URBAN PLANNING AND SOLAR POTENTIAL: ASSESSING USERS' INTERACTION WITH A NOVEL DECISION-SUPPORT WORKFLOW FOR EARLY-STAGE DESIGN

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Abstract

The need for sustainable architecture and urban design and planning has long been acknowledged, along with the necessity for adequate, early-phase guiding instruments. This paper aims at exploring the effectiveness and usability of a novel decision-support workflow for neighbourhood-scale projects, developed to provide practitioners with early-stage design alternatives in an interactive and iterative sequence. The prototype includes a performance assessment engine, which quickly computes an estimate of the daylight and passive and active solar potential for each design alternative. To assess the added value for design and the educational features offered by the workflow, workshops were organized with architects and urban planners. Participants were asked to work on a realistic micro-urban design project by means of two different approaches: making use of their conventional tools and methods, and then using the prototype. In addition to these design phases, the workshop included ranking design alternatives with respect to their performance before and after using the prototype, and filling pre- and post-workshop questionnaires to gather the participants' level of experience and their feedback. The main outcomes from these tasks show that the prototype yields a strong potential in terms of design guidance, despite mixed results in the level of success in the before and after ranking phases. Results also highlight the necessity to pursue the development and adoption of energy-oriented early-stage design instruments.

Keywords:
early-design; decision-support; urban design; solar potential

1 INTRODUCTION

The increasing necessity for the building sector to comply with various normative frameworks [1,2] and energy rating systems [3] has led to the spread of integrated design processes, supported by multi-criteria design tools, aimed at addressing urban planning and architectural practices in a more holistic and sustainable way [4,5].

In the specific context of early-phase neighbourhood projects, practical use of developed tools and methods remain limited, particularly due to their lack of guidance and integration within the design process [6,7]. Most programs are conceived for analysis rather than design, leading them to be used mainly at the detailed stage [6]. As a result, some architectural features are found to be unfavourable for the minimization of buildings' energy need only when the process is already at an advanced stage and changes are no longer possible.

Most existing design decision-support methods and tools are conceived to perform a full simulation of a unique building [8,9], task of a certain level of complexity in terms of inputs and computational time. At the urban-scale, existing methods cover the need for a relatively fast assessment through a user-friendly interface [10] and for detailed comprehensive energy flow assessment [11]. However, such tools require information typically unknown at the early-design phase (e.g. material), provide limited guidance, and are not designed to generate and compare design alternatives. To better target current shortcomings, it is essential to give greater importance and care to the design process when developing decision-supports.

As an attempt to do so and to address the mentioned limitations, a workflow was developed to support decision-making, targeting the assessment of the performance of early-design neighbourhood projects. The performance is here defined as (i) the passive solar, (ii) daylight and (iii) active solar potential. To verify whether our proposed workflow could fulfil its intended role, it was implemented as a prototype that was tested through workshops organized with practitioners.

2 OVERVIEW OF TESTED PROTOTYPE

The core of the prototype is coded in C# and packaged as a Grasshopper[1] plug-in for Rhino[2], with a customized interface for gathering the user-inputs. It also makes use of additional Grasshopper plug-ins: DIVA-for-Grasshopper [9] and Lunchbox[3]. Users provide an abstracted neighbourhood base design by positioning building points and specifying ranges of variables to explore (e.g. min-max height). A series of design alternatives (or variants) is then automatically generated by the prototype's engine, by randomly sampling from the specified variables ranges. Geometrical parameters such as the plot ratio and overall form factor are computed for each variant, as well as irradiation-based parameters (e.g. south-façade mean annual irradiation), following an irradiation simulation. These serve as inputs to the performance assessment engine that computes an estimate, through predictive mathematical functions, for the energy need for heating and cooling (indicator of the passive solar potential) and for the spatial daylight autonomy (indicator of the daylight potential). These predictive functions take the form of a multiple linear regression, defined from a dataset of simulated values for various neighbourhood designs, taken as reference and further detailed in [12]. The main advantage of this approach compared to a standard simulation is a reduced computational-cost and complexity. The third criterion – the active solar potential in terms of energy production from roof-mounted systems – is computed by an algorithm based on an irradiation threshold. Finally, the generated and assessed design variants are shown in the form of an irradiation map with a panel containing the corresponding information (e.g. building dimensions), along with graphs showing the relative performance of all variants with respect to the three criteria. More details on the workflow and its implementation can be found in [12].

This paper details the approach adopted to test the prototype through workshops, and presents the main outcomes from specific workshop tasks.

3 WORKSHOP

3.1 Objectives

The main goals of the workshops were to: (i) assess the potential of the proposed workflow as a solar/energy performance-based design decision-support method for the early-design phase of neighbourhood projects; (ii) verify if the workflow could bring new knowledge and help improve the performance of a design; (iii) identify bugs and improvements in the interface and workflow; (iv) assess the predictive accuracy of the underlying mathematical functions. In this paper, we present results for points (i) and (ii) only, focusing on the potential usability and added value of the prototype.

3.2 Participants

Three workshop sessions were organized; a first test-run was conducted with four colleagues, followed by two 'official' sessions with four professionals each, amounting to 12 participants in total. Participants consisted in one engineer and 11 architects, of which 4 declared themselves urban designers as well. Experience levels ranged from 1 to 15 years.

3.3 Schedule and tasks

The schedule of the workshop is shown in Fig. 1. Prior to the event, participants were asked to fill a questionnaire including questions on their level of experience with tools and performance assessment methods. The workshop began with a brief introduction to the tasks and performance criteria addressed by the proposed prototype as introduced earlier. Participants were then asked

[1] http://www.grasshopper3d.com/

[2] https://www.rhino3d.com/

[3] http://www.theprovingground.org/

to provide a neighbourhood design solution consisting in the composition of mix-used buildings for a given existing area (112 m by 87 m) of the city of Lausanne (adapted from a master plan [13]). The design process was split in two stages corresponding to two different design variants; participants first designed variant A (VA), using their usual design techniques and tools (e.g. common modelling software – SketchUp, Rhino, etc. – and/or physical 3D model), then provided a revised design, variant B (VB), following the prototype test. The reason for requesting two design variants lies in the fact that we wanted to compare designers' common approach (VA), and the possible improvement obtained following the use of the prototype (VB).

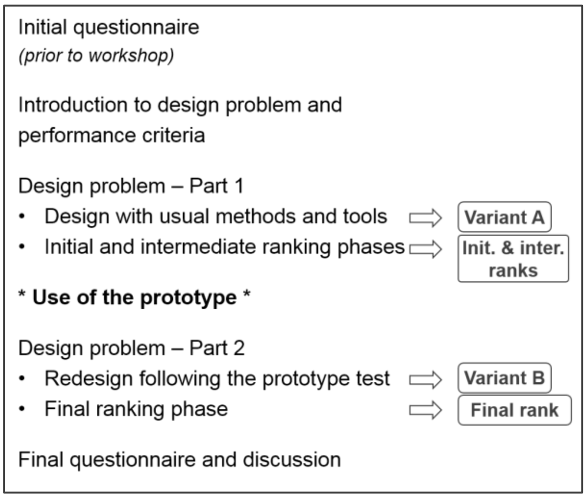


Fig. 1: Workshop schedule and tasks.

To test participants' capacity in estimating the relative performance of a set of designs in relation to the three main solar criteria considered by the prototype, the design phases were spaced out by three ranking tasks: two (initial and intermediate) performed after the generation of VA, and a final one carried out after the generation of VB. The initial task consisted in ranking, with respect to each solar criterion, four design variants: participant's VA and three other given design variants (V1-V3). In the intermediate phase, the actual performance of V1-V3 were disclosed and based on this new knowledge, participants had to rank their VA a second time, as shown in Fig. 2.

After the initial and intermediate ranking tasks, participants were shown a demo of the prototype to be tested and given instruction sheets before proceeding with the test and the development of VB. They had to re-create something similar to their VA and explore the generated variants to see if they could improve their design. In the final ranking task, they were then asked to rank this last variant, along with an optional revised rank for VA, again relative to the known V1-V3. The workshop concluded with a questionnaire to collect the participants' impression and suggestions. Following the workshops, all variants VA and VB were modelled and simulated (as previously done for V1-V3) to verify if the orders from the ranking phases were correct, i.e. matching the simulation values taken as reference. In the next section, we attempt to provide answers to goals (i) and (ii) introduced earlier by looking at the results from the questionnaires and ranking phases.

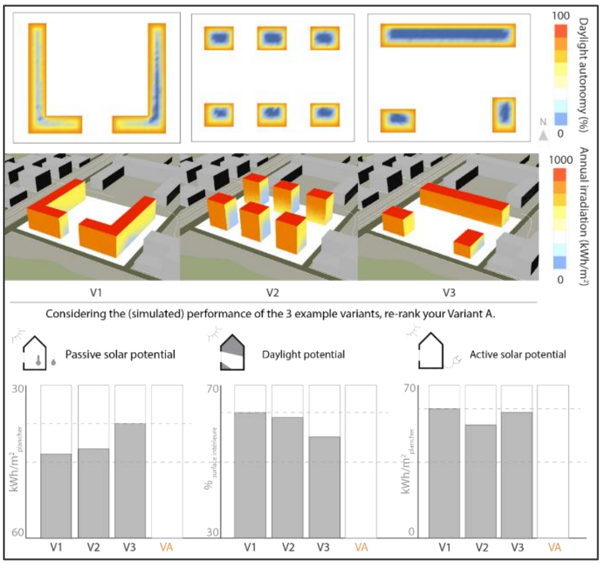


Fig. 2: Sheet given to the participants for the Intermediate ranking phase.

4 RESULTS

4.1 Initial questionnaire

The initial questionnaire contained questions related to the background and level of experience of the participants. Fig. 3 summarizes the results regarding the type of assessment typically conducted at the early and detailed design phase for each performance criterion of interest in the current context of the prototype and workshop. In the rather rare cases where an assessment is done, it generally occurs at the early phase through the application of simple methods such as rules of thumb and visualization (e.g. sun path diagram). External consultants are solicited to some extent both at the early and detailed phases across all performance criteria, while simulation is conducted, here by a small portion of participants, mostly for daylight and active solar potential assessment.

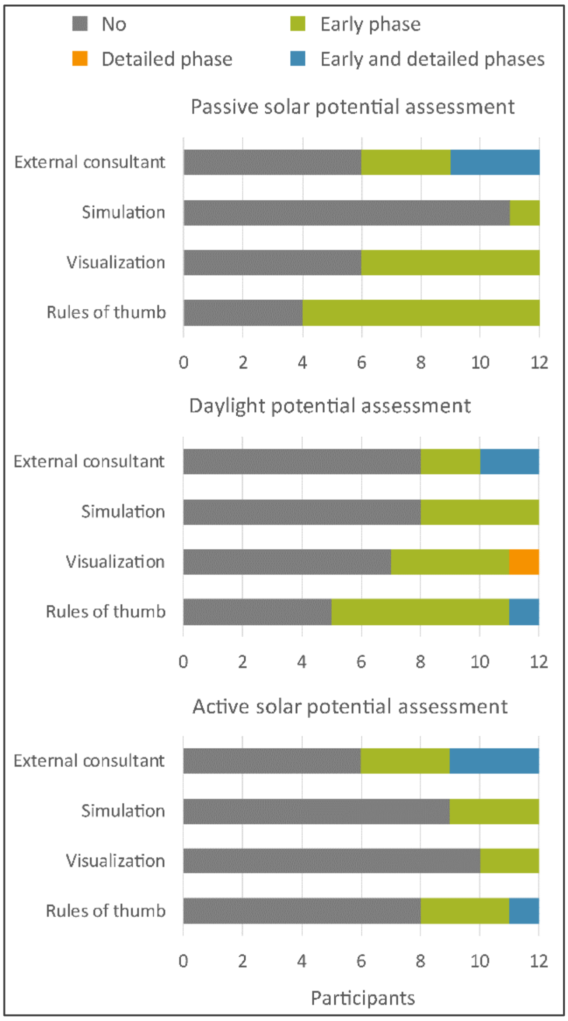


Fig. 3: Results from the initial questionnaire regarding the type of performance assessment typically conducted.

4.2 Ranking of variants

To test the educational feature of the prototype, we asked participants to rank a series of designs with respect to each of the three performance criteria in different phases, as explained earlier. To analyse the answers, we computed the Kendall rank correlation coefficient, which evaluates how similar are two sets of ranks assigned to the same set of objects [14]. This value depends on the number of inversions of pairs of objects between the two ranks. A value of 1 (respectively -1) indicates a perfect (resp. inverse) correlation, i.e. that, in this case, the rank provided by the participant is the same (resp. opposite) as the rank resulting from the simulation of the variants (reference value).

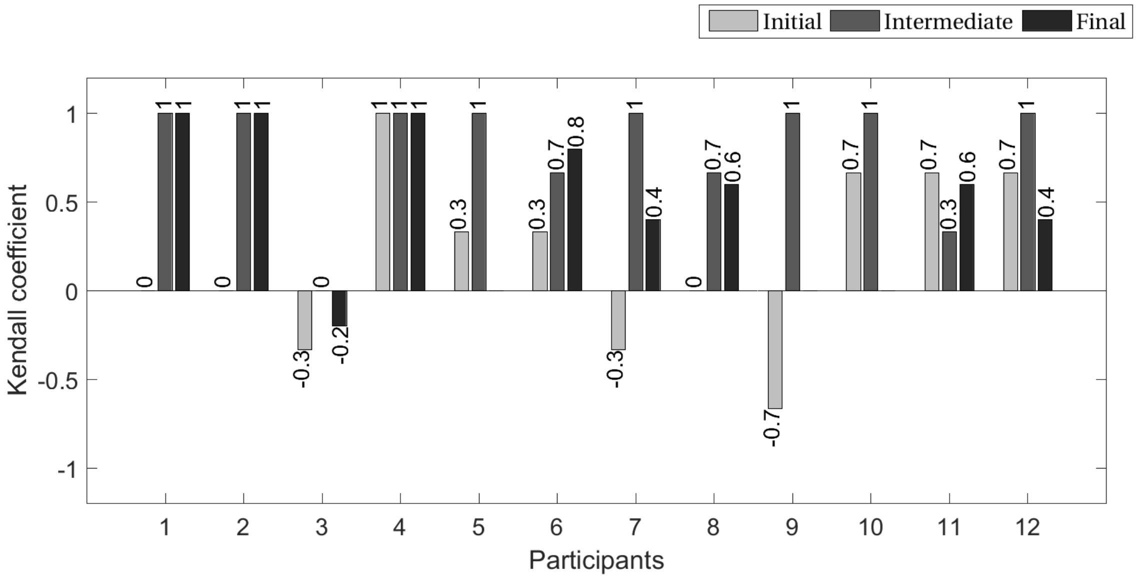
Results are shown for each ranking phase and participant in Fig. 4 for the passive solar and daylight potential. The most striking observation is the general increase in the success rate between the initial and the intermediate ranking phase. This jump can be explained by the fact that participants had to directly rank only one variant (VA) in the second phase as opposed to four in the first one, task that was furthermore facilitated by viewing the performance of the provided examples (V1-V3). From the second to the third ranking phase, results are less consistent. First, it is to note that three participants (numbered 5, 9 and 10 in the graphs) could not fulfil all workshop tasks due to technical difficulties linked to reproducing their variant A in the prototype and as such, did not provide a variant B and final ranking. Among the other participants, there is no trend for the passive solar potential; the final rank was either fully correct as in the intermediate phase (participants 1, 2, 4), better (part. 6 and 11), or worse (part. 3, 7, 8, 12). As for the daylight criterion, there was one perfect ranking for both the intermediate and final phases, while there was an increase for four participants and a decrease for another four.

However, when we compare results from the initial to the final ranking phase with abstraction of the intermediate phase and for both criteria, we observe an increase in 13 out of 18 cases (72%), or an overall jump (for all participants) from 0.19 to 0.62 and from -0.25 to 0.47 for the passive solar and daylight potential respectively, as shown in Fig. 5.

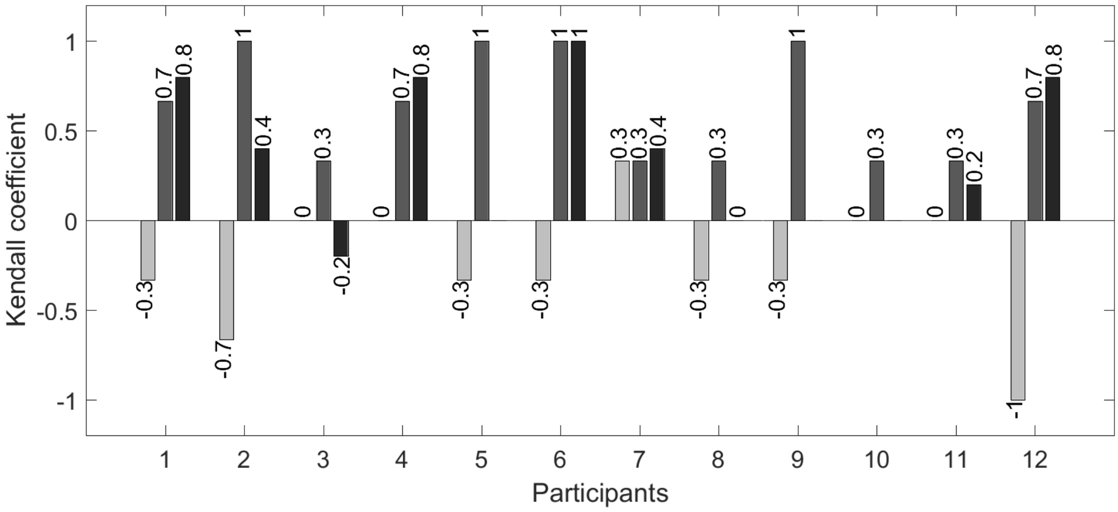
Possible explanations for these mixed results may be found in the rather short timeframe of the workshop and the current capacity of the underlying performance assessment engine, which both imposed limits on design flexibility. These limits had an impact from a ‘time to think’ perspective but also from a tool functionality perspective, because design options allowed by the tool were restricted to a pre-defined range to make sure the prototype could generate alternatives and evaluate them. While the former may have limited the opportunity to fully assimilate and explore performance results for alternative options, the latter may have diverted the participants’ attention towards trying hard to overcome this pre-defined range rather than learning from the tool in its present form.

4.3 Final questionnaire

When answering the open questions of the final questionnaire, some participants mentioned realizing that their intuition was not always correct and that such a tool could be very useful for them. Other qualitative results collected shed an optimistic light on the outcome of the workshops. The main positive feedback gathered relates to the interface and general approach of the prototype: intuitive, interactive, easy to understand and use, complementary to existing tools, promising. The predominant weaknesses are linked to the current limitations in the number and types of user-inputs and the generation of variants: more flexibility or precision required in inputs to enforce specific typologies and ensure credible designs, difficult to visualize and compare variants in synthetic way.



(a) Passive solar potential criterion



(b) Daylight potential criterion

Fig. 4: Level of success in ranking *the design variants for the (a) passive solar potential and (b) daylight criterion, for each participant and phase.*

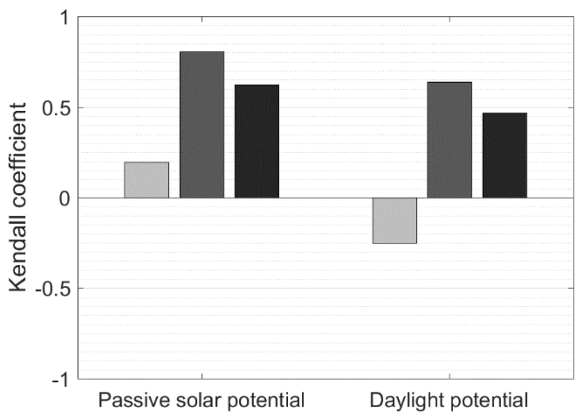


Fig. 5: Level of success in ranking the design variants over all participants at each phase.

Multiple suggestions were also given to overcome the current limitations and to expand the usability and relevance of the prototype, such as by adding specific parameters (e.g. maximum distance between buildings) and providing an automatically generated summary report.

4.4 Main findings

Regarding the potential of the workflow as a decision-support (workshop goal (i)), we observe that the objectives which we intended to fulfil in terms of prototype features – integration within the design process, relevance of approach, simplicity of user-inputs, intuitiveness of workflow and interface – were asserted by a majority of participants through their feedback, and by the fact that they could all easily use the prototype, despite their overall low experience level with performance assessment tools.

As to verifying if the workflow could bring new knowledge and help improve a design's performance (workshop goal (ii)), we conclude from this first test that these goals can only be achieved if design flexibility is increased significantly, so as to enable highly customized building massing options. A new workshop with a revised format will thus be needed, that includes more participants and extends the timeframe, so as to enable a dedicated focus on assessing the educational potential of the prototype.

5 CONCLUSION

A workflow was developed and implemented as a prototype for supporting energy-conscious decision-making at the early phase of neighbourhood projects. Put to test through workshops with practitioners, the prototype appears as highly promising in terms of the relevance and usefulness of its approach, as well as its intuitive and simple interface.

Future work will include integrating suggestions made by participants particularly to allow a larger design flexibility, and addressing the technical issues – expected due to the youth of the prototype. The latter were identified as straightforwardly solvable.

Finally, we will investigate the possibility of replacing or coupling the currently random generation of design variants with an optimizer (such as a genetic algorithm) to better guide the search for performing alternatives.

6 ACKNOWLEDGMENTS

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