

# The Development and Verification of a Computational Tool for the Evaluation of the Visual Accessibility of Architectural Spaces

Dawid Wolosiuk – TU Wien – dawid.wolosiuk@tuwien.ac.at

Harald Hofstätter – TU Wien – harald.hofstatter@tuwien.ac.at

Ardeshir Mahdavi – TU Wien – amahdavi@tuwien.ac.at

## Abstract

The present paper presents a tool for the assessment of the visual performance of spaces, especially with regard to the requirements of visually impaired people. This tool was one of the key deliverables of a recently completed project (ViDeA) addressing the special architecturally relevant needs of the visually impaired building users. Implementation of building regulations related to visual accessibility in a reliable manner (during design process) requires expert knowledge and the use of sophisticated visual simulation software. Toward this end, the tool attempts to facilitate the accurate evaluation of visual conditions in the proposed designs. The paper describes the general structure and implementation details. It also documents the preliminary verification of the tool based on a case study of an underground metro station.

## 1. Introduction

Partially sighted people constitute a large part of the population (over 246 million worldwide, WHO, 2012). The specific requirements of this population in view of the universal design has not been sufficiently addressed. International and national standards (e.g., ISO, 2011; DIN, 2009; SIA, 2009; ASI, 2013; BSI, 2009) provide some information on the threshold levels for certain relevant visual indicators (e.g., luminance contrast and average illuminance). Less attention seems to have been paid to further visual performance indicators (for example, light distribution uniformity), which are equally relevant in evaluation of visual quality of spaces. The threshold values for these indicators had to be derived in a process of original optometric

experiments in the ViDeA project involving both partially and full sighted participants.

There is a long list of visual simulation applications that can support the building design process. However, to our knowledge there is a lack of visual performance simulation tools that would be suited to specifically address the needs of visually impaired people.

## 2. A Visual Performance Assessment Tool

### 2.1 General Structure

The standard workflow in ViDeA begins on the client's side where a 3d model is created or imported to a CAD software (see Fig. 1). Utilizing software's GUI (Graphical User Interface) it is semantically enriched. Thereby, visual properties of the surfaces and lighting system details are specified.

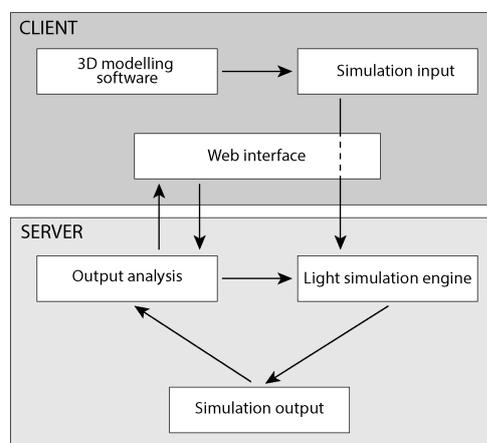


Fig. 1 – ViDeA tool workflow (Wolosiuk et al. 2015)

This data set together with user-specified observer positions constitute the input for an advanced lighting simulation engine. Simulation results in the values of a number of view dependent visual indicators such as UGR (Unified Glare Rating). The user is presented with the results of the simulation via a dedicated Web interface, where rendered images can be further analyzed in whole or in parts (e.g., mean luminance or contrast ratio for a selected segment of the rendered image).

Computed values of numeric indicator values are compared with pertinent threshold values, which are determined via optometric experiments (conducted in the course of the ViDeA project) and literature. The set of relevant visual indicators that was selected for the projected space evaluation is as follows:

Luminance contrast according to Michelson (Rea, 2000):

$$C_M = (L_{max} - L_{min}) \cdot (L_{max} + L_{min})^{-1} \quad (1)$$

Luminance contrast according to Weber (Rea, 2000):

$$C_W = (L_g - L_l) \cdot L_g^{-1} \quad (2)$$

Mean Luminance ( $L_m$ ) and mean Illuminance ( $E_m$ )

Light Distribution Uniformity (DIN, 2011):

$$U_o = L_{min} \cdot L_m^{-1} \quad (3)$$

Unified Glare Rating (CIE, 2011):

$$UGR = 8 \cdot \log[(0,25 \cdot L_b^{-1}) \cdot \sum[(L^2 \cdot \Omega) \cdot p^2]] \quad (4)$$

The indicators set was based on examination of related literature (e.g. CIE, 2011; DIN, 2009 and 2010; ISO, 2011; SIA, 2009; Bright et al., 1997; Buser et al., 2008; Joos et al., 2012; Schmidt and Buser, 2014; BMG, 1996) approved and supplemented by recommendations from optometrists involved in the project.

## 2.2 Implementation

To cater for the ViDeA tool's requirements in view of 3D modelling, camera tools, "layers" grouping, and material selection functionality, Trimble SketchUp was selected (Trimble, 2014). This tool comes with a built-in Ruby API that allows for a further functionality extension through various plug-ins. The already existing "su2rad" (Bleicher, 2015) plug-in, was altered to support the project goals. The original plug-in functions as a bridge between SketchUp and RADIANCE advance lighting simulation software (Ward, 1994) (Fig. 2). It facilitates

access to the initial simulation settings, allows for the assignment of Radiance compliant materials to groups of 3D objects (per layer, per color), and exports stored camera positions.

