# Importance of Model Level of Detail and Level of Information in Non-image Forming Simulations: A Case Study on Real-life Office

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**Abstract**

Complex multispectral simulations and measurements of the luminous environment are required to assess daylight's Non-Image Forming (NIF) effect accurately. In the study, a cellular office located in Ljubljana, Slovenia, was modelled at different levels of detail (LOD) and levels of information (LOI) to determine their impact on the accuracy of the simulation results compared to the experimental measurements of illuminance and spectral irradiance at the vertical plane under clear sky conditions. The difference between simulations and experiments was evaluated through Relative Melanopic Efficacy error, comparing median values and IQR, and performing a pairwise statistical analysis with the Mann-Whitney test. The results were analysed on the level of the entire room, individually investigated measuring points and four view directions. The results showed that the simulation model's LOD and LOI significantly influence the error between simulated and experimental results. Furthermore, it was demonstrated that lower error was achieved for the measuring point further away from the window and view directions either pointed towards the window or to the surfaces with spectrally neutral materials (i.e. white wall). Generally, a model with high LOD and medium LOI is recommended for representative NIF simulations.

*Keywords: NIF-effects, level of detail, level of information, daylight, circadian lighting, office*

## 1. Introduction

It is generally accepted that to accurately evaluate the potential of Non-Image Forming effects (NIF) – effects of light which influence the rhythm of our circadian systems (Touitou et al., 2017) and consequentially also our moods, behaviour and alertness (Bellia and Fragliasso, 2021), one has to measure or simulate the luminous environment using intricate instruments or use complex multispectral simulations (Maskarenj et al., 2022). By default, these methodologies are inherently more time-consuming. For example, measurements of the circadian environment require spectrally distinctive measuring equipment (i.e., spectrometers). Furthermore, to achieve a spectrally discerning ability to predict the NIF environment, the simulation software (e.g., ALFA (LLC Sollemma, 2023)) has to utilise multiple parallel RADIANCE (RADSITE, 2012) raytracing algorithms which are computationally and timely consuming (Gkaintatzi-Masouti et al., 2021) and under assumptions that the material properties of the indoor luminous environment are correctly determined. Therefore, the primary goal of this study is to determine to what extent the information embedded in the simulation model expressed as the level of detail – LOD and the level of information – LOI affect the accuracy of the simulation results in comparison to the real-life measurements conducted in a small cellular office located in Ljubljana, Slovenia.

## 2. Methodology

### 2.1 Experiment

A real-life office at the Faculty of Civil and Geodetic Engineering in Ljubljana (46.05° N, 14.49° E) has been chosen as a case study. The selected cellular office is a typical office at the faculty, located on the 4th floor, and has dimensions of 5.00 m x 2.60 m (depth x width), with a floor-to-ceiling height of 2.40 m (Figure 1). The office has one window with dimensions of 1.20 m x 1.60 m (width x height) and is oriented towards the SE. The office was emptied of any redundant stationery, books, and chairs. All other furniture was left in the room to give the room a certain level of complexity, which would be appropriate to be modelled with simulation models (Figure 1). The benchmark experiment of the office was executed on the 24$^{th}$ of February 2022 under clear sky conditions at 30-minute measurement intervals from 11:00 until 13:30 local solar time.


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The interior luminous conditions were measured with a custom rig (Figure 1), which emulated an average sitting occupant with a corneal height of 1.20 m. The rig simultaneously measured illuminance and spectral irradiance at the vertical plane (corneal height). FLA 603-VL4, V(λ) calibrated lux-meters (Almemo, 2023) with absolute error ±1 lx were used for illuminance measurements and calibrated concave slit grating spectrometer StellarNet BLACK-Comet (StellarNet, 2023) equipped with 180° cosine receptor at 1.5 nm resolution for the entire visual spectrum (380-780 nm) was used for measurement of spectral composition of daylight. The horizontal illuminance was also measured at a plane of 0.85 m above floor level. Exterior luminous conditions were simultaneously monitored on the faculty's roof with an external measuring rig (Figure 1), measuring global illuminance and global spectral irradiance during the experiments. Measurements were done at two preselected points in the office (L1 and L2, see Figure 1) for four cardinal view directions (0° – oriented towards the window, 90°– oriented towards the wall, 180° – oriented towards the door, 270° – oriented towards the cabinets), simulating various gaze directions of a hypothetical office occupant.


