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DEVELOPMENTS OF A BIM ADD-ON TOOL FOR DEEP RENOVATION OF BUILDINGS

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Abstract This paper presents the current state of development of a generation and performance evaluation tool to assist building practitioners in the early stages of deep renovation of buildings. This includes the tool workflow and its modules, such as the generative design method, the building performance evaluation mechanism, and the optimization procedure that improves the building geometry and construction system, and sizes the energy systems (HVAC and renewable energy production). The tool is currently able to use a wide variety of EnergyPlus objects, allowing for various template and detailed HVAC, DHW, and thermal and electrical energy production systems and components, as well as numerous internal gains types, construction elements and energy saving controls, to be accounted for and simulated in the generated buildings. Some applications examples are presented to demonstrate the tool capabilities. Lastly, some conclusions are made.

1. INTRODUCTION

In the early design stage of deep renovation of buildings, architects seek to accommodate a set of preferences and requirements in the form of floor plans. This consists in finding the best indoor arrangement of rooms. The number of potential solutions is vast and each alternative has a different impact in the final building performance. To prevent later cumbersome changes, it is important to take the most adequate choices early on from energy efficiency and human comfort perspectives. For this reason, the research units ADAI and INESC Coimbra from the University of Coimbra, and CIAUD from the Faculty of Architecture of the University of Lisbon are carrying out a research project entitled Ren4EEnIEQ (http://www.adai.pt/ren4eenieq/) to develop a BIM add-on tool for deep building renovation scenarios. The tool will be capable of importing 3D point clouds from surveyed built environment (or from 3D city maps), identify and build surfaces according to the nature of the objects (vegetation, terrain, surrounding buildings, existing structures, etc.), generate alternative building geometries, evaluate the performance of each solution, optimize the construction system (each building element individually) and building geometry (window size and orientation, overhang/fins dimensioning, building orientation when possible, adjust the rooms walls, etc.), and correctly sizing the energy systems (HVAC and renewable energy).

2. TOOL WORKFLOW

The tool workflow (depicted in Figure 1) consists in a BIM environment add-on to import the point clouds from the 3D scanned built environment, and automatically identify and draw the mesh of the terrain and the shells of the indoor spaces, including openings, in the form of surfaces to be used as environment constraints to the generated building. After this information has been imported and the user specified the building requirements and preferences in the LSP module – some of that information is pre-defined in a database (e.g., kitchen, living room, etc.; with the corresponding occupation, lighting, equipment, and activities profiles) –, the EPSAP module will seek alternative building designs [1–3] for the user to choose from. After, the performance of the selected solutions is assessed using the BPS module [4].

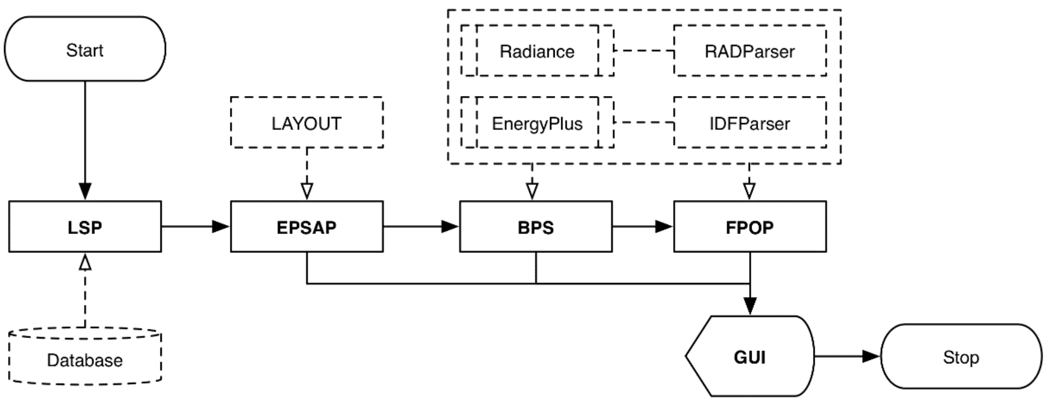

Figure 1: The tool workflow.

