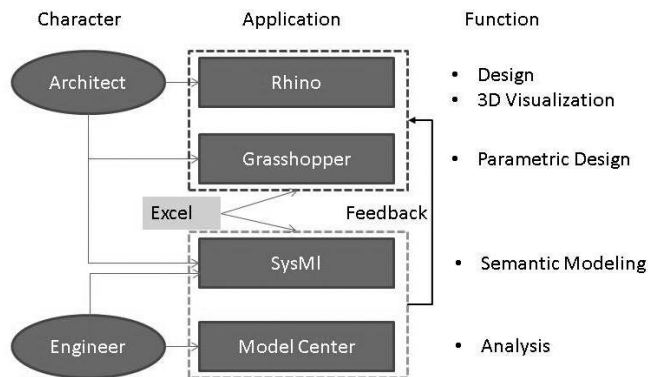
Fig.01 Diagram of relationships among applications involved in the Nat-Vent approach.

Parametric modeling tool

For the Geometric design side of the project we have created a definition in Grasshopper, which is a parametric modeling tool that works within Rhinoceros 3D modeler environment. Grasshopper is a graphical algorithm editor tools that allows creating your very own parametric designs after just a few modeling steps in a Grasshopper definition. This Grasshopper definition contains all the basic elements of any offices' buildings: Basic structure, floors, exterior walls, interior walls, openings, roofs. The Grasshopper definition contains also all the topological relationships among the previously mentioned elements. The topological relationships keep the model coherence even if the geometric values have changed.

One of the main goals of our project is to visualize the geometric impact of decisions taken in the performance analysis domain. Size of rooms and windows, height of stories, and orientation will influence the results of ventilation performance, and also affecting the appearance of the building. In order to keep track of the parameters variations, in the Grasshopper definition, we have generated specific Visual Basic scripting components that are capable to read data from Microsoft Excel. Microsoft Excel offers a well-known spreadsheet platform that can be accessed by architects and engineers to create instances of the building design. The same Microsoft Excel spreadsheet feeds the SysMl model to generate analysis in ModelCenter. The instances of Grasshopper can be "baked" in the Rhino environment generating CAD geometry to visualize changes in the buildings geometry.

Spreadsheet or databases tool

From the parametric models of the buildings, generated in early stages of design, Nat-Vent will obtain data that will feed a Microsoft Excel spreadsheet with all the numerical values required for natural ventilation calculations. Microsoft Excel features calculation, graphing tools, pivot tables, and a macro programming language in the Visual Basic language for several applications. This level of interoperability and easy accessibility were the main reasons to choose Microsoft Excel as the numerical repository of the Nat-Vent project. The Microsoft Excel numerical data will be automatically pushed from the CAD geometry and can also be manually edited or changed after optimization processes.

Equations solver

Afterwards, and using System Modeling Language SysMl as translator, Nat-Vent will perform natural ventilation simulations using ModelCenter as an equations solver. ModelCenter is used in a variety of applications, primarily system design and optimization in the aerospace and defense industry. It is also used for process design and optimization in the manufacturing industry. For this project, we used the SysML plugin ParaMagic to create parametric instances from Microsoft Excel data. Once an instance is created, we will run the SysMl to create a corresponding ModelCenter model. Then, to generate accurate results, in ModelCenter, we add weather into the model, so that we could perform uncertainty analysis.

Case Study

This section of the report shall present the Case Study where we tested the Nat-Vent approach in a five-story offices building. In this stereotype of buildings, natural ventilation is generally regarded as a preferred ventilation option because it is a healthy and energy-efficient mean of supplying fresh air (ASHRAE, 2005). In the USA, it is seldom being applied with the following reasons:

1. The performance of the system is highly determined by climates;

2. The lack of effective tools during the building-design stage;

3. Security and facility management concerns arising from operable windows;

4. Noisy and air pollutions from outside environments.

Among these reasons, this case study focuses on the second one, which we believe is one major barrier of effectively natural ventilated building designs.

Model Analysis Descriptions

This project starts from modeling generic natural-ventilated buildings in Sysml, and exam the model through some Instances produced from parametric geometric iterations. The aim of those Parametric iterations is to model the natural ventilation system to survey different options of a building in a short period of time in early stages of design. The building is a five-

story, open plan, office building located in Atlanta with stack assisted cross ventilation. Opening areas for natural ventilation should be sized to deliver the amount of ventilation necessary for cooling and fresh air. For the purpose of analysis, we will set up a benchmark scenario in which the rest related parameters are normalized such as building operation hour, people intensity, and lighting intensity. We will create 3 different instances of buildings with similar characteristics, but with different dimensions of floor area, number of windows, windows area, etc. These instances will be produced using a parametric modeler (Rhino + Grasshopper) and taking the variable data from a Microsoft Excel spreadsheet.