The output of the original plug-in is a folder containing simulation files structured in accordance with RADIANCE guidelines. To perform a simulation of an exported scene, Radiance and operating systems command line interface (CLI) knowledge is required. The ViDeA extension alters this original plug-in to make it possible to import into the model, luminaire source geometry and photometric data extracted from IES photometric data files (IESNA, 2002). Moreover, the developed plugin allows to easily exchange imported luminaire instances against other options in the luminaire database.

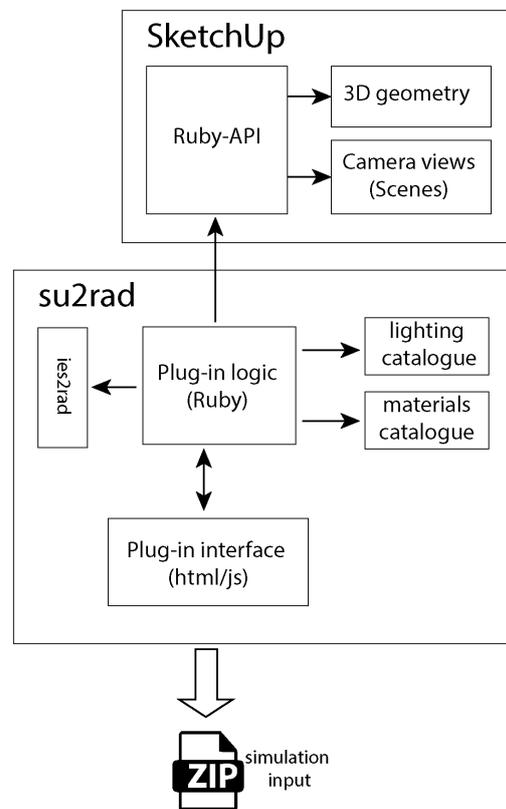


Fig. 2 – Plug-in architecture

The plug-in also enables users to import Radiance compliant materials list stored in a text file and add them to the native SketchUp materials list. This allows for the use of the native "paint bucket" tool for the custom Radiance material assignment. It also adds additional view and renders settings that are

required for calculation of the visual performance indicators.

To remove CLI, a web-application was created (Fig. 3). It presents the user with numeric and visual simulation results together with warning information in case the values are outside the recommended ranges. Likewise, tools are provided for an interactive analysis of the rendered views.

Simulation files are automatically compressed during the export process to facilitate the upload process. Uploading is done via dedicated web-interface. The simulation is automatically initialized on the server by the execution of the relevant Radiance executable and system commands. All relevant simulation output (indicators, rendered images) is processed and stored in a database for rapid queries.

During image analysis, an R-tree data structure (multi-dimensional tree data structures that provide efficient spatial access to their elements, see Guttman, 1984) is generated from values obtained from each pixel.

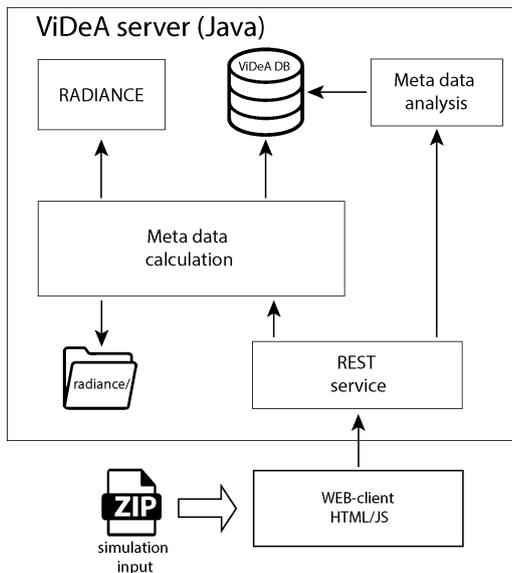


Fig. 3 – Web application architecture

The interface offers the possibility to select a point, segment, or surface of interest in the image. Multiple descriptive statistics are calculated based on pixels' meta-data (e.g. luminance values) including minimum and maximum values, mean, variance, and standard deviation. This data is then used to calculate visual performance indicators for selected segments of the image.

### 3. Illustrative Example

#### 3.1 Input Data

In order to illustrate the workflow and verify the ViDeA tool, an existing metro station in Vienna was selected as a study case. Toward this end, the following data was acquired:

Blueprints and photographic documentation for the recreation of 3D space;

Photometric profiles of electric lighting;

Luminance images;

Optical properties of the building materials.

The project partners supplied the blueprints as well as the photometric lighting profiles (in form of IES files). The station was also well documented in a set of luminance images captured using a fish-eye lens. These images are later used for model validation.

Using a portable spectrophotometer, a series of on-site measurements was performed to determine the average reflectance of the building materials. The collected data had to be converted to a radiance compliant format.