The evaluation criteria can be thermal comfort, visual comfort, or energy consumption. In the case of thermal comfort and energy consumption, the assessment is carried out using the EnergyPlus software (http://www.energyplus.net) that is coupled to the tool through the IDF parse library. In the case of visual comfort, the assessment is carried out using the Radiance software (http://radiance-online.org) through the RAD parser library. After the performance criteria is chosen, the FPOP module will seek to improve the performance of the alternative buildings by changing their geometry [5]–by preserving the changes that presented better performance–, construction elements, and prevent under- and over-dimensioning of the energy systems. Coupled to the EPSAP, BPS, and FPOP modules, the GUI allows the user to visualize the buildings' geometry, construction cost, and the performance of the overall building and of its systems.
The simulation results are then presented in output files by system, space and meter type, and in a graphical user interface (GUI) that displays the building floor plans and the overall and space performance reports. The GUI displays the best of the generated layouts (though the user can visualize other layouts and storeys, if available) and a set of performance reports, as well as other results, such as the building areas and the building and systems costs. The performance reports illustrate graphically the dynamic simulation results for the whole building and for its individual spaces, through a set of variables that are accessible for user selection depending on the simulated systems: *e.g.*, indoor and outdoor air temperatures, cooling and heating energy consumption and demand, infiltration rate, water consumption, primary energy consumption, thermal discomfort, electric equipment energy consumption. Moreover, the user can also select the report period for which each graphic will be generated: all year, trimester, coldest day, or hottest day.

3. BUILDING AND ENERGY SYSTEMS MODELING

Currently, the following EnergyPlus main functionalities are implemented in the tool for dynamic simulation, according to the latest specifications (version 9.0.1):

- User defined materials and constructions for the building surfaces and sub surfaces;
- Automatic definition of thermal zones for the building spaces generated by the tool;
- Allocation of user defined internal gains (people, lighting, and equipment) to the thermal zones;
- Optional window shading and daylighting controls;
- Simple zone ventilation and infiltration and detailed airflow network options;
- Forced and natural ventilation options;
- Cold/hot water systems: terminal zone equipment, equipment connections, storage tanks;
- All the HVAC system templates of EnergyPlus: *e.g.*, ideal loads air system, baseboard heat, zone unitary system and terminal units, fan coil units, packaged terminal units, VAV system, hot and chilled water plant loops and respective energy production equipment (*e.g.*, boilers, chillers);
- Various zone HVAC detailed systems: *e.g.,* ideal loads air system, low temperature radiant floor, baseboard water convective, baseboard electric, packaged terminal units, water-to-air heat pump, VRV unit, air terminal VAV reheat, air terminal uncontrolled;
- Several HVAC components: pumps, pipes, fans, humidifiers, heat exchangers, heating and cooling coils, solar collector flat plate, district heating and cooling, boilers, water heater tank;

- User defined plant loops (hot/cold water, steam), using the HVAC components, to feed zone HVAC water/steam systems and/or DHW equipment;
- User defined air loops, using the HVAC components, to feed zone HVAC air systems; and,
- User defined electric load center, comprising inverters, batteries, transformers, and photovoltaic and/or wind turbine generators.

In addition, the tool presents several useful features regarding the EnergyPlus interaction:

- Various buildings and systems templates are available;
- Object values (*e.g.*, properties, setpoints) are assigned in a specific database;
- Detailed systems are easy to define;
- Simple connection between different component types;
- All equipment and system nodes are automatically defined;
- Most object names are automatically defined, depending on the equipment, systems and zones for which they are assigned; and,
- Possibility to define equipment and construction costs, which are then automatically sorted by type in the GUI.

Figure 2 illustrates an HVAC air loop comprising a unitary system with heating and cooling coils for zone climatization.