**Fig. 1: Floorplan of the studied office (top-left), representing the equipment used for measurements (top-right). Picture of the office measured in the experiment (middle). Interpretation of LOD for the studied office (bottom).**

## 2.2 Simulation

The digital models of the office were defined in the Rhinoceros software, while the simulations were executed with a plugin software for calculating circadian environment ALFA. The first step in establishing appropriate simulation geometry was determining the corresponding LODs and LOIs of the models. Both were considered in implementing geometry models intended for simulations to analyse luminous environments. Therefore, based on the already established LOD for BIM, we have defined a specific interpretation of LOD for luminous environments (EN 17412-1, 2020). Hence, the standard definitions were appropriated for the particularity of the requirements of the study of luminous environments. In total, 4 LOD levels, i.e. 100, 200, 300 and 500 (see Figure 1 and Table 1) and 3 LOI levels, i.e. minimum (LOImin), medium (LOImed) and maximum (LOImax), were used for the study. LOImin represents a spectrally neutral material environment, LOImed represents materials selected with visual matching from the ALFA library, and LOImax represents actual materials measured with a spectrophotometer.

**Tab. 1: Description of the LOD used in the modelling (see also Figure 1).**

| LOD100 | LOD200 | LOD300 | LOD500 |
|---|---|---|---|
| Shoebox model, maximum level of geometry abstraction No furniture. | Defined wall thickness, defined window with simple frames, simple walls, segmentation in walls excluded, and added doors. No furniture. | Detailed walls, windows, doors, generic furniture (e.g. generic wardrobes, simple generic tables, chairs). | Detailed walls, windows, doors. Actual geometry of furniture in the office. |

The simulations were performed with ALFA for the same conditions as the measurements (clear sky, half-hour steps, 24th of February, 11:00–13:30 local solar time). Analogously to the experiment, four view directions were simulated for each analysis point (L1 and L2), matching positions from the experiment. Simulations were executed for each possible combination of LOI and LOD. Experiment and simulation results were compared using the Relative Melanopic Efficacy – RME (Potočnik and Košir, 2020) factor, the quotient between photopic lx and equivalent melanopic lx, which enabled expression of the accuracy of the simulation procedure regardless of absolute irradiance. $RME_{error}$ was calculated using the following equation:

$$RME_{error} = \frac{RME_{experiment} - RME_{simulation}}{RME_{experiment}} \times 100\% \qquad \text{(eq. 1)}$$

Hence, the negative values of $RME_{error}$ indicate that the software overestimates the RMEs, while positive $RME_{error}$ suggests that the simulation underestimates the RME compared to the experimental results.

## 3. Results

The results will be presented in 3 subsections. The first subsection will give the general impression of the impact of LOD and LOI on the accuracy of the simulations. The second and third subsections will delve deeper into the interpretation of errors occurring when categorising the results by the position in space and view direction.

### 3.1 Accuracy of simulations in relation to LOD and LOI

The results shown in Figure 2 demonstrate considerable differences in the error between LOI and LOD combinations compared to the experiment. As shown in Figure 2, the lowest median $RME_{error}$ when evaluating the simulation results from the standpoint of LOD is calculated for the LOD100 (-4.05 %), while the highest $RME_{error}$ is calculated for LOD300 (5.37 %). Additionally, we can observe that as the level of detail increases (LOD), the variation in the data error decreases (drop in IQR from 16.41 pp at LOD100 to 12.13 pp at LOD500). We could argue that the LOD500 model is the most reliable among the studied geometric models with the lowest IQR and second lowest median $RME_{error}$ (3.65 %). To assess the statistical significance of variations in geometric between LOD100 to LOD200, LOD200 to LOD300 and LOD300 to LOD500, a pairwise statistical analysis with the Mann-Whitney test for non-parametric comparison of medians was executed. This analysis revealed that we cannot reject the hypothesis that the medians from LOD100 to LOD200 do not differ ($p = 0.36$). On the contrary, statistically significant different medians between pairwise comparisons of LOD200 and LOD300 ($p < 0.001$) and of LOD300 and LOD500 ($p < 0.05$) have been identified. In other words, these results suggest a statistically significant effect of changing the level of detail in the model except for the case of increasing the LOD from 100 to 200.

When we compare the results from the standpoint of LOI, as shown in the a) plot of Figure 2, the highest median $RME_{error}$ is detected with the lowest level of detail LOImin (-6.04 %) and the lowest median $RME_{error}$ is detected with the highest level of detail LOImax (0.69 %). The lowest IQR was calculated with LOImed (13.42 pp) and the highest with LOImax (20.72 pp). Pairwise Mann-Whitney test comparison revealed a statistically significant difference in means between pairs: LOImin and LOImed ($p < 0.001$), LOImed and LOImax ($p < 0.001$), and LOImin and LOImax ($p < 0.05$). Hence, the results indicate a statistically significant effect of LOI on the $RME_{error}$.

