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Building performance information and graphs approach for the design of floor plans

Informação de desempenho de um edifício e gráficos de abordagem na concepção de projetos

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ABSTRACT – This research focuses on a new workflow between the fields of Space Layout Planning (SLP) and Building Performance Simulation (BPS) for the early stages of building design with the aim of reducing the energy needs of a building and improving indoor environment quality. Parameters of environmental performance requirements, such as temperature, view, acoustics, and so forth, were selected from different international standards. The intention is to link these performance parameters to a graph that supports schematic design tasks during the creation of architectural floor plans. Programming tests were run to add the information to the graph. A prototype for the early stages of the design is presented in which designers can visualize performance information during the schematic design of floor plans for a building. The complete framework for a BIM (Building Information Modeling) application is described and a case study is presented to demonstrate the usability of the concept.

Keywords: building information modeling, space layout planning, floor plan design, building performance simulation, building energy performance, architectural design.

RESUMO – Esta pesquisa concentra-se em uma nova linha de trabalho entre os campos de *Space Layout Planning* (SLP) e *Building Performance Simulation* (BPS) para fases iniciais de projeto e está destinada a reduzir as necessidades de energia de um edifício e melhorar a qualidade do ambiente interior. Foram selecionados parâmetros de desempenho do ambiente de diferentes normas internacionais, tais como: temperatura, acústica, visual, etc. O objetivo é vincular esses parâmetros de desempenho a um arquivo gráfico. Este gráfico suporta desenhos esquemáticos que são elaborados durante o processo de projeto. Testes de programação foram executados para adicionar estas informações ao gráfico. Um protótipo para as fases iniciais é apresentado. Este protótipo permite aos projetistas verificar, ainda em fase de planta esquemática, informações sobre o desempenho do edifício durante o processo de projeto. A estrutura completa para a aplicação do *Building Information Modeling* (BIM) é descrito e um estudo de caso é apresentado para demonstrar a aplicação do conceito.

Palavras-chave: *building information modeling*, *space layout planning*, processo de projeto, desempenho energético do edifício, projeto arquitetônico.

Context

State-of-the-art practice in the three fields of BIM-BPS-SLP is showing increasing interest in the topic of sustainability, as well as in efforts to make the link to the field of architectural design and CAAD (Computer Aided Architectural Design). Building Performance Analysis plays a key role in the assessment of sustainability (Altan, 2008) and the connection to digital simulation has increased in recent years (U.S. Department of Energy, 2010). Recent research and projects carried out in the United Kingdom (University of Sheffield[1]) and the United States (University of Berkeley[2] and University of Oregon[3]) show the advantages of using digital tools in the simulation and evaluation of building performance. The third field, Space Layout Planning, is a relatively well-known and widely researched field where four trends have been identified—Shape Grammars, Generative System, Constraint-Based and Expert Systems—which support the creation of architectural floor plan layouts. Recent

[1] Urban Sustainability for the Twenty-Four Hour City: Development of Decision-Making Tools and Resources, Steve Sharples, Dr Mohamed Refaee. 2003-2008 Funded by EPSRC Grant GR/S18380/01.
[2] Center for the Built Environment, a National Science Foundation Industry/University Cooperative Research Center.
[3] Energy Studies in Buildings Laboratory, School of Architecture and Allied Arts, University of Oregon.

findings in this field (Lobos, 2011) show that the use of graph techniques allows complex information to be handled and added to the design, and sustainable design is indeed complex information.

Space Layout Planning (SLP) is a discipline that deals with the creation of floor layouts supported by computers (Figures 1 and 2). The four aforementioned trends have been developed since the 1950s starting with Buffa and his SLP (Systematic Layout Planning). Willian Mitchell and Dillon (Jo and Gero, 1998) were the first researchers to take the problem to the architectural design field. Since then four main approaches have been developed: Expert Systems, Shape Grammars, Generative, and Constraint-Based. Use of some commercial software, such as Alberti and Affinity, has also been attempted in order to provide support, but the results have not been efficient enough.