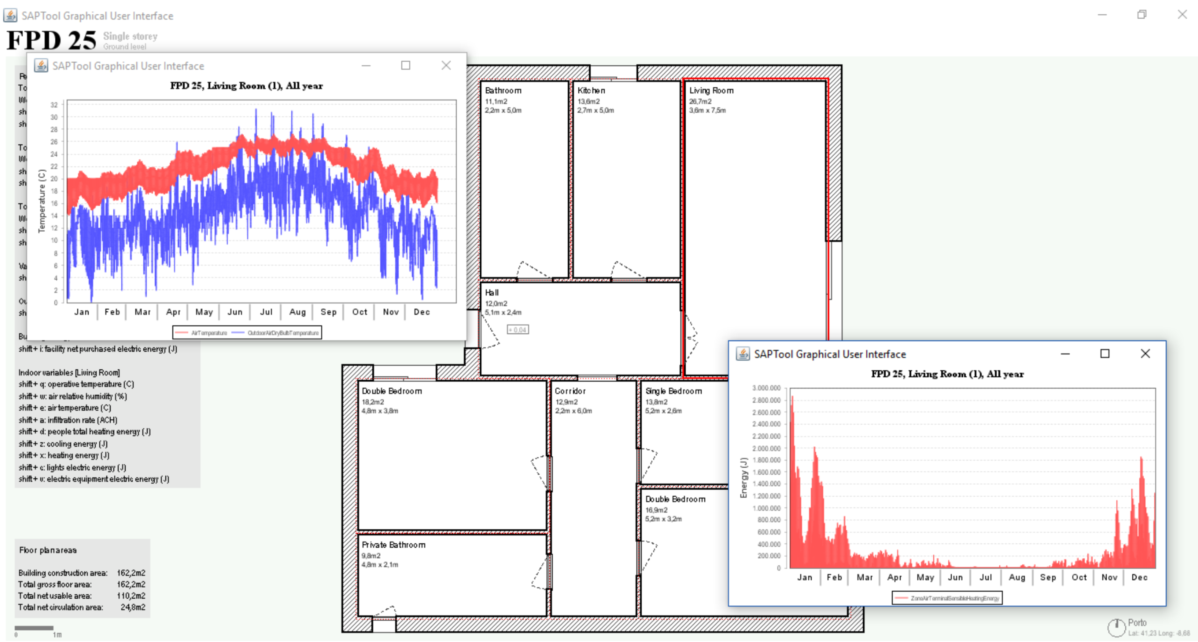

Figure 2: Building design example, and graphics depicting zone indoor and outdoor dry-bulb temperatures and heating energy for whole year (HVAC air loop with unitary system).

4. APPLICATIONS

The capabilities of this tool are especially useful in scenarios that require fast prototyping, as the ones that occurred in Portugal in 2017, which resulted from the forest fires that destroyed hundreds of residential buildings. Figure 3a depicts one of the houses that were scanned using terrestrial laser scanning (TLS) and will be used as showcase of the developed tool. However, the tool is capable of dealing with new construction and take into account the urban context (to cast and reflect solar radiation). Figure 3b illustrates a collaborative work to promote LSF construction in hot arid climate in Kuwait [6]. This work consisted in statistically analysing the impact of 6010 alternative buildings with different insulation levels and position in the exterior walls that satisfy the same initial geometric and topologic requirements. The performance results were then compared with the current Kuwaiti building code. Figure 3c presents examples of single-family houses with one or two storeys. The generated houses were generated to include renewable energy production from photovoltaic and wind turbine systems. Besides energy production, the models also consider a wide range of HVAC systems and hot water equipment. Figure 3d depicts multi-storey buildings generated and evaluated with different types of occupation in different levels (residential, stores, services, etc.). Despite being developed as an assistive tool for building designers, the developed algorithms have also a scientific component to it, as these can produce large sets of buildings to be statistically analysed to determine building performance aspects according the construction thermophysical properties, geographic location, and weather data, such as to determine the constructive system thermophysical properties in different climate locations [7], identify the most promising building design guidelines [8,9], or to develop machine learning approaches [10].