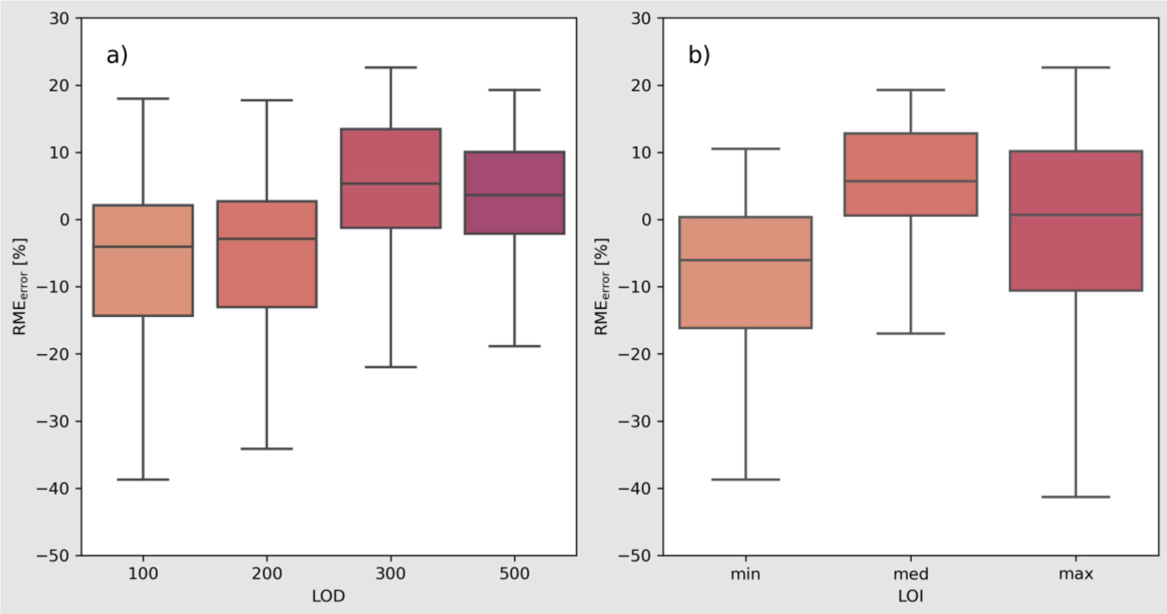


**Fig. 2: $RME_{error}$ between experiment and each simulation combination based on LOD classification (left plot) and LOI classification of results, on 24th of February, 11:00–13:30.**

## 3.2 Accuracy of simulations in relation to LOD and LOI by measurement points

The investigated office was analysed from two measurement points. The L0 measurement point is closer to the window and is influenced more by direct daylight. In contrast, the L1 point is more influenced by the reflected light of diffuse/reflective surfaces of the office. Therefore, we were interested in investigating the results when categorised by point of measurement. In plot a) of Figure 3, we show the results of our analysis of the data grouped by measuring points, which reveal a lower median $RME_{error}$ (-2.61 %) and smaller IQR of 14.66 pp for the point L1 (point further away from the window). Contrary to L0, which expresses underestimation of RME, specifically a median $RME_{error}$ of 5.36 % with a larger IQR of 16.43 pp. Mann-Whitney comparison of medians reveals a significant difference ($p < 0.001$) between observed points, which means that the position in the space has a statistically significant influence on the accuracy of the result. Therefore, we can say that when observing all cases by points, the simulation results for the L1 point tend to be slightly more accurate than the ones for the L0 point.

To further investigate the results, we split the data for LOD and LOI (Figure 3, plots b) and c)). When results are categorised according to LOD, the smallest median $RME_{error}$ for point L0 is identified with LOD100 (-0.13 %). In contrast, LOD500 expressed the slightest error (0.38 %) and IQR (8.84 pp) among results for L1. The largest median $RME_{error}$ of 13.14 % was observed with LOD300, and the smallest IQR is expressed with results at LOD500 for point L0 (Figure 3, plot b)). Analogously to the results presented in Figure 2, when observing the results from the viewpoint of LOI, we can observe the lowest median $RME_{error}$ for the LOImin (-1.45 %) and the lowest median $RME_{error}$ (-2.89 %) for the L1 point with the simulation where LOImax materials were used. The lowest IQR for L0 (5.94 pp) and L1 (5.29 pp) points were identified for the LOImed case.

