Influence Of Façade Details On Early Design Decisions Regarding Daylight Performance Of Neighborhoods

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Abstract
Neighborhood form and building façade design are key drivers of indoor daylight performance. Architectural design at the neighborhood scale starts with massing scheme proposals and other design specifications including façade design are typically enriched sequentially in subsequent design stages. In this study, we simulate multiple pairs of early design massing schemes and compare their daylight performance at sequentially increasing façade level of detail (fLOD). We found the design-decision between two schemes to be more robust at high window-wall ratios (WWR) as the difference in the estimated daylight performance of two massing schemes was amplified at high WWR. At medium and low WWR, the performance difference between the massing schemes, and the resulting design-decision depended on the façade design choices such as the distribution of openings across different orientations and balcony design. Also, at high stringency in decision criteria (i.e. requirement of higher margin of difference in performance), higher fLODs were found to improve the accuracy of decision.

Introduction
In this study, we address a common and important early stage activity in neighborhood design, i.e. relative comparison of performance between two or more massing schemes proposals. Such a comparative performance evaluation is crucial as it sets the course for the evolution of the design. In the design process for a given project if daylight performance is included as an important decision-making criterion at the early design stage, the massing scheme with superior performance will be selected and different building levels design aspects such as façade details will evolve over time on the selected massing scheme. C. Reinhart and LoVerso (2010) describe this as an ‘outside in’ approach that design practitioners tend to follow ‘towards all building aspects’ where ‘once a basic building form has been conceived, different façade variants can be explored’. Ratti, Baker, and Steemers (2005) describe the influence of the urban in the form of a cascade effect, with the urban form of being at the top of the physical scale of the built environment. However, such an approach assumes that the comparative performance of two massing schemes will not change as their design evolves or that the form has negligible interactions with the façade and other related design decisions taken later in the design process. Common modelling practice for the early design stage at the neighborhood scale is thus based on the premise that if all building parameters other than the form are kept equal, we should be able to estimate the effect of the form. Several researchers working at the urban and neighborhood scale (Nault (2016); Compagnon et al. (2015); Sattrup and Strommann-Andersen (2013); Dogan et al. (2012)) have proposed and utilized simple façade related inputs for urban scale studies.

Heschong Mahone Group (2012) acknowledge the inherent limitation of the early design stage when most design parameters are unknown. For early design, comparative performance evaluations, their recommendation is to use optimistic assumptions (such as high reflectance values for internal surfaces) that help present the maximum performance potential of each design alternative being compared. There is growing interest in methodological treatment of decision-making process using building performance simulation (BPS) tools. (Hester et al. (2017); Basbagill et al. (2014b); Hopfe and Hensen (2011); Chinazzo et al.(2015)). At the early design stage, there is an additional need to address the limitation of several unknown building attributes. Hester et al. (2017) show that statistically significant difference between alternatives can be seen if some additional design attributes can be defined qualitatively ("good", “fair” or “poor”). Basbagill et al. conducted sensitivity analysis on thousands of computationally generated building alternatives and present the prognosis of possible future performance for any given design decision as a probability distribution of performance values. However, design development often occurs in an incremental manner with multiple dependencies among attributes. A study of reliability of decision making while respecting geometrical dependencies and level of design detail development may find better integration with the design process.

Decision-criterion is an essential element of the decision making process. We examine the effect of increasing fLOD in massing models, under increasing level of stringency in decision-making to better understand the relationship between decision criteria and accuracy in decision-making. We calculate the accuracy of decision-making in terms of likelihood of making the correct relative comparison between two massing schemes at a
given level of façade detail evolution for a given decision criterion.
We begin by gauging the reliability of design decision between two massing schemes without any explicit information regarding the façade design and then continue examining the state of decision making as façade design is allowed to evolve on both massing schemes.

**Methodology**

Using parametric modelling tools, we virtually propagate the design process for a given pair of massing schemes and determine if the design decision between them would change with increasing façade level of detail. While doing so, we compare the accuracy of design decision making at low versus high fLOD. At low fLOD, indoor daylight simulations are carried out for the massing schemes based on an assumed version of common modelling practice at the early design stage. The design decision that would be made as result of these simulations is noted. Next, to each of these proposed massing schemes, façade details are applied in three incremental levels of detail and design specificity. The design decision outcomes at each level of façade detail are enumerated and then compared to those achieved at the highest façade level of detail. Spatial Daylight Autonomy (sDA) (C. F. Reinhart and Walkenhorst (2001); IESNA (2012)) is used as the performance evaluation metric which is based on indoor illuminance at the work-plane.

Figure 1 shows the test site and three selected forms that are compared in this paper. These were selected from a larger test array of 45 massing schemes created as a representative set of possible residential neighbourhood form in the given test site. Table 1 shows a summary of the important geometrical properties of the test array from which three massing schemes were chosen. Façade details were applied to each form in four incremental levels using the parametric modelling environment, Rhino/Grasshopper (McNeel, 2015, 2013). Levels of façade details included in the experiment are based on their anticipated effect on daylight performance evaluations when using climate based daylight modelling (CBDM) at the neighborhood scale. The method of specifying geometrical inputs and simulation inputs at each fLOD has been formulated with the intent to isolate the effect of a fLOD. The variants developed at various levels of façade detail are based on possible design solutions. The levels of façade details thus show multiple paths of design progression with respect to the façade and are described in detail in the following subsections.

**fLOD 0**

fLOD0 or baseline façade inputs – represent the condition when no specific information regarding the façade is available. At this fLOD, windows are assigned to a given form in a manner typical to many simulation interfaces and early design modelling procedures, that is, the windows area is distributed uniformly on all vertical surfaces and windows of arbitrary dimensions are placed vertically centred with respect to the floor and the ceiling. (Figure 2). Effect of active shading systems is also excluded in these preliminary runs to mimic the expected daylight performance calculation that maybe done at the early design stage especially at the urban scale. The difference in performance using these default façade inputs is noted as the baseline performance differentiation value between the two forms. Pairs of neighborhood forms which were found to be 10% apart (+/- 1%) and 20% (+/- 1%) apart have been short listed for further investigation in this paper (Figure 1).

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Maximum</th>
<th>Minimum</th>
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<tbody>
<tr>
<td>Number of Buildings</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Building depth (m)</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>Building Height (in floors)</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Site coverage ratio</td>
<td>0.32</td>
<td>0.19</td>
</tr>
<tr>
<td>Floor to ceiling height (m)</td>
<td>3.5 (fixed)</td>
<td></td>
</tr>
<tr>
<td>Density (total built area/site area)</td>
<td>1.0 (fixed)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Summary of geometrical properties of forms in test array**

The first level of façade detail (fLOD 1) is based on a designer’s knowledge of the desired window-wall area ratio (WWR) for their specific project. A common alternate method of specifying window area in early design stage models is the window to floor area ratio (W/FA).

**Figure 1:** Test site used and three forms selected out of an array of test forms based on difference in sDA calculated using default façade inputs. All forms were modelled at a density/ floor-area-ratio of 1.0.
However, the WWR method is more relevant to this study as the density and consequently the floor area is constant (+/- 0.5% difference) among all the design alternative forms. Since the façade area varies with the alternatives, using the WWR better reflects the design opportunities offered by a particular form and its consequent impact on façade design variants and performance. Three ‘levels’ of WWR are included 40%, 30%, 20% indicating high, medium and low WWR. The height, head-height, number of windows, and vertical placement of windows is kept unchanged across all WWRs and forms.

**fLOD 2**

The second level of façade detail (fLOD 2) is devised around design decisions regarding the distribution of glazing on various vertical surfaces for a given WWR decided at fLOD 1. This is implemented by varying the WWR of individual facades but keeping the overall WWR of the building consistent with fLOD 1 value. We generate four variants at this level of detail with the intent to induce the maximum possible range in performance. The first variant favours vertical surfaces with higher sky view factor (SVF) for higher window area assignment and the second variant favours vertical surfaces with low SVF. While SVF is a widely used indicator for solar availability (Chatzipoulka et al. (2016); Cheng et al. (2006); Robinson (2006)) human comfort related factors would drive active blind operation, another important aspect influencing daylight availability indoors. Thus two additional variants are generated at this fLOD, one favouring east facing facades and the other favouring west facing facades as feasible design solutions. These additional variants serve as means of further exploring the daylight performance possibilities at this fLOD.

**fLOD 3**

The third level of façade detail (fLOD 3) is based on the moderating effect of large fixed shading elements (balconies). Balconies are a common design element in residential buildings and their addition involves their placement on one or more facades of each building, depth of projection, orientation (horizontal/vertical) and width along the facade. The vertical faces identified as the favoured facades at fLOD 2 are selected as the facades where the balconies are introduced. In order to examine the possible effect of balconies on daylight performance evaluation, multiple possible projected balcony design types are tested as this fLOD and each fLOD 2 variant results in multiple ‘child’ variants at fLOD 3. The balcony depth is tested in increments of 0.6 m and 1.2 m covering 50% of window width and an extensive version covering 100% of the window width with both horizontal and vertical projections. A visualization of the balcony types can be seen in figure 4a.

**Simulation process for calculating sDA**

For each variant generated, sDA is calculated using Radiance/DAYSIM. Simulating indoor illuminance values and calculating spatial daylight autonomy (sDA) can be challenging to implement and interpret at the early design stage as the properties of the building interior are largely unknown. However, sDA has been found to be more robust than other CBDM metrics to design factors such as interior material properties which are often unknown at the early design stage (Brembilla, Hopfe, and John Mardaljevic 2017). Thus we chose to calculate sDA values in conjunction with active blinds controlled as per BLINDSWITCH-A 2012 model (Van Den Wymelenberg (2012)) for higher fLODs. BLINDSWITCH-A 2012 model uses external incident irradiation on the window.
and penetration depth of direct sunlight into the building interior as inputs. Partial blind occlusion positions in the BLINDSWITCH-A model are ignored in our calculations given the scale of the simulations. Eight DAYSIM simulations are carried out per variant to model blinds in open and closed position on the four faces per building. The eight illuminance result files are then compiled into one composite illuminance file while applying the blind schedule specific to each building face, using Matlab. Radiance simulation parameters input are as per the IES Lighting Measurements method LM-83-12 (IESNA 2012) including indoor and exterior reflectance properties. The glazing visible light transmittance is set at 0.6. In order keep the size of the result files reasonable, the grid size for the placement of the interior photo sensors has been kept 1m x 1m and is laid in the top and bottom floor of each building. The .epw weather file for Geneva, Switzerland is used.

**Calculation of decision accuracy**

In this study, we regard fLOD 3 as the closest pragmatic estimate of performance where all the façade design decisions that are strongly related to the form have been included. At fLOD 3 we generate 16 possible design variants per WWR level per neighborhood form. These variants of one neighborhood form when compared to their counterparts of the other design alternative, result in 64 possible comparisons ((4 X 4) X 4) when keeping the WWR and balcony type consistent between comparisons. The outcomes of the comparisons are classified into three categories or three possible outcomes: (a) form 1 is better than form 2 (sDA_{form1} - sDA_{form2} > decision criteria) (b) the alternatives are equivalent in performance (|sDA_{form1} - sDA_{form2}| < 5%) (c) or that form 2 is better than form 1 (sDA_{form2} - sDA_{form1} > decision criteria). A minimum of 5% difference criteria in sDA performance is assumed for a neighborhood form to be evaluated better than another. This minimum differentiation criterion is further considered in 1% increments. 1% improvement in the case of the massing schemes modelled represents an additional area of a typical Swiss apartment meeting the sDA criterion.

The accuracy in classification of neighborhood design alternatives into the three categories mentioned above (a, b, c) at low fLODs (0, 1, 2) is assessed using a common classifier performance evaluator, called the classification accuracy. It measures the ratio of correct decisions made by a classifier. A simple tool called the confusion table is used and the ‘true positives’ (TP) as coded as correct instances of finding sufficient performance difference between two alternatives. ‘True negative’ (TN) were coded as finding correct instances of equivalence in performance. Successful identification of both scenarios is considered important and is weighted equally. Where TC is the total number of comparisons, the accuracy at a given fLOD is:

\[
\text{Accuracy} = \frac{TP + TN}{TC}
\]

Accuracy is then calculated over a range of decision criteria starting from the lowest stringency level of 5%.

**Results**

**Reliability of simple massing models (fLOD 0)**

fLOD 0 cases reflect performance comparison of two massing scheme proposals when no façade related information is available or supplied to the simulation model.

![Figure 3(a): Comparison 1 (form2-form1): ~ 10% difference in sDA at fLOD 0; 3(b) Comparison 2 (form 3- form1): ~ 20% difference in sDA at fLOD 0.](image-url)
We assess the reliability of fLOD 0 models by comparing the design decision made at fLOD 0 to design decisions that could be made when the massing schemes are evolved to fLOD 3. Figure 3(a) and (b) present the evolution of daylight performance of two massing schemes as their façade design progresses to fLOD 3. Figure 3(a) presents the case with a performance difference of 9.15% in sDA between an example pair of massing schemes (‘Comparison 1’) at fLOD 0. Figure 3(b) presents a case with a performance difference of 20.2% in sDA between an example pair of massing schemes (‘Comparison 2’) at fLOD 0. In both comparisons we find that only the high-WWR fLOD 3 variants (40% WWR) comply or concur in all cases, with the observation made at fLOD 0. At the medium-WWR and low-WWR, we find several instances where the performance of the two forms would be regarded as equivalent and façade design choices lead to a loss of difference in performance. In comparison 1 (Figure 3a), two cases are found where the ranking of the forms is reversed, however the difference in performance in these two instances is below the 5% and thus we would once again evaluate them as being equivalent in performance rather than as cases of reversal in ranking.

Utility of fLODs in accuracy of design decision making

Figure 4(a) shows the evolution of the performance of the two massing schemes in comparison 2 at WWR of 20%. Initial difference of 20.2% at fLOD 0 diminishes to 5.04% once the WWR is corrected to 20% at fLOD 1 and blind operation is included. An intermediate comparison is also shown when the WWR is corrected to 20% but blind operation is not included. In this step the performance difference in nearly halved from fLOD 0 and then further halved at fLOD 1. Addition of active blind operation thus further erodes the difference between the two schemes. However, façade design choices further on, shown at fLOD 2 and 3 can either further diminish the difference in performance or increase it, as shown in a matrix form in Figure 4(b). While initially the differentiation between the two forms drops at fLOD 1, higher differentiation can be achieved at fLOD 3. fLOD 1 thus appears to be a good indicator of the absolute performance that is likely to be achieved but appears to present a pessimistic point of view in terms of the performance difference that can be reached. This can also be seen in Figure 5(top) there fLOD 1 is found to detect instances with insufficient difference or (form1≈form2; TN) much more effectively.

Figure 4: (a) sDA values for example form 1 (orange points) and form 3 (black points) across the fLODs and all façade variants at 20% WWR (b) Difference in sDA values between form2 and form 1 across fLODs and all façade variants. Numbers (1,2,3,4) indicate fLOD 2 variants and alphabets (a,b,c,d) indicate fLOD 3 variants.
than other fLODs while it fails to detect cases where a superior performing form is identified (TP). At fLOD 0, the opposite happens, we are not able to detect or ‘foresee’ TN cases at fLOD 3.

If we examine the overall accuracy of decisions made based on information available at each fLOD (0,1,2) (Figure 5(bottom)), the accuracy is being driven by TN cases (form1=form2) as they happen to dominate the comparisons at fLOD 3 for comparison 2. This indicates that the current methodology needs to be further assessed and could benefit from in-built flexibility or higher weighting being given to identification of true positive cases. We also examined the difference in accuracy derived out of increased fLOD at different WWRs and between the two comparisons. Higher fLODs in most conditions were found to boost accuracy, however, given the limited number of cases analysed in this paper, conclusive inferences cannot be drawn yet on the variation in utility of the fLODs. Also important to note is that 100% accuracy is not achieved at LOD2, indicating that further changes in relative performance continue to occur at fLOD 3. At this time, we have not included further levels of façade development due to low expectation of influence from other design factors and low relevance to the neighborhood scale. Low expectation of influence from factors beyond the façade design is further addressed in the discussion section below. However, it may be beneficial to demonstrate if fLOD 3 indeed results in saturation of accuracy values by further exploration of fLODs.

**Discussion of results**

As mentioned above, we are treating fLOD 3 as the ground truth or the highest level of façade detail relevant to the early design stage at the neighborhood scale. Outstanding design decisions that may influence the performance evaluations are accounted for by using a conservative 5% margin as condition of insufficient differentiation in early design stage performance. Nohan et.al. 2015 found the effect of internal reflections to be less than 4.5% on DA under low outside view factor conditions. This effect would be diminished near the windows where the direct light would dominate the illuminance values. The internal reflections depend on internal partitioning of the space, window placement with respect to the partitions and choice of surface finishes. Since these are typically decided later in the design process, they were accounted for as an accepted margin of error in early design performance assessments, as mentioned above.

One drawback of the current methodology used for calculating the accuracy metric is that it gives equal weight to instances of positive identification of a superior performing form, verses none. Thus identification of instances of equivalence is also considered useful to know. However, fLOD 3 at low WWR, is dominated by instances of equivalence and at high WWR instances of inequality dominate and then these dominant conditions drive the accuracy at lower fLODs. In figure 5 (bottom) we observe that in some cases the accuracy of fLOD 1 is higher than that of fLOD 2. This is because fLOD 1 is able to identify more instances of equivalence, which also happen to be dominant at fLOD 3. This is referred to as a minority class problem (Espíndola and Ebecken (2005)) when some cases, though important, occur in minority and fail to influence the accuracy metric. The current methodology for calculating the accuracy metric does not account for this issue. The methodology also needs to be tested on more comparisons drawn from the test array with varying degrees of differentiation in order to check the ability of higher fLODs in improving accuracy of decision making.

**Conclusions**

Existing studies have mainly used the understanding of level of design development at various stages of the design process to set the broad scope of simulation inputs for performance evaluations. By formulating various façade related inputs into incremental levels of design development, and virtually progressing the design process across these façade levels of detail, we are able to assess the validity of simple early design massing models. In addition, a method for calculating accuracy in decision-making at a given level of design development using BPS
tools is presented. The loss of accuracy due to under-specification or unavailability of facade details at the early design stage is made explicit. If the accuracy achieved is found to be acceptable to the decision-maker at the current fLOD, a decision can be made.

In the two cases assessed we found that knowledge of the intended WWR for the project is a prerequisite for a meaningful performance assessment. Underestimation of WWR is may result in dismissing the performance improvement found at fLOD 0 as insignificant. Both fLOD 2 and fLOD 3 were found to have inconsistent effect on different forms. As a result, design choices at these levels of detail can either diminish or increase the performance gap between two given forms, in some cases reverse ranking as well.

The presentation of accuracy in decision making per fLOD per the decision criterion, put forth a method/tool for a designer to take better control of the design process and manage the level of design development while making a risk aware decision. By applying the presented modelling workflow to a large array of test forms, we anticipate finding empirical relations between accuracy at a given fLOD and difference in geometrical and other easy-to-compute parameters for a given pair of forms. An accuracy prediction model would not only address uncertainty due to unknown future facade-design decisions, but also bypass the heavy computational requirements of carrying out a virtual artificial design evolution of the simple early design schemes. We also envision a notation of accuracy that could be added when reporting performance gain on a given metric. For example ΔsDA(300,50%)=10.5%(F0,Ac=73%) would signify 10.5% difference in sDA between the given design proposals, at fLOD 0, with a corresponding accuracy rate of 73%.

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