Building Information Modeling (BIM) is the most up-to-date technology for 3D modeling of buildings (Figure 3) (Eastman *et al.*, 2011). The main difference to traditional 2D/3D CAD software (AutoCAD, VectorWorks) is that BIM creates just one model and from this single model we can obtain all the information (2D drawings, 3D views, schedules, cost, etc.) in a very accurate and coordinated process. Every object represents a real object, that is, a wall is not an extruded 3D box, but a wall with properties (length, height, cost, material, layers, attachment to roof and openings for doors/windows, etc.). This means that we deal with complex information. Currently the USA-GSA (General Service Administration) forces offices to use BIM models in all public buildings (GSA, 2007). It will soon be the standard for architects, engineers and builders. For this reason we chose this environment for our research. There are currently five BIM software programs for architecture in the market: Allplan (Nemetscheck), Archicad (Graphisoft/Nemetscheck), Revit Architecture (Autodesk), Microstation (Bentley), Digital Project (Gehry Technologies) (Eastman, 2011).

Building Performance Simulation (BPS) has become more important in recent times due to climate change and greater awareness about the consumption of resources (energy, water, materials and land) (Hermelink *et al*., 2013). This field has been rapidly introduced into the agenda of most countries (as Sustainable Design) for government (GSA, 2012), as well as society and academia. For architecture, sustainability means trying to create the most comfortable space for the user of a building, but using as few resources as possible. Comfortability is measured in terms of different aspects that are related to the perception of users (temperature of the rooms, illumination, acoustic response, etc.). The resources utilized to produce this comfort are (at different stages): orientation/location, form/size, materials, building techniques and mechanical devices and their use during the building cycle, and, of course, a large amount of energy (Figure 4).

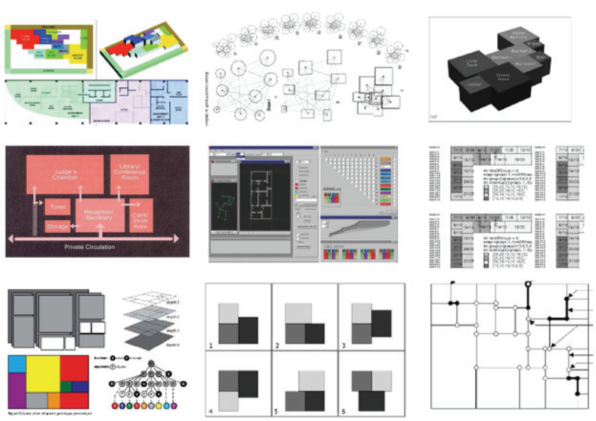

Figure 1. Summary of Screenshots of Researches and Prototypes from the last ten years.

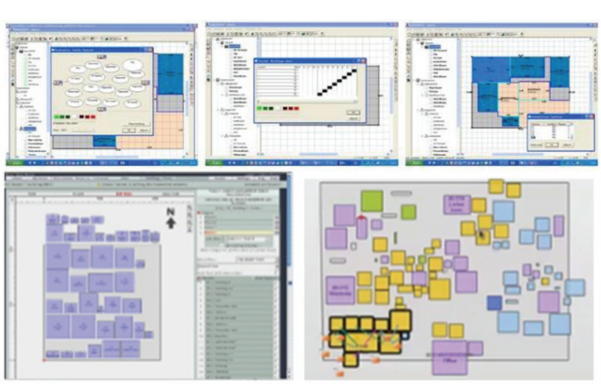

Figure 2. Alberti and Affinity for Space Layout Planning.

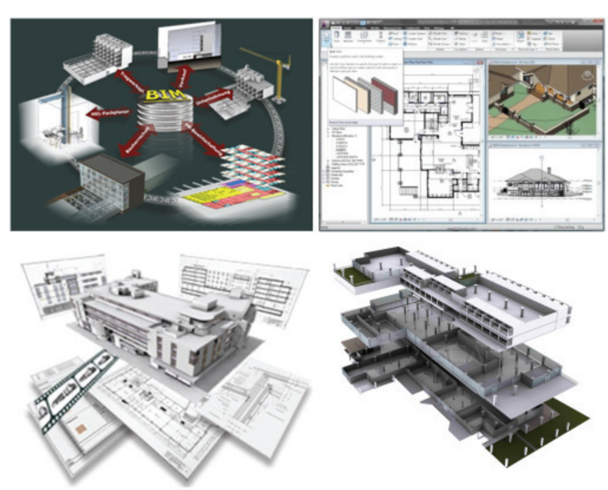

Figure 3. Building Information Modeling scheme, examples from Revit, Archicad and Digital Project.

Current software programs for BPS (Building Performance Simulation) are able to carry out in-depth analysis of the performance of the building design (thermal, solar, acoustic, etc.), but they cannot deal with Space Layout Planning to generate or analyze floor-plans.