The most effective and accurate method for natural ventilation analysis requires thermally dynamic simulations. As an alternative, empirical-driven models are also extensively used during the early-design phase of the building. For this project, we have implemented the empirical models (i.e. algebraic equations) as constants in the SysML model. By integrating with ModelCenter, we will perform the parametric study to explore the optimum design (i.e. opening areas). To quantitatively compare different design alternatives, a performance indicator has been developed that contains the back-up mechanical cooling load. This indicator will return as numeric feedback into the spreadsheet to perform optimization based on changes of the model's parameters.

To start the new building design, we first build a parametric diagram in SysML with ModelCenter as the constraints. By following the rules of ParaMagic, we create instance automatically from Microsoft Excel. By right clicking the block that includes the parametric diagram and solving the model, a ModelCenter file will be generated.

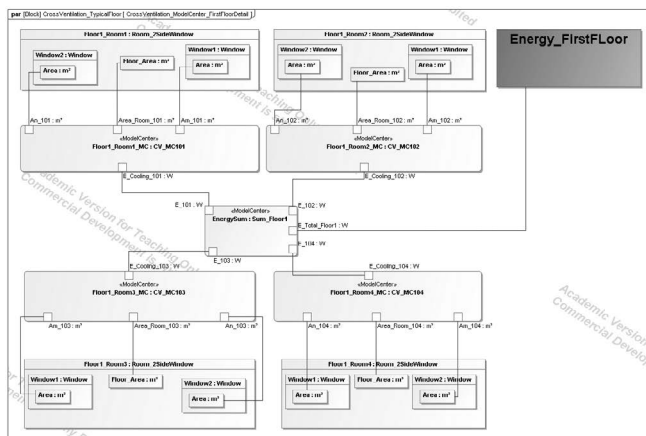As the ModelCenter file has all the design information

from the instance created from Microsoft Excel, we will performance uncertainty analysis for this specific design. In the ModelCenter file, we add another item, weather, to explore the performance of this design under other possible weather conditions.

The control logic is when indoor air temperature is higher than 22 C (i.e. indoor set point temperature) and outdoor air has cooling potential (i.e. outdoor air is cooler than 22 C), natural cooling system will control window open areas. After window area is adjusted, wind pressure drives outdoor air flow through open windows. Finally, the status of fresh air and air temperature in the room will be updated. This activity needs to repeat every certain time, so indoor environment will be monitored.

Results

The aim of these parametric iterations is to model the natural ventilation system to survey different options of a building in a short period of time in the early stages of design. We compared three design scenarios and showed the distribution of cooling energy need. Among these three design scenarios, the third design has the most natural cooling potential, so it requires the least mechanical cooling energy. However, the occurrences of extreme weather conditions (i.e., low wind speed) are not negligible, so this building needs to install certain amount of mechanical cooling to maintain a high-level thermal comfort environment.

Even though the third scenario has the most naturally cooling potential, mechanical ventilation system is still needed to maintain a consistently thermal comfortable environment in this climate condition. Thus, the building will dominantly use natural ventilation, and the back-up mechanical ventilation may be needed in some extreme weather conditions.
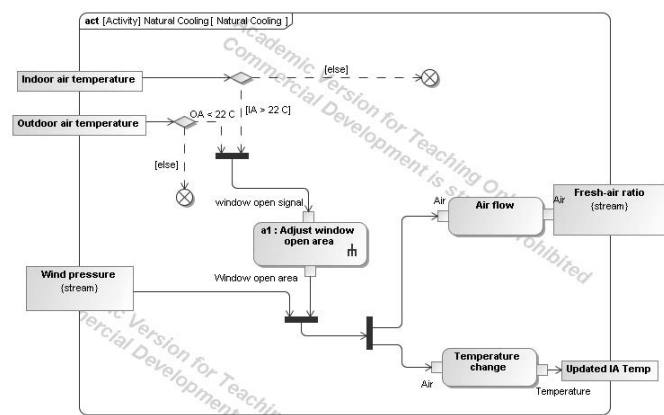

Fig.02 Parametric diagram of the energy consuption of one floor.