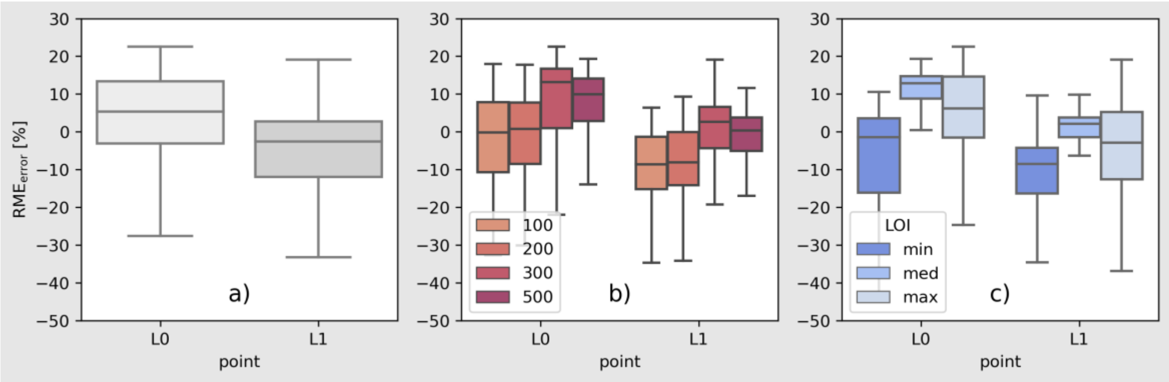


**Fig. 3: $RME_{error}$ between experiment and simulations according to the investigated points in the office (plot a), by point and LOD (plot b), by point and LOI (plot c).**

## 3.3 Accuracy of simulations in relation to LOD and LOI view direction

The observed office was relatively small. However, it featured a varied selection of views, where view direction 0° was pointed towards the window opening and a big bookshelf. View directions 90° and 180° were characterised by a white wall with low furniture, and view direction 270° was pointed toward the large floor-to-ceiling cabinets. Thus, we were interested in exploring the relationship between $RME_{error}$ and the investigated views. Plot a) of Figure 4 presents the $RME_{error}$ calculated according to the view direction. The lowest median $RME_{error}$ (0.44 %) and IQR (8.23 pp) were calculated for the 90° view. A similarly slight variation in results expressed in IQR of 10.43 pp was calculated for view direction 0°, which is the view 90 ° characterised by plenty of daylight and a low amount of detail. On the contrary, by increasing the amount of detail in the views, the IQR increases, resulting in the highest IQR (30.9 pp) and the most prominent $RME_{error}$ (-19.51 %) of views at 270°. However, when looked at in depth from the standpoints of LOD (plot b) in Figure 4) and LOI (plot c) in Figure 4) we can argue that this high variance in results is due to the complexity of the views (i.e. a high portion of visible cabinets, floors, walls, ceilings etc.). Furthermore, combinations like LOImax and LOD100 (plot d) in Figure 4) resulted in a high median $RME_{error}$ of -28.79 %. In comparison, the combination of LOImax and LOD500 resulted in distinctively lower median $RME_{error}$ (6.43 %) and almost negligible IQR (4.83 pp). As shown in plot d) in Figure 4, similar is valid for combinations of LOD500 and LOImed, LOD300 and LOImed, and LOD300 and LOImax. Conversely, combinations involving LOD500 and LOImin (median $RME_{error}$ of -29.17 %) and LOD300 and LOImin (median $RME_{error}$ of -30.70 %) result in significantly reduced prominent overestimation of RME compared to the experimental values.