Development

The early stage of building design is the most important one. Decisions made at this stage have a great impact on the building's energy performance. There are currently many strategies for simulation in the early stages, but Space Layout Planning (SLP), despite its long tradition (Liggett, 2000; Medjdoub and Yannou, 2001; Elezkurtaj and Frank, 2002), has not been incorporated into them. The field of Space Layout Planning has been researched since the 1950s and it has produced satisfactory results. It has demonstrated a wide range of possibilities to support architects in the creation of floor plan layouts. On the other hand, there have been numerous advances in Building Performance Simulation (BPS) for the early stages of design (Attia *et al.*, 2009; Augenbroe, 1992; Bambardekar and Poerschke, 2009) and Building Information Modeling (Eastman *et al.*, 2011; Schlueter and Thesseling, 2009; Bazjanac, 2008). Nevertheless, these advances have not included the Space Layout Planning stage (exceptions include the Onuma and Affinity plug-ins for some BIM software, but they do not consider energy performance). This research seeks a methodology that unifies both criteria, Building Performance Simulation and Space Layout Planning, in a unified environment (Building Information Modeling) and shows a case study to demonstrate the validity of the proposal.

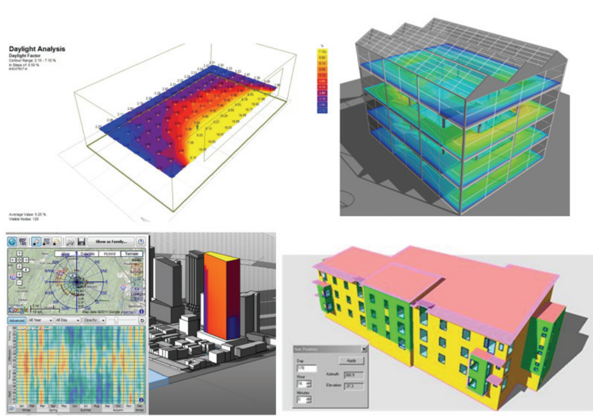

Figure 4. Lighting Analysis in Ecotect: Daylight Factor, Design Builder, Vasari and TAS.

Method

The hypothesis is as follows: is it possible to visualize variables of performance parameters during the Space Layout Planning stage in a BIM environment? This paper describes the first part of the research and deals with the visualization of such variables.

The first task was to define the parameters to be considered. Various international standards and assessment schemes were reviewed (BREEAM-UK, LEED-USA, DGNB-Germany) and certain common attributes to define performance parameters were extracted (Table 1). From this analysis one can conclude that aspects such as daylighting, view out, acoustics, and so forth, are considered to evaluate the quality of the space. Finally certain Chilean norms were reviewed to acquire real data to be used in a case study.

All these variables must be considered in the early stages of the design. At this stage architects produce a schematic design and this basically uses rectangular arrangements with each rectangle representing a required area or room. Architects move and resize these rectangles until most of the design constraints (aesthetics, client needs, construction regulations, etc.) are met (Figure 5). Subsequently, at the stage of design development these rectangular shapes are turned into walls, windows, and doors, and the final re-

Table 1. Comparison between BREEAM, LEED and DGNB (Lobos, 2011).

BREEAM-England	LEED-USA	DGNB-Germany
Daylighting	Daylight & Views, Daylight 75% of Spaces	--
View out	Daylight & Views, Views for 90% of Spaces	--
Internal and external lighting levels	Thermal Comfort, Permanent Monitoring system	Visual Comfort
Thermal comfort	Thermal Comfort, Comply with ASHRAE 55-1992	Thermal Comfort in the winter
Thermal zoning	--	Thermal Comfort in the summer
Acoustic performance	Minimum IAW (Indoor Air Quality) Performance	Acoustic comfort
Office space		Space efficiency

sult is a floor plan that contains precise sizes, functions and materials. In this paper, rectangular shapes are considered for the Space Layout Planning process.

Graph Theory applications are considered for the Space Layout Planning process, since they have been widely researched and tested in architecture (Earl and March, 1979; Wilson, 1999; Rahman *et al*., 2002), as well as in various other disciplines. Graphs allow users to handle and visualize complex information and relationships.

The problem of Space Layout Planning and the variables of environmental performance are currently handled separately by architects. Architects imagine and group the rooms and the performance targets in a purely mental manner. This traditional method is done in two dimensions and tends to avoid exploring all alternatives because of time restrictions as well as the possibility of leading to the risk of omission of performance variables. On the other hand, most of the software for Building Performance Simulation (Ecotect, Green Building Studio, TAS, Design Builder, etc.) normally requires the redrawing of all three-dimensional volumes for calculations (zone/space modeling). This means extra effort in the early stages and leads to the workflow being separated from the schematic design since it requires floor plans to be ready.

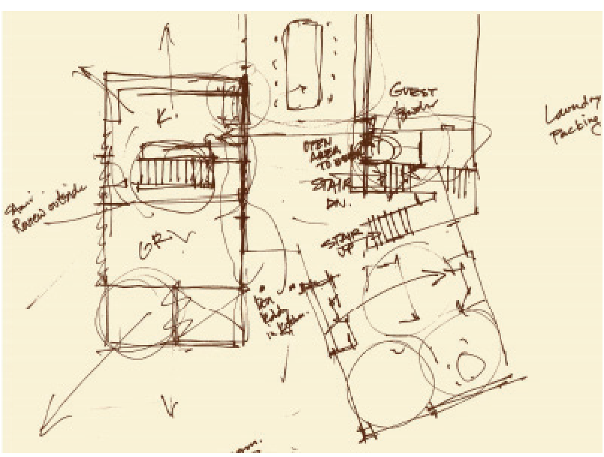

Figure 5. Hand-sketched schematic floor plan ("[...] it combines layout of rooms, relationship to the landscape, views, and location of the main entrance [...]" [Lawrence and Gomez Architects, 2011]).

This paper presents a prototype that shows the variables (and their values) to architects during the design of a floor plan. Several graph tests, graph editing, and programming techniques are carried out to develop a brand new concept that links both worlds.

Description of the variables

Of course, the complete range of variables that affect the environmental performance in the Space Layout Planning stage is highly complex. Nevertheless, current global concern about this problem has motivated governments, universities, and industry to quickly identify and classify these variables and which of them have the greatest impact. This has allowed several tables with values to be produced (European Committee for Standardization, 2002; Roderick *et al*., 2009). These tables (Table 2) are normally available in a hard-copy format (printed books), such as ASHRAE, CIBSE, IESNA, ISO7730, while the architect's work for this stage is commonly developed in a digital environment, such as traditional CAD software or, more recently, using BIM software (Eastman *et al*., 2011; Bazjanac, 2008; Krygiel and Nies, 2008). In this Space Layout Planning stage architects draw shapes, usually rectangular as explained above, which represent spaces or areas in the client's Space Program. Those spaces have specific sizes and complex functional relationships. Architects must complete this stage successfully from the architectural point of view (aesthetics, composition, functionality). However, the variables of performance

Table 2. Examples of values for the lighting of the task area.

Work place illuminance (lux)	Illuminance of surrounding areas (lux)
≤ 750	500
500	300
300	200
≥200	Etask
Uniformity ≥ 0,7	Uniformity ≥ 0,5

Source: European Standard EN 12646-1 part 1 (European Committee for Standardization, 2002).

Table 3. Sample of variables to be shown in the prototype.

Parameter	Unit	Sample 1 Corridor	Sample 2 Classroom	Sample 3 Director's office
Temperature	°C	15°C-20°C	Min 12°C	-
Illumination	Lx	150 (lux)	300 (lux)	500 (lux)
Acoustic (Minimum Air Noise)	Db	45 dB	50dB	35 dB
View/Glazed	%	20%	20%	-

parameters do not always fit the geometric solution of the floor plan, so the visualization of these variables during the creation of the floor plan is a crucial task to ensure the performance quality of the design.

The variables have been divided in two groups: those which depend on the geometry of the building (daylight, lighting levels, solar penetration), and those depending on materials and more accurate climate data (zone temperatures, air change rate, reverb, etc.). For this example the following ones will be considered: Temperature (°C), Illumination (Lx), Acoustics (Db.), and View/Glazed (percentage of the exterior rooms' area). This type of information is expected to be added to the graph model. Energy analyses, formulas or physical calculations are not part of this research. To prove our concept, a small group of values for these parameters were selected to be used in the prototype (Table 3).

Experiments

Case study

Public buildings have been chosen as a case study since they must fulfill a new Building Performance Regulation introduced in 2012 by the Chilean Ministry of Public Works (Ministério de Obras Públicas, 2012). In this new norm we can find comprehensive information about performance parameters and the target values that must be met by different types of spaces/rooms in a Chilean public building.

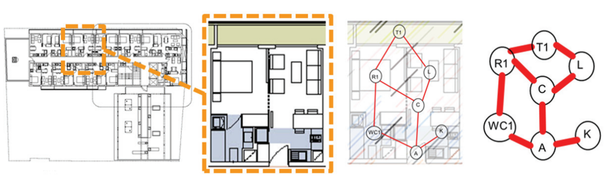

Figure 6. The Building, the Floor-plan, the Flat, and the Graph (Lobos, 2011).

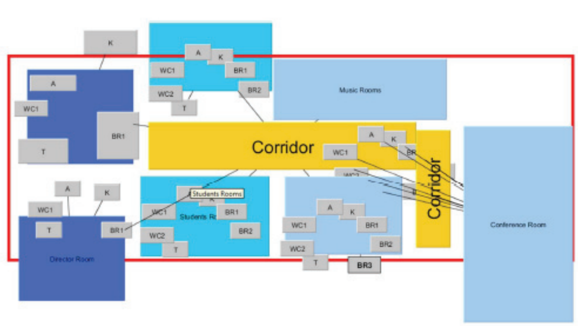

Figure 7. Graph file supporting the design of a new schematic floor-plan.

Following Lobos (2011), Liggett (2000), Medjdoub and Yannou (2001), Earl and March (1979), Rahman *et al.* (2002), graphs have been chosen to describe and visualize floor plan information. Graphs can represent a schematic floor plan (Figure 6) and new design can be done. A case study (Figure 7) will be discussed in the next section. However, our hypothesis is that additional information about performance parameters can be added to such graphs and visualized to support the Space Layout Planning process. To prove this, a comprehensive investigation has been carried out into the properties of graphs and the use of graph editors. The experiments were performed on an existing graph prototype (Lobos, 2011) and they consisted of the exploration of possibilities of turning graphs into XML (Extensible Markup Language) language and editing their structure and codes by adding new information. These tests were done in a Visual Studio programming environment and using an XML Editor. Various code lines containing the selected parameters were added to the structure and tested.

After all the tests it was concluded that it is possible to edit the graph structure, add external information, and finally visualize this information in a user-friendly environment. The experiment was as follows: several graphic software and XML editors were tested. Satisfactory results were obtained after using and testing about 15 graphic software programs (Table 4). The test consisted of a set of actions such as opening external graph files, importing spreadsheet tables, creating simple graphs, editing graph geometry, and exporting graphs using the XML extension.

After these tests yED software was selected to create the graph and after three tests related to XML editions, XML Blueprint 8 software was chosen for the XML edition. By editing the XML structure it was pos-

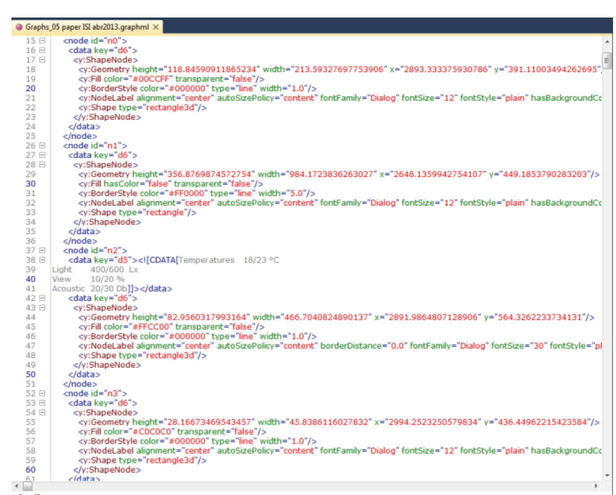

Figure 8. Edition of XML schema for a Graph.

Table 4. Comparison of different graph software (Lobos, 2011).

Comparison of different graph software					
	Clear description of the application	**Open a file**	**Import Space Program**	**Layout from Space Program**	**Export to an editable file**
Graph gear	√	√	*	x	x
aiSee	√	x	√	√	x
Birdeye	√	x	x	x	x
Flexvizgrap	x	x	x	x	x
SpringGraph	x	x	x	x	x
yED	√	√	√	√	√
Tulip	√	√	x	x	x
Grafos	√	x	x	x	x
uDraw(Graph)	√	x	x	x	x
Tom Sawyer Perspectives	√	√	√	√	x
Cricketschirping	x	x	x	x	x
Graph Browser	x	x	x	x	x
GraphSharp	√	x	x	x	x
MSAGL	x	x	x	x	x
Algraf project	√	x	x	x	x

Note: (*) not direct, but through XML file.

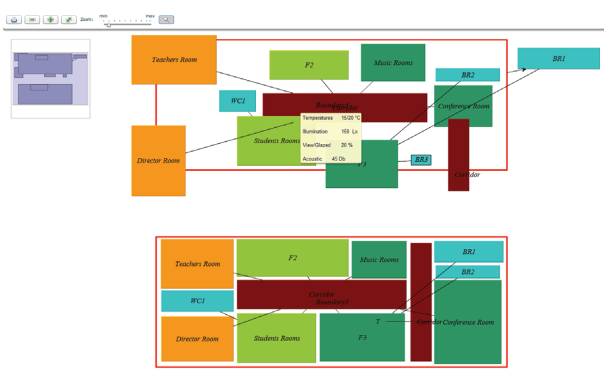

Figure 9. Visualization of performance parameters (yellow window) for a corridor during design stage.

sible to add some new code lines containing information about the required values for each parameter in relation to the Chilean norm. Figure 8 shows code lines 39 to 41 which contain this information. The environment selected for the visualization was HTML since it can be accessed online. Microsoft Internet Explorer 11.0 was used for the test since it is so widely used.

In this new interface the experience is as follows: the user moves the mouse pointer over any room and automatically a blinking message appears and shows the information about required performance for the selected room. When the mouse pointer is moved away from the room, the information disappears and information about other rooms can be shown by merely moving the mouse pointer without clicking. This allows architects to visualize specific information while they make decisions about Space Layout Planning.

The main advantage of this framework is that designers can decide on crucial aspects of the project (orientation, size, room distribution) using real information from existing standards or norms in an integrated digital environment. These decisions can be made in an early schematic phase where the design can be changed easily. Design options can also be explored with ease to find the optimal room performance.

A single case study for the early stages of design is presented, where the architect must design a simple layout for a small school in Santiago, Chile. He must meet the spatial program requirements (list of rooms: corridors, conference room, music room, principal's room, etc.). Once he opens the prototype, a graph can be obtained easily from the spatial program requirements and he can then create the rectangular arrangements by respecting aesthetics and/or any other criteria (such as structural factors, cost, or functionality). By moving and resizing the rooms, the prototype allows rapid work and easy exploration of design alternatives: if the architect changes the rooms, he can decide whether to meet the comfort parameters or continue iterating the design. There is no need to put the comfort data back into the prototype. Finally a schematic floor plan is created that can be exported to the next stage, called "Design Development", where detailed floor plans are specified (walls, dimensions, material types, etc.) in CAD or BIM software. This can be done by using vector/raster information exchange formats that allow subsequent construction of a BIM model from the schematic floor plan. In Figure 9, comfort parameters can be seen for a corridor during the design process. After the designer's iterative process, the schematic floor plan is ready.

Conclusions

A missing link between Building Information Modeling (BIM), Space Layout Planning (SLP) and Building Performance Simulation (BPS) has been detected. The possibility of creating a unified workflow was investigated and the possibility of linking BIM+BPS has arisen to support the creation of architectural floor plans. Real variables from real cases have been used to show architects the performance parameters that must be met by the rooms (in accordance with Chilean Building Performance Regulations) during the schematic floor plan design stage. The information is added to a graph and then visualized in real time so that the architect can make better decisions.

The edition of graphs allows designers to input and use complex information during the early stages of architectural design. Regulations and norms from different countries can be accessed and entered into the system.

Variables of performance parameters were shown as an example, but the concept can be expanded to orientation, minimum/maximum room size, finishing materials, and many other aspects. Indeed, an important link can appear between the different fields related to the building cycle, meaning that there is great potential for integration between architects and consultants in aspects such as light, acoustics, thermal, envelopes, and so forth.

Outlook

It is expected that in the future there will be BIM (Building Information Modeling) integration. C# (C Sharp) programming language is currently being successfully tested to prove this concept in the BIM software Autodesk Revit Architecture. At the date of submission of this paper, this phase is being developed successfully as a plug-in for Autodesk Revit. On the other hand improvements are expected, such as greater ease of graph edition, connection with various official external databases for parameters and values, support of decision-making by optimization, and self-generation of layouts.

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