Fig. 03 SysML activity diagram illustrate space cooling through natural ventilation

Instance 1 (authors' work)

Instance 2 (authors' work)
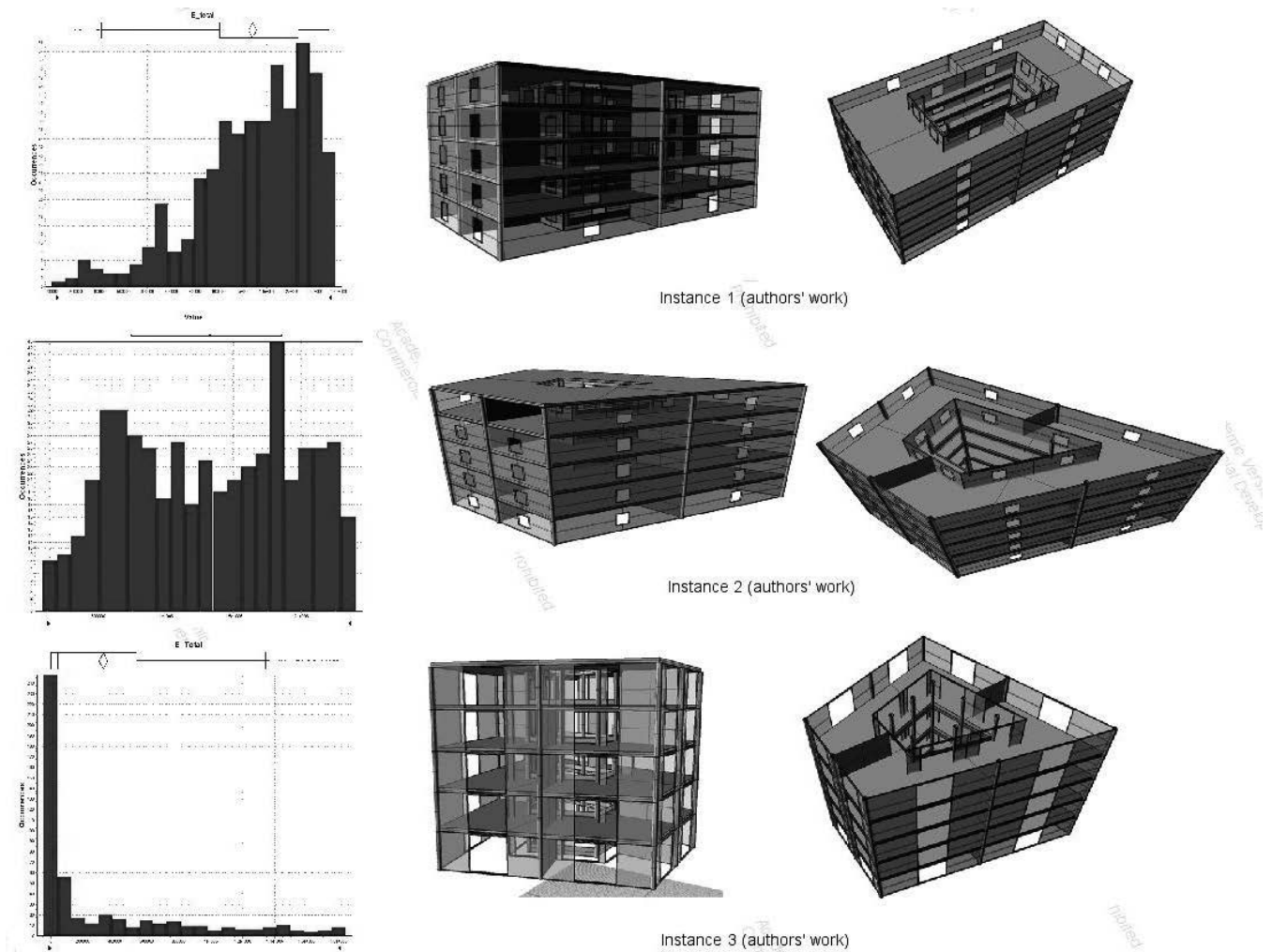

Instance 3 (authors' work)

Fig.04 Comparison of 3 instances scenarios results

Conclusions

Today, having a special awareness about natural ventilation is not a common practice in early stages of a building's design. Most of these concerns come in mature stages of a building's design. In addition, every change done at early stages of a building's design will produce a significant impact in costs and energy efficiency. This initial Nat-Vent Implementation has shown to be a suitable tool to be shared among architects and engineers. Nat-Vent extends natural ventilation analysis to those without an engineering background and gives understanding about how size of rooms and windows, height of stories, and orientation will influence the results of ventilation performance as well as affect the appearance of the building. After the case study, we conclude that SysMl tool has some issues to create generic parametric diagrams. For instance, to parametrically change the number of stories of the building, it is necessary to create different parametric diagrams for every scenario.

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