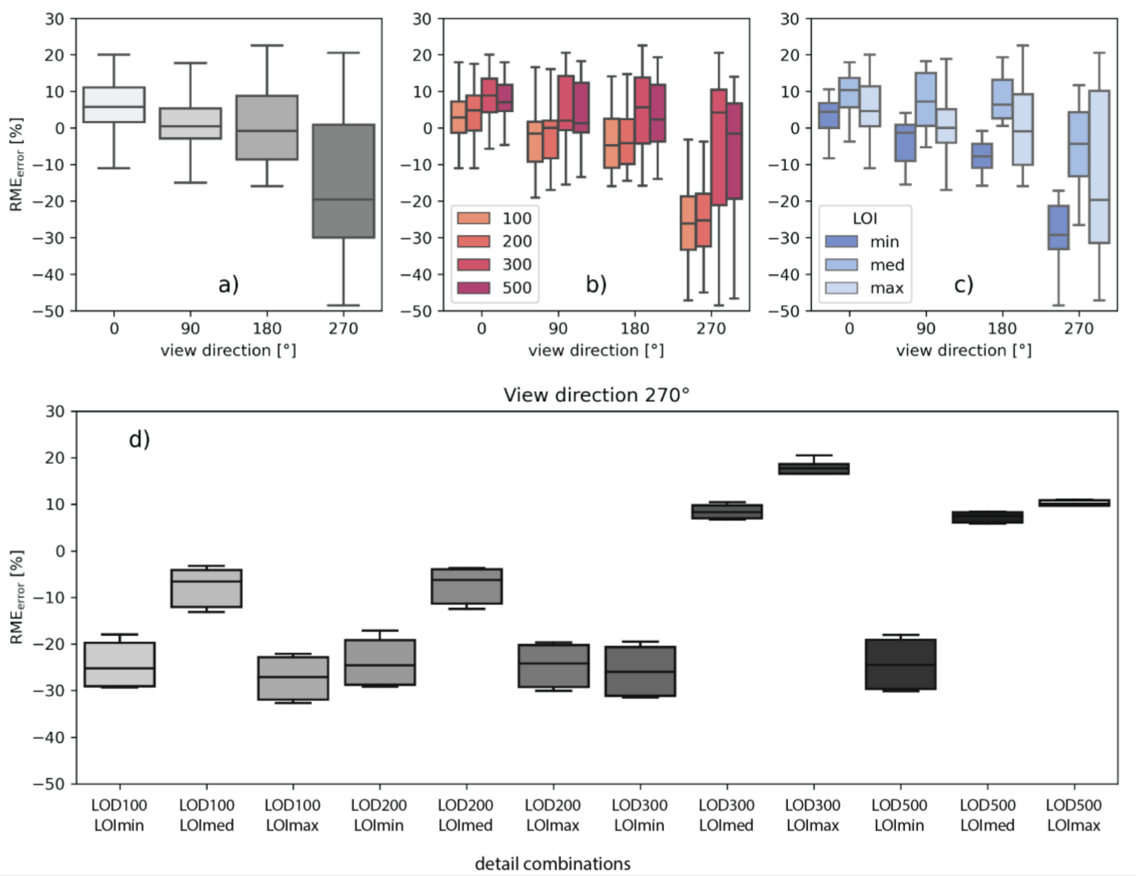


**Fig. 4: $RME_{error}$ between experiment and simulations according to the view direction (plot a), by view direction and LOD (plot b), by view direction and LOI (plot c). $RME_{error}$ for the view direction 270° by LOI and LOD combinations (plot d).**

## 4. Discussion and Conclusion

This study has investigated if and to what extent the level of detail (LOD) and the level of information (LOI) of a digital model for luminance environment simulations can affect the accuracy of results compared to the experiment on an example of a cellular office. The study's results have clearly shown that both LOD and LOI in the case of the investigated cell office under clear sky conditions significantly affected the simulation results. The rise of information in LOD caused a lower IQR and neutralised the overestimation of RME of the models without modelled furniture (i.e. LOD100 and LOD200). An increase in the information about materials lowered the median $RME_{error}$. However, on the other hand, the increase in the LOI also resulted in a higher IQR of simulation results. By itself, this might seem counterintuitive. However, comparing different LOD and LOI combinations for the view direction 270° has shown that the best performance will be identified with configurations where both LOD and LOI of the model are high (LOD300 or above and LOImed or above). Furthermore, significant differences in simulation accuracy were found between the two investigated spatial points and various view directions. The slightest errors were identified for the point further from the window (i.e. L0) and views directed towards the window (i.e. view 0°). On the other hand, the most prominent errors were found for the point closer to the window (i.e. point L1) and the views directed towards the wooden cabinets (i.e. view 270°).

As stated in the introduction, the simulation procedures for Non-image-forming effects of light are usually quite time-consuming, especially if the simulated materials are also measured by a spectrophotometer, which is expensive and often unavailable to everyone. Thus, we could argue that achieving a high LOD of the model is essential for the best results under clear-sky conditions. Later, the high LOD model can be reasonably combined with materials chosen from the simulation tool's library using visual matching. To be able to generalise these findings, the limitations of this study would need to be addressed through additional work. The study was executed only for one day and one type of weather conditions. Evaluation under overcast skies might mitigate the error due to the influence of direct sunlight. The office chosen was relatively small; a study of a bigger space is needed to see if the same LOD relationship is also valid for larger rooms. The simulation errors in the study were investigated solely through RME. Further insight might be gained by evaluating the differences between simulated and experimental spectral distribution curves.

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