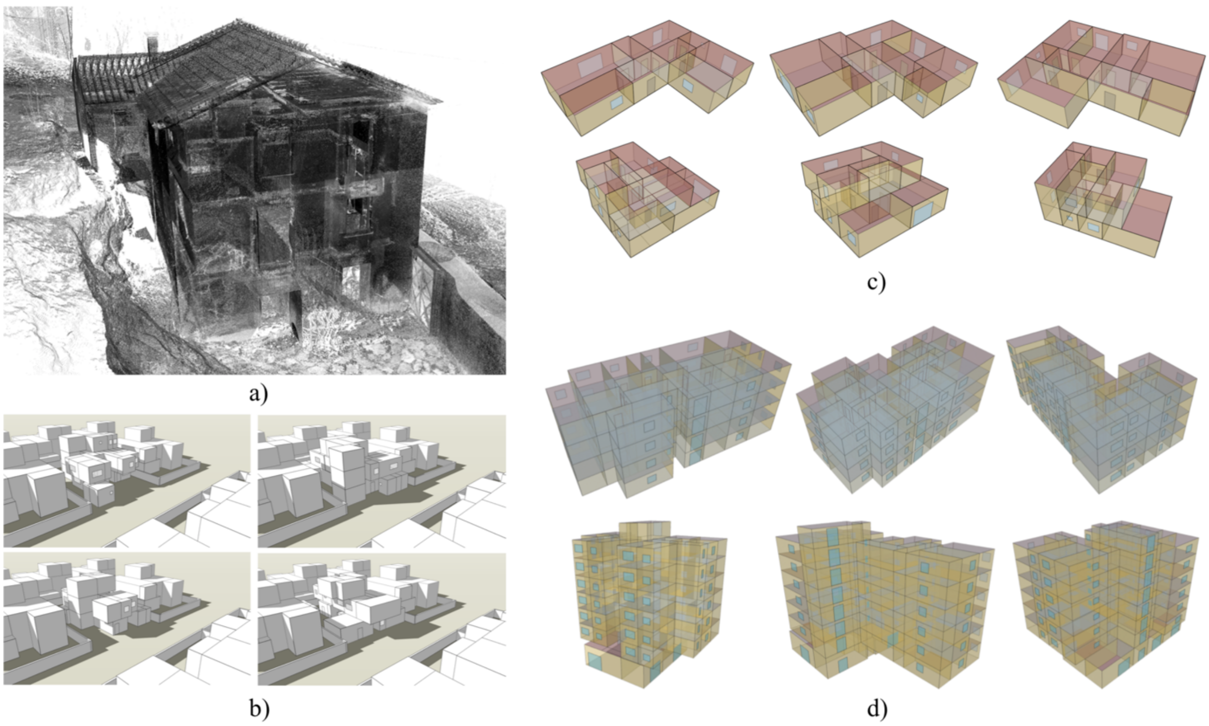

Figure 3: a) Example of a 3D point cloud scanned house destroyed during the 2017 forest fires in Portugal and being used for fast prototyping of houses; b) Six examples of randomly generated three-storey houses in an urban quarter in Kuwait; c) Examples of the generated single-family houses; and, d) multi-storey buildings with service spaces and residential occupation.

5. CONCLUSION

Building performance simulation software can contribute significantly to the improvement of buildings' energy efficiency and thermal comfort by supporting the decision-making process. The current tools are, however, difficult to implement in the building design process, as they usually increase the effort of an already long architectural design methodology. In order to overcome this deficit, the tool presented in this paper automatically combines the generation, evaluation and optimization of alternative design solutions in the space planning phase. It offers a wide variety of EnergyPlus objects, thus allowing to simulate several internal gain types, water systems, template and detailed HVAC systems, electricity generation systems, and individual components. These are semi-automatically defined, sparing the user from complex tasks, such as naming, assignment and linkage of systems and equipment nodes. In addition, a simple graphical user interface displays the main building and space performance reports in a user-friendly environment. Therefore, this aiding tool can offer building practitioners a valuable interactive decision support appliance.

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