PERFORMANCE DRIVEN DESIGN OPTIMISATION WITH SCIENTIFIC WORKFLOW SYSTEM

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ABSTRACT
This paper proposes the use of a scientific workflow system to facilitate the implementation of a performance driven design process. The use of a scientific workflow system would enable the architect to customise and automate his/her own workflow for each project. Through this the architect will be able to manipulate the data generated from a performance driven design process efficiently and explore more design options. A simple example is presented to demonstrate the design process proposed. The scientifc workflow system, Kepler is used to oversee the design process and it is linked with the 3D modelling program, SideFX Houdini 3D. Lighting simulation program, Radiance and lastly Evolutionary Algorithm (EA) is used for the optimisation of the design.

Keywords: Performance driven design, Scientific workflow system, Evolutionary algorithm, Parametric design, Design process

INTRODUCTION

The integration of environmental simulation and Computer-Aided Design (CAD) programs into a common platform is essential for a performance oriented building design. This integrated environment facilitates a performance driven design process by providing feedback on the architect's design decision. Furthermore, the automation of the design performance assessment and the employment of optimisation algorithms enable the architect to generate a multitude of possible design variants and thus explore more design possibilities.

Research shows that the majority of architects and engineers use simulation programs for validation and not for exploration of alternative designs (Flager and Haymaker 2007). One of the reasons is that the data from most of the CAD program are not sufficient and often not compatible with simulation programs. This greatly impairs the flow of the design process, as architects then have to manage and error check the various domain specific data exchange, instead of spending time on developing the design.

There are basically three level of integration of CAD and simulation programs into the design process. At the first level, a standard CAD system is linked to a set of simulation programs so that one can easily evaluate design variants that are generated manually. There are various research efforts in this field to achieve this smooth transition from the CAD system to each domain specific simulation program. (Citherlet, Clarke et al. 2001; Malkawi 2004) One of the example is the post processing and mapping of Building Information Modeling (BIM) 3D model to domain specific simulation program (Sanguinetti, Abdelmohsen et al. 2012), it tries to achieve a smooth transition between design and evaluation by processing the data from the BIM model and preparing it for the different simulation programs. Another example is The Design Analysis Integration (DAI) initiative.(Augenbroe, Wilde et al. 2003; Augenbroe, Wilde et al. 2004) It uses a workbench to manage the process and at the same time make use of existing file formats like Industry Foundation Class (IFC) for the information exchange. DAI do not prescript the work flow for the user but give the user certain amount of flexibility to customise their workflow.

At the second level, a parametric CAD system such as Grasshopper or Houdini3D is linked to a set of simulation programs so that design variants can be more easily generated and evaluated without manually remodeling each design from scratch. Parametric modeling refers to the process in which the architect defines the design with a set of parameters. For example a set of parameters to control the height, breath and length of a rectangular block tower. This can speed up the process of design generation as various different designs can be generated by varying the parameters. As a result more “what if” scenarios and designs could be explored and evaluated(Shea, Aish et al. 2005).

Lastly, an optimisation algorithm is used to close the loop by linking the simulation results back to the parametric CAD system, so that one can more easily explore the performance tradeoffs of a large number of design variants without the need to manually define the parameters for each design variant.(Caldas 2006; Shea, Sedgwick et al. 2006; Flager and Haymaker 2007; Flager, Welle et al. 2009). The use of optimisation algorithms such as Genetic Algorithm (GA) and Ant Colony Algorithm is usually a more bottom up approach, where the architect sets up rules, constraints and boundary conditions for the generation of design alternatives. It is more of an exploratory nature in which the algorithm takes a more active role in the design process and might generates unexpected design alternatives.

This paper proposes the adaptation of a scientific workflow system as an environment for the architect to set up design loops for performance driven design optimisation. The use of a workflow system in the scientific community is common practice, as most of an experiment involves repetitive cycles of simulation, analysis and management of results. The use of a scientific workflow system enables the automation of the cycles and at the same time allows the scientist to concentrate on the research and not the computation management. There is an array of available workflow system for tasks of different purposes (V. Curcin 2008; Deelmana, Gannonb et al. 2009). This paper presents the initial approach of the adaptation of the tool for the architecture design purposes.

SCIENTIFIC WORKFLOW SYSTEM

A workflow is an abstract description of the steps needed and the information flow between the steps for executing a specific process. Each step is made up of a series of activities. The activities include processing of data for the next step, execution of a simulation with the provided data or the analysis of the given data. The steps are executed in order from start to finish and most of the time it is repeated in cycles with variation of the value of the information, but not the nature of the information. The workflow is usually constructed with a visual front-end or hand-coded.