#### 3.2 Modelling

The 3D model of the station was recreated in Archicad (BIM software) and exported in a Sketchup compliant format (Fig. 4). Given the added functionality in the modified "su2rad" plug-in, the luminaire source geometry (extracted from IES file) was imported to the 3D model and then duplicated and positioned according to the plan documentation. In the following step, the 3D model was semantically enriched by associating previously gathered material properties to the surfaces. This was done using another new plug-in' feature that allowed to add the on-site collected materials (in radiance compliant format) to the native Sketchup material collection, thereby enabling the use of the built-in "paint bucket" tool.

Finally, using native Sketch-Up camera and 3d view storing functionality, a number of viewer positions (matching those from luminance camera) were selected for rendering.

Simulation is carried out automatically after the upload of a ZIP file (outcome of the modeling phase) via ViDeA web interface to the dedicated server.

The end product of the simulation is a set of rendered views with pre-calculated view dependent visual indicators (UGR, mean luminance/illuminance, light distribution uniformity), ready for analysis. Rendered images and those obtained from the luminance camera were compared toward model performance evaluation.

### 3.3 Simulation Results and Verification

Figs. 5 and 6 contrast the false color images obtained from the luminance camera with the computationally rendered images. Table 1 shows the resulting average luminance values for the specific segments of the images (see Figs. 5 and 7).



Fig. 4 – 3D model of the metro station

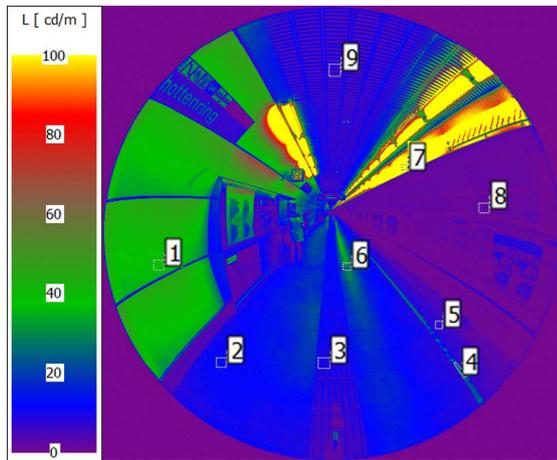


Fig. 5 – False color image obtained from the luminance camera

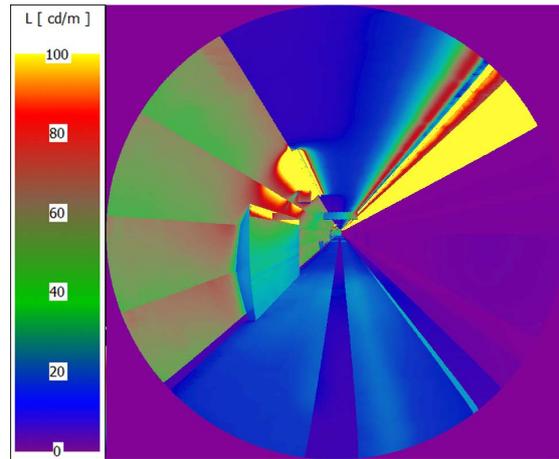


Fig. 6 – False color rendered image

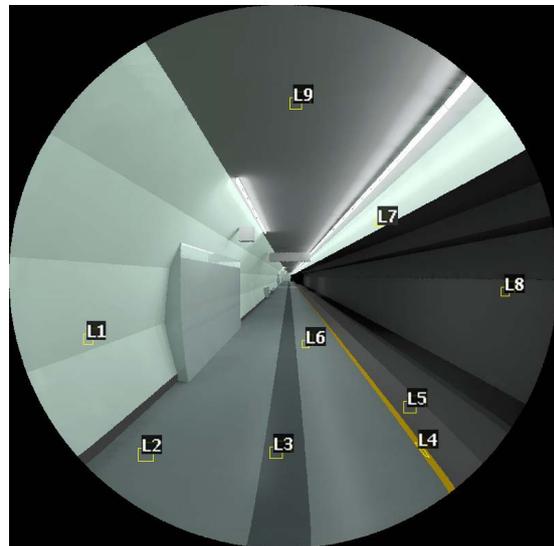


Fig. 7 – Rendered image

Table 1 – Luminance result comparison

Region	Average Luminance [cd/m <sup>2</sup> ]	
	Camera	Simulation
1/L1	41.5	43.5
2/L2	12.6	12.7
3/L3	8.7	7.7
4/L4	23.4	22.6
5/L5	7.4	7.3
6/L6	25.2	23.8
7/L7	218.2	217.0
8/L8	2.3	2.1
9/L9	7.9	8.5

The good correlation between the simulations and the measurements are arguably the result of two factors. One factor is attributable to the reliability of the adopted computational engine (Radiance). The other factor pertains to the deployment potential of the developed environment toward a proper and effective generation of simulation input models. Hereby, the effectiveness relates to the circumstance that the components of the model (geometry, surface properties, luminaire specifications) can be conveniently obtained and reliably assembled. Likewise, consideration and inclusion of empirically obtained information regarding the specific requirements of visually impaired people enriches the informational background for the evaluation of the calculated values of pertinent visual performance indicators.

## 4. Conclusion

This paper reported on a visual simulation and analysis tool that was developed as a part of the ViