

DaylightGen: From Daylight Intentions to Architectural Solutions

Implementation and experimentation of a generative and parametric design tool

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Abstract. *This paper addresses the integration of the daylight effect during the early stages of the architectural design process. The first part presents a design assistance method that helps designers to characterize their daylight intentions and materialize them in architectural solutions. In this part, we describe the implementation of this method in a design tool, denoted DaylightGen, the implemented process and the different system components. The second part of this paper focuses on the investigation of the potential of the proposed method in design process. It was evaluated in educational design case study. This part integrates the experimentation process and his results.*

Keywords. *Computer aided architectural design; intentions oriented design; generative and parametric design tool; daylight simulation tool; design tool experimentation.*

THE DAYLIGHTGEN METHOD

This method proposes to help young designers to integrate their daylight effects intentions during the first step of the design process. The designer describes the daylight effects that he would like to integrate in his project. The described intentions are characterized and translated into potential solutions. The generated solutions will be used as a base line models to start the project design (Gallas et al., 2011).

The *DaylightGen* method is organized in five steps (Figure 1). The method process starts by the “declare intentions (1)” step where the designer de-

scribes his daylight intentions using a visual support. The designer uses pictures representing daylight effects to describe his own ideas.

He selects those are corresponding to his intentions. The second step “characterize intentions (2)” of the method process aims to identify and characterize the designer’s intentions. They are translated in a physical and geometrical information that will be used at the “solution generation (3)” step. During this step the method will propose architectural solutions that create the described daylight effect and verify by the way the designer intentions. The solution

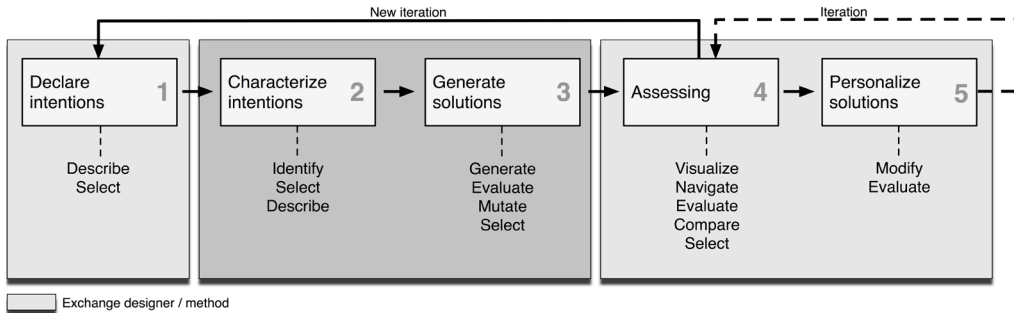


Figure 1
DaylightGen method process and activities.

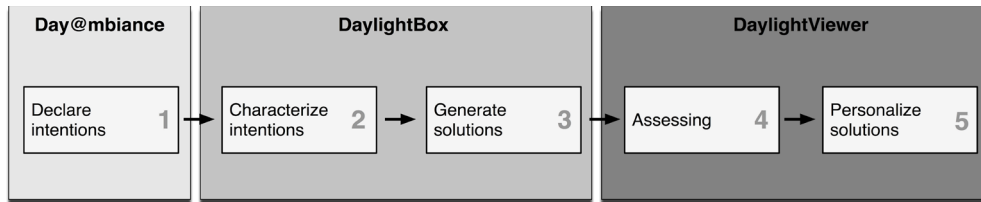


Figure 2
DaylightGen implementation tools.

generation step is organized as an iterative process of a *generation*, *evaluation*, *mutation* and *selection* activities. The fourth step of the *DaylightGen* method process is the “*assessing (4)*” step where the generated solutions are visualized and presented to the designer as a result of the “*generate solutions*” step. The “*assessing*” step integrates five activities where the designer *visualizes* and *navigates* in the collection of generated solutions, *evaluates* and *compares* them and finally *selects* the best ones. The method process ends by the “*personalize solution (5)*” step where designer could modify the generated solution features and transform them to integrate new ideas. The modified solutions will be visualized and evaluated with an iterative manner. The “*personalize solution*” step accompanies the designer and takes end when his is satisfied.

THE DAYLIGHTGEN TOOL

This method is implemented in a design assistance tool denoted *DaylightGen*. This prototype is composed of three tools: *Day@mbiance*, *DaylightBox* and *DaylightViewer*. *Day@mbiance* is used to implement the “*declare intentions*” step activities, *DaylightBox*

materialize the “*characterize intentions*” and the “*generate solutions*” activities and finally the *DaylightViewer* integrates the “*assessing*” and the “*personalize solutions*” step’s activities (Figure 2).

Day@mbiance

Day@mbiance is a navigation tool in a references images base proposed by Salma Chaabouni (Chaabouni et al, 2008). The images base is structured as a *MySQL*® database and managed by *Mamp*®. The navigation in the images base is realized by a *PHP*® application with a *Flex*® interface. A web browser (*Firefox*®) is used to visualize the *Day@mbiance* functions and results (Figure 3).

Day@mbiance is used to identify the designer daylight intention. Its process starts with a first

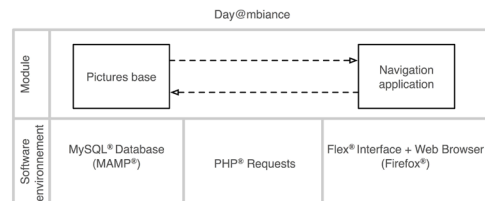
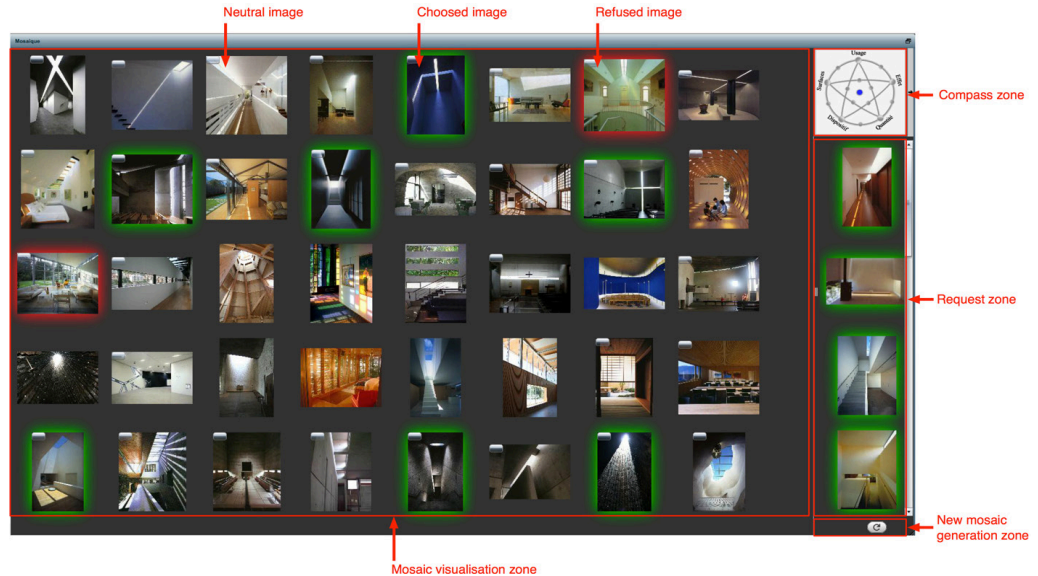


Figure 3
Day@mbiance implementation modules and environment.

Figure 4
Day@mbiance interface.



mosaic of images representing daylight effects. Designer chooses images that represent his intentions, refuses that are at the opposite and leaves others neutral to finally generate a new mosaic that takes into account his choices (Figure 4). All images are indexed by keywords that describe the visualized architectural configurations and daylight effects. This process will be repeated until the designer finds a collection of relevant images that corresponds to his intentions.

All images used by *Day@mbiance* are indexed using a keyword collection structured in a thesaurus. The thesaurus is divided in five facets that describe all images features: the daylight effect type, the quality, the quantity of daylight, the space surfaces aspects and the space function. The indexation process is realized by *Image* (software developed by Pascal Humbert form *MAP-CRAI*) (Figure 5).

The user's choice is then characterized a set of relevant keywords. The Keywords used to index the images has a pertinence weight that varies between -1 (not relevant) and 1 (relevant) (Halin, Créhange and Kerekes, 1990). When the designer choose an

image, the pertinence weight of the keywords used to index it increases, when the image is refused the weight decreases and finally the weight stay the same if the image is neutral. The pertinence Weight of the keywords is used when *Day@mbiance* generate a new mosaic to take into account the designer preferences.

DaylightBox

The *DaylightBox* tool is implemented in *Rhinoceros*[®] modeler environment and his graphical algorithm editor *Grasshopper*[®] (Tedeschi, 2011). *DaylightBox* is a *Grasshopper*[®] definition that integrates six modules: a referenced images base (*Day@mbiance images base*), a daylight effects knowledge base (*knowledge base*), a parametric model (*geometry*), a generative algorithm (*Galapagos*[®]), a daylight simulation tool (*simulation*) and a solutions database (*solutions storage*) (Figure 6).

The first module "*Day@mbiance images base*" is a *cluster* that integrates a plug-in to connect *Grasshopper*[®] to the pictures base used by *Day@mbiance*. This module selects the most significant keywords

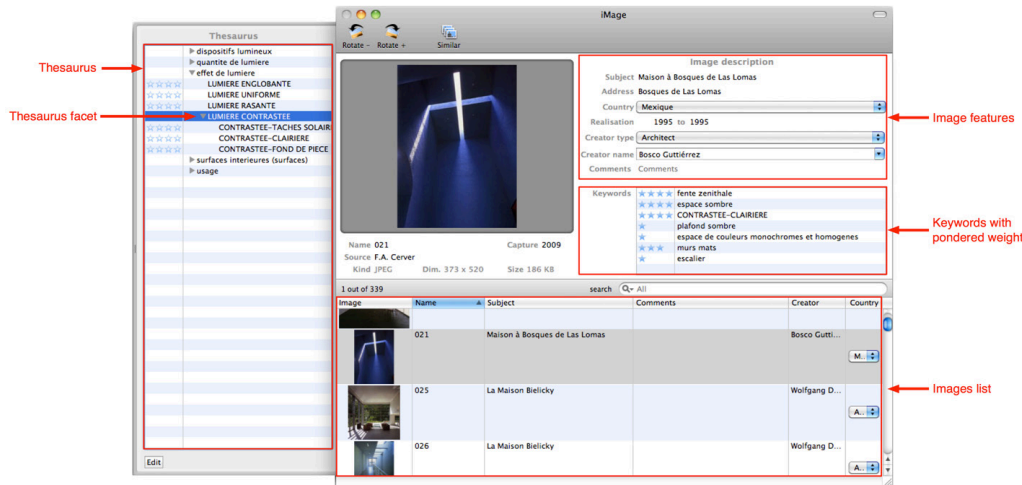


Figure 5
Picture indexation using
"Image".

that characterize represented daylight effects in order to highlight the designer intentions. After that, the designer selects one of the identified daylight effects to start a solutions generation process. The second module "knowledge base" is used to identify and characterize the designer's intentions. This knowledge base contains the quantitative and qualitative features of different and recognized daylight effects. These features are integrated in a fitness function attached to each known daylight effect. It is composed of variables that characterize solar gains and their spatial distributions.

The third module "geometry" is a parametric model of parallelepiped shape defined by thirteen parameters (Table 1). These parameters define all the spatial features that influence the daylight behavior. The model parameters are implemented in sliders that determinate their data types and their variation ranges.

The fourth module is a generative algorithm (*Galapagos*) that controls the parametric model features to generate solutions verifying the fitness value. The genetic algorithm uses the fitness function and his objective value (*fitness* value) to optimize

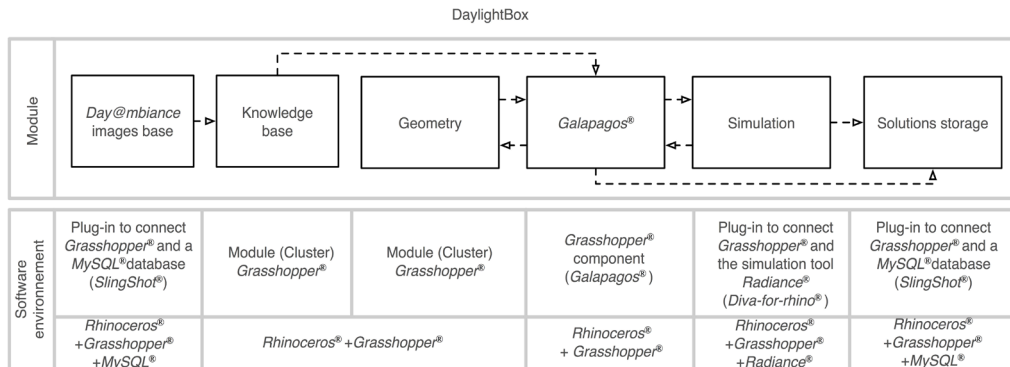


Figure 6
DaylightBox modules and
software environment.

Table 1
Parametric model features.

Model parameters	Data type	Variation range
Dimension	Integer	250..750
Aperture rate	Floating	0..1
Aperture proportion	Integer	1..5
Aperture orientation	Integer	0..7
Aperture direction	Integer	0..1
Aperture number	Integer	1..10
Aperture position	Integer	1..11
Aperture face	Integer	0..1
Surface type	Integer	0..3
Aperture surface type	Integer	0..2

the solution generation process.

The fifth module “simulation” integrates the plug-in *Diva-for-Rhino*® (Jakubiec and Reinhart, 2011) to connect *Grasshopper*® to *Radiance*® simulation software. The system process iterate on a cycle composed of three main steps:

1. The genetic algorithm *Galapagos*® finds architectural parameters values using the selection, crossover and mutation operators. It optimizes the generated solution behavior and tries to reach the fitness value.
2. The parametric model “geometry” generates architectural models defined by the parameters values provided by the genetic algorithm.
3. The simulation module analyzes the daylight features of the geometry generated by the parametric model. The simulation results are used to compute the fitness value.

The generating process ends after a fixed number of generations. All the generated solutions features (parameters and fitness values) are stored in a *MySQL*® database using the sixth module “solution

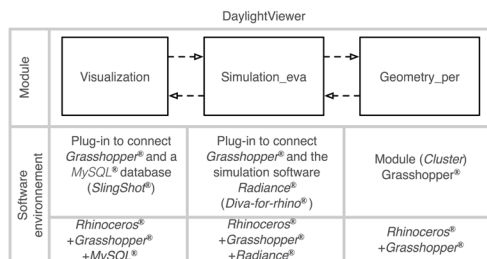
storage”. This module create a link between *Grasshopper*® and *MySQL*® using the *Slingshot*® [1] plugin.

DaylightViewer

The *DaylightViewer* tool is implemented in *Rhinceros*® modeler environment and his graphical algorithm editor *Grasshopper*®. *DaylightViewer* is a *Grasshopper*® definition that integrates three modules: a visualization interface defined by the “visualization” module, a simulation module “simulation_eva” and the parametric model “geometry_per” (Figure 7).

The first module “visualization” imports the best solutions according to their *fitness* value (solution with the lower value of fitness). The selected solution are visualized and organized in a colored grid from the best to the worst one. The user selects the number of solution to visualize and navigate under the visualized solutions (using *Rhinceros*® visualization windows) to select those corresponding to his intentions. The second module integrates a simulation tool that makes realistic and quantitative simulations in order to verify that chosen solutions produce the described daylight effect. The third module is composed of geometrical operators that could be used by designer to transform the proposed solutions. The module “geometry” presents the features of the selected solution and the list of sliders to modify the parameters values. The transformed solution could be evaluated (realistic and quantitative simulations) and exported it in 3D geometrical objects (bake them from *Rhinceros*® to *Grasshopper*®) (Figure 8).

Figure 7
DaylightViewer modules and software environment.



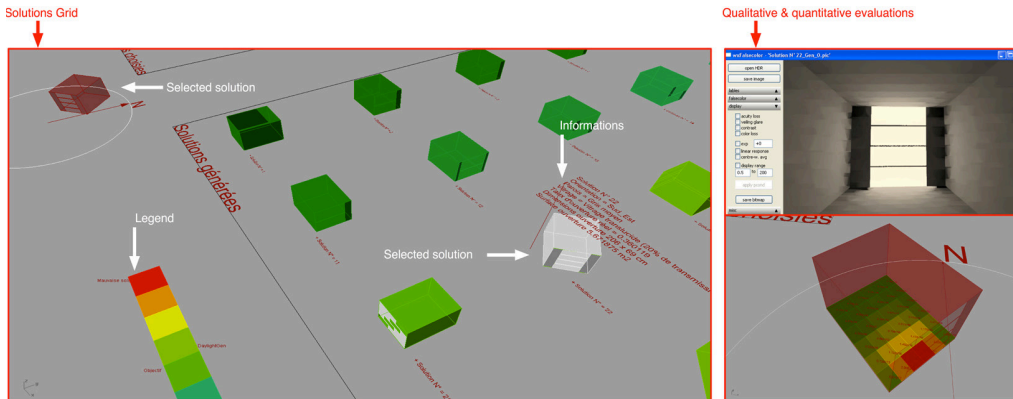


Figure 8
Solutions grid and evaluation
visualization.

THE DAYLIGHTGEN EXPERIMENTATION

The third part of this paper assesses the *DaylightGen* tool contribution during the early design steps. We try to determinate:

- the adaptation level of the method activities and functions to the early design steps features,
- the capacity of the assistant method to take into account the uncertainty that characterize early design steps,
- the creativity level and the capacity of the method to help designer to explore new ideas,
- the capacity to satisfy and materialize designer intentions.

The potential of the method has been evaluated in an educational context. We proposed to 16 Master degree students in architecture to design a project by using the *DaylightGen* tool. They worked in pairs during three hours to design a temporary exhibition space dedicated to a designer (*Jean Prouvé*). The project program is composed of two temporary exhibition rooms. The first integrates a graphics media describing the designer life. The second room is dedicated to the exhibition of models and some architectural components.

Experimentation process

The experimentation process is organized on three steps. The first step aims to prepare the participants

to the experimentation activities. We organize a training sessions to present the experimental framework, the design assistance method targets and the utilization mode of the different components of *DaylightGen* tool (*Day@mbiance*, *DaylightViewer* and *DaylightBox*). The second step is organized in design sessions for duration of three hours where a pair of student tries to design a project sketch that express particular and significant interest to daylight atmospheres. The experimentation participants are authorized to use different sketch and modeling tools (paper format, *Photoshop*®, *AutoCad*®, *Sketchup*® and *Rhinceros*®). All design sessions are captured on video to keep the student's discussions and the exchanges with the different tools (Figure 9).

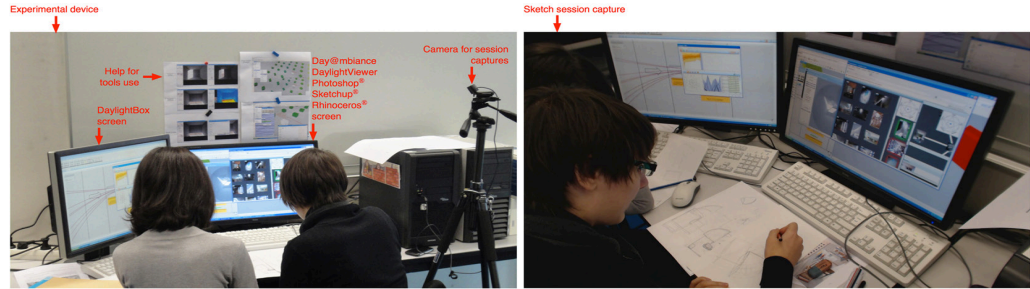
The third step of the experimentation process aims to evaluate the participation of *DaylightGen* tool during the conceptual design phases. The evaluation step starts by analyzing the captured sessions. Analyzing the experimentation feedback questionnaire realized with all participants concludes the evaluation step. This online questionnaire [2] integrates questions about the different functions and the results obtained by *DaylightGen* tool.

Experimentation results

1. Video capture analyze

We determinate the design process used by the experimentation participants by analyzing the de-

Figure 9
Experimental device.



sign sessions videos. We identify the major design activities that participate to the design process and their chaining. All design activities and the design supports used are transcribed in time line diagrams (Figure 10). The diagrams analyze reveals three design approaches (Figure 11). The first one (used by group 1 and 2) starts by formulating design problem, implanting the project, formulating and declaring daylight effect intentions using *Day@mbiance*,

identifying and selecting daylight effect, generating solution and proposing a spatial configuration for the project. The second approach (used by group 4-5-6-7) starts by formulating design problem, implanting the project, proposing a spatial configuration, formulating and declaring daylight effect intentions using *Day@mbiance*, identifying and selecting daylight effect, generating solution. The third one (used by group 3) starts by formulating design prob-

Figure 10
Example of design activities diagram.

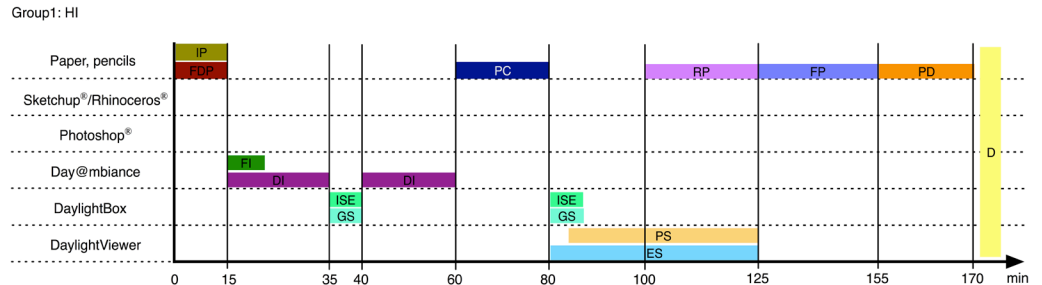


Figure 11
Design approaches.

Approach 1	Group 1-2	FDP	IP	FI	DI	ISE	SG	PC	ES	PS	RP	FP	PD	D
Approach 2	Group 4-5-6-7	FDP	IP	PC	FI	DI	ISE	SG	ES	PS	RP	FP	PD	D
Approach 3	Group 3	FDP	FI	DI	ISE	SG	IP	PC	ES	PS	RP	FP	PD	D

FDP Formulating design problem	ES Evaluate solutions
IP Implanting project	PS Personalize solutions
FI Formulating intentions	RP Reshape the project
PC Proposing spatial configuration	FP Finalize the project
DI Declaring intentions	PD Project delivery
ISE Identifying and selecting daylight effect	D Debrief Experimentation
GS Generating solutions	

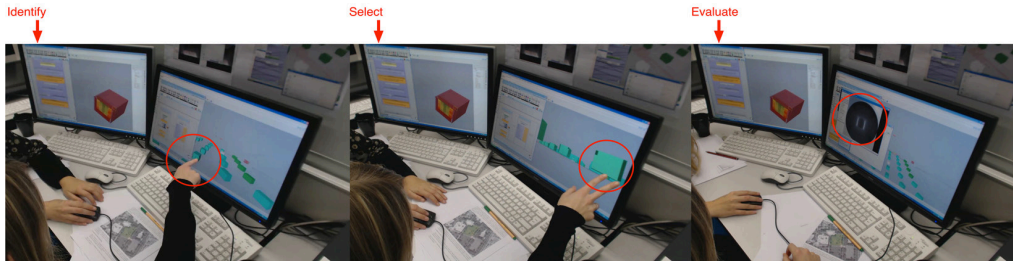


Figure 12
Identify, select and evaluate
generated solutions.

lem, formulating and declaring daylight effect intentions using *Day@mbiance*, identifying and selecting daylight effect, generating solution, implanting the project and proposing a spatial configuration for the project. All design approaches ends by the same way: the designers evaluate and personalize the generated solutions, reshape the proposed project, finalize the project and debrief the experimentation session.

The participants on the experimentation use different design supports to formulate design intentions and materialize them in architectural solutions. They associate mosaic navigation activity, manual sketches and oral expression to precise the daylight effect intentions that correspond to the project constraints. The solutions grid generated helps students to explore and define new design issues. The navigation in solutions grid helps students to locate and identify interesting solutions that could be implemented in their projects (Figure 12). Students express their interest by manual gesture and some oral expressions like *“this is small, it concentrate daylight”* to identify and describe a solution with one small

aperture in the corner or *“this is a jail effect”* to describe a solution with two long and fine vertical apertures in the right and left side of the aperture face. The students use the evaluation function to visualize the daylight effect generated by the selected solutions and verify if they corresponds to the described intentions. They operate different simulations at different times and for different sky conditions.

The navigation on the solution grid and the evaluation of the selected solutions gives to participant’s new ideas that were integrated using the modification and personalization functions proposed by the *DaylightViewer* tool. They used these functions to combine different configurations and exceed the parametric model limits. The group 3 used the modification, the evaluation functions and *Photoshop*[®] to create a new architectural solution with apertures on three faces that could not be realized by the generative model (aperture only on one face) (Figure 13).

The best-generated and personalized solutions was integrated and implemented in the project by analogy. The final daylight effect generated was

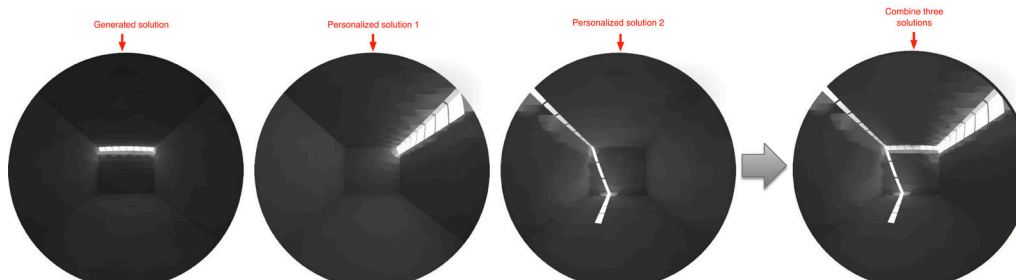
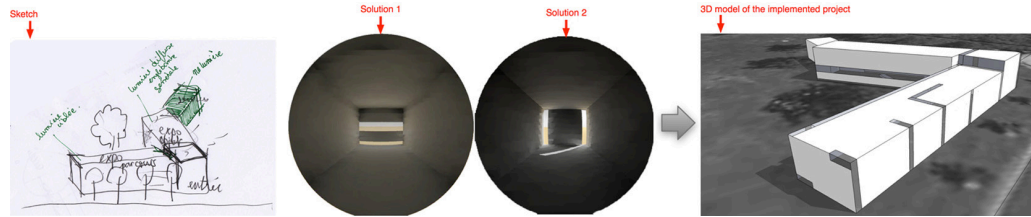


Figure 13
Combine generated and
personalized solutions.

Figure 14
Generated and personalized
solutions implementation.



evaluated using shadow visualization functions of *Sketchup*® and daylight simulation plug-in (*Diva-For-Rhino*®) of *Rhinoceros*® (Figure 14).

2. Questionnaire answers analyze

The questionnaire answers was used to identify what users think about the design assistance method and about the functions proposed by the different tool participating on the process. The main part of participants declares that the use of images to identify the daylight effect intentions is really adapted to the conceptual design steps. They say that images constitute a first level of the implementation process of design intentions. The students are satisfied by the generated solutions that verify at different levels of accuracy the described intentions. Student's answers reveals that the parametric model used for the generation activities needs to integrate more apertures types and more precise functions (multiple aperture with different sizes and shapes, aperture on different surfaces, integrate personal architectural configuration in the generation process).

The majority of participants consider evaluation and personalization functions as very useful because they allow users to reshape proposed solutions and to integrate new ideas. Students consider that the evaluation of these new solutions helps designer to create an iterative process that makes the project design progress.

CONCLUSION

This paper presents the implementation process of the *DaylightGen* method, the choice of the software environment, the modules and the component used to create the design assistance tool. It presents also the different steps, devices and results of the experi-

mentation process used to validate the *DaylightGen* method and tools targets. The experimentation results validate the capacity of the proposed method and tool to assist the daylight integration during early design steps. These results confirm the possibility to use the design intentions as basic information in design assistance tools. The experimentation results reveal some limits that concerns the number of identified daylight effects, the fitness function precision and parametric model possibilities that could be developed in future work. These results show that the proposed method could be ameliorated and adapted to a professional design context.

ACKNOWLEDGEMENT

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[2] <https://docs.google.com/spreadsheet/viewform?formkey=dGtLWXdsTHFvS0h5RFAzLWVwaEM0N3c6MQ>