The visual front-end of a workflow system is usually a graph illustrating the order of the execution of steps needed to complete a specific process. The connecting wire between each node is representation of the flow of data between the different steps. The users can usually alter the workflow by manipulating the graph, it varies depending on different systems.

One key advantages of using a workflow system is that it serves as a form of documentation for one's design process. As alterations to the design are common during the architectural design process, a well documented design process facilitates making changes to the design. The workflow could be reused, improved or altered after each project. It also enables the sharing of workflow between collaborators. Some workflow systems allow the nesting of sub-workflow within a workflow. This means as long as the inputs and the outputs of different steps are well defined, nested workflows could be distributed for collaborative purposes. This results in a modular workflow system which is highly flexible and customisable.

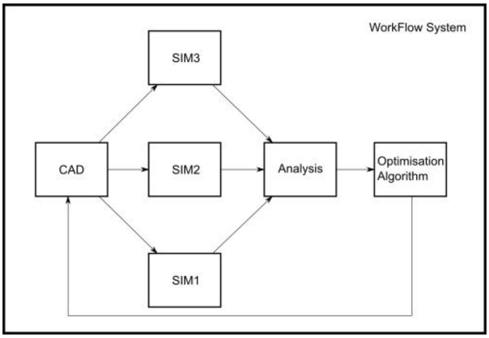

Figure 1 Possible modular workflow with well-defined data exchange

The diagram in Figure 1 conceptually illustrates a modular workflow system with well defined data exchanged between each sub-workflow. In this case, each sub-workflow could be authored by different professionals. For example, the architect might author the CAD sub-workflow while the mechanical engineer authors the SIM1 sub-workflow. This could be possible by the usage of common file exchange such as Industry Foundation Class (IFC) or an agreed upon data format between the two professionals.

THE WORKFLOW SETUP

A workflow which uses Evolutionary Algorithm (EA) for its feedback mechanism was setup. The workflow is made up of two main components; the feedback and evaluation component. The Kepler system (Pennington, Higgins et al. 2007) was used for managing the workflow of the design process. The Kepler system uses a Director and Actor modelling paradigm in which the Actors are the workflow components while the Director is in charge of the overall workflow orchestration. SideFX Houdini3D was the 3d modelling program used for the parameterising and generation of the design schema. For the evaluation tasks the workflow is able to link the Radiance lighting software for simulating solar irradiation and Python scripts were written for the calculation of the RETV value and for the implementation of EA in Kepler system.

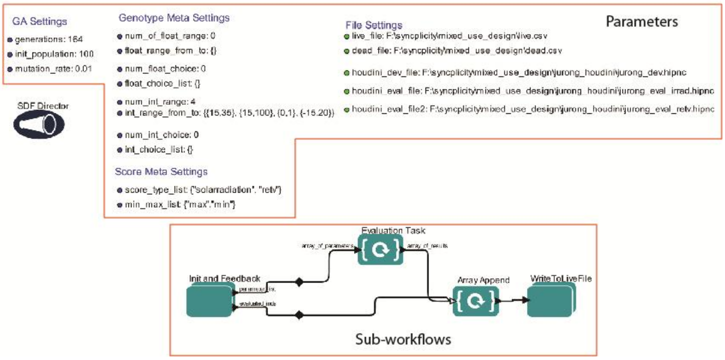

Figure 2 Parameters and sub-workflow

Figure 2 shows the workflow. Each node in the graph is a nested workflow. The parameters shown in Figure 2 are the necessary inputs for running the workflow. It includes information for running the EA, to generate the designs and also the location of files necessary for running the workflow. These parameters feed the sub-workflows with the information for running the workflow.

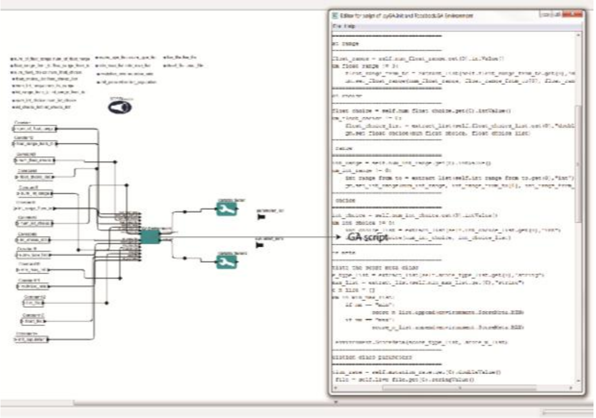

Figure 3 Inside the "Feedback" sub-workflow

At the start of the workflow is the “Init and Feedback” sub-workflow.(Figure 3) This sub-workflow is in charge of doing the EA feedback mechanism. It generates new designs either randomly in the first cycle or by reproduction at the subsequent cycles. The sub-workflow is made up of an EA environment node written in Python script. The node takes in the Genotype

Meta settings and produce the parameters for generating the design variants. It takes in the Score Meta settings for manipulating the evaluation scores produced by the evaluation task, whether to minimise or maximise is specified at the “min_max_list” parameter. Lastly, it takes in the “live_file” and “dead_file” parameters for writing the results.

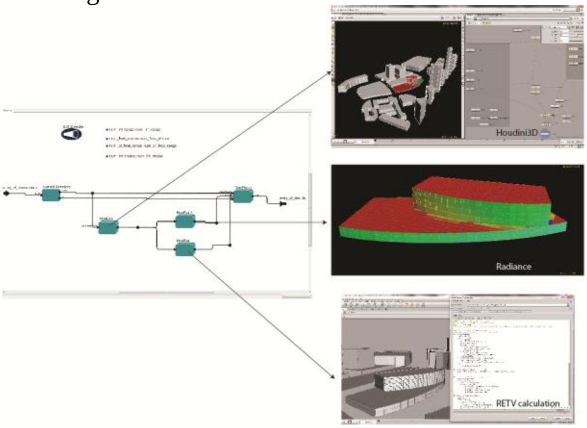

Figure 4 Inside the "Evaluation" sub-workflow

The design variants are send to the “Evaluation Task” as a array of parameters.(Figure 4) The sub-workflow includes generating a 3D model by accessing the 3D software Houdini3D, extracting the geometry data and sending it for evaluation tasks such as solar irradiation or RETV evaluation. This is done by using the Python Houdini3D Advance Programming Interface (API). A Python script was written to access Houdini3D and the parameters are passed to the script as variables for generating a design variant. The geometry of the design variant is then extracted and processed for the relevant simulations. All these are done through the use of a library of Python codes and API written by the authors.

The parameters and the scores of each design variant is sent to the “WriteToLiveFile” sub-workflow in which the designs are written to a .csv file. The cycle repeats itself at the “Init and Feedback” sub-workflow where it will read the .csv file produce from the previous cycle and perform EA feedback mechanism.

APPLICATION AND CASE STUDY

A simple case study of a mix-used development in Singapore was done to demonstrate the workflow setup. It is parameterised as follows:

- The two storeys commercial mall is not altered during the design generation. The residential tower above the mall varies with the parameters X and Y which determine the footprint of the residential tower. This in turn will affect the height of the tower as shown.
- The orientation and location of the residential blocks.
- The height of the residential block exceeds 60m, instead of one 60m tower it will generate two 30m towers.

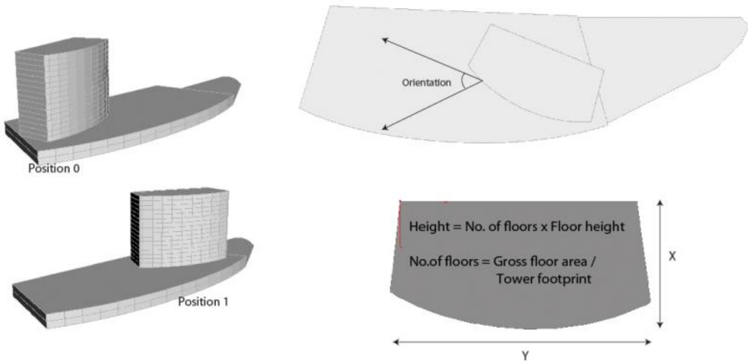

Figure 5 Design schema and parameters

The environmental strategy is to maximise the amount of solar irradiation falling on the building envelope while minimising solar heat gain. This corresponds to the conflicting objectives of generating as much electricity from the installation of Building Integrated PhotoVoltaics (BIPV) while at the same time reducing the amount of solar heat gain. It is an attempt to source for possible energy source on site and still reduce the demand of cooling energy in the building.

The evaluation methods used are the Radiance ray-tracing lighting simulation for the measure of solar irradiation and Residential Envelope Transmittance Value (RETV) (Chua and Chou 2010) for assessing the solar heat gain of the envelope. RETV is a measure of the solar heat gain from the building envelope, it is developed by the Building and Construction Authority (BCA) of Singapore.

The design schema is optimised using an EA. At each cycle :

1. A population of 100 design variants are randomly generated by assigning parameter values to the four parameters described above.
2. Each design variant is evaluated and assigned scores for the two evaluation methods.
3. A sub-population of 50 design variants are randomly selected from the main population and pareto ranked according to their scores.
4. 30 design variants at the bottom of the ranking will be “killed” and 20 new design variants are reproduced from the “stronger” design variants, the reproduction process is done through crossover techniques and mutation occurs at a rate of 0.01.
5. The cycle is repeated from step 2 with the “fitter” design variants. At the end of each cycle the design variants that are “alive” or “dead” are written to two .csv files live.csv and dead.csv respectively. The architect will be able to check the progress by reading the .csv file.

As a result, the population of designs gradually evolves after each cycle. The optimisation loop stops as specified by the user at the start or anytime during the process. It is an performance driven design exploration of the possible design variants.

RESULT

The EA process ran for 160 generations and 4000 designs were produced. The graph in Figure 9 shows the design variants produced at each generation. One can observed that after each generation the design variants are moving towards bottom right corner of the graph forming the pareto front, where it is of high solar irradiation and low solar heat gain. Thus, achieving the aim of increasing the generation of electricity with BIPV while still keeping the cooling demand as low as possible.

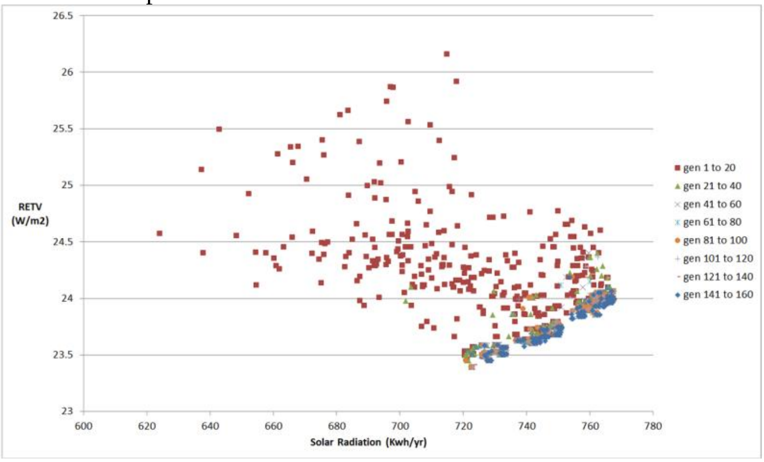

Figure 6 Graph of EA results

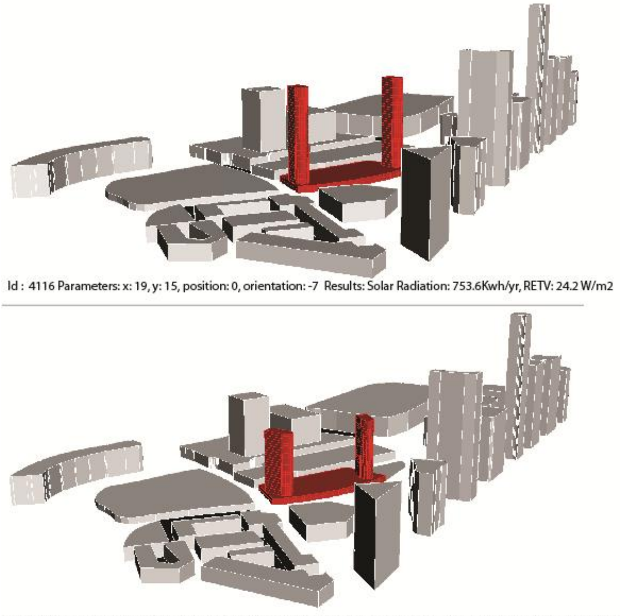

Figure 7 Design 4209 (top) Design 4116 (bottom) on the pareto front

CONCLUSIONS

The case study illustrates a basic workflow set up with Kepler. This workflow or its sub-workflow can be packaged and shared as a template for future use. It can be reused or altered to fit the specific project. For example, another user might not be proficient in using Houdini3D and is only proficient in Rhinoceros3D. The Houdini3D actor node could be replace with a Rhinoceros3D actor node. This applies to the evaluation actor node too. As more users are willing to contribute , it will expand the capability of the workflow system and accommodate more digital tools for design purposes. It is also possible for the designer to first do a series of non-looped experiments where the designer 'learns' what needs to be optimised. The designer could then incorporate an optimisation algorithm to optimise the key aspects. By having well orchestrated workflow, it is possible for architects to “plug in” design into the workflow to be evaluated and optimised for its environmental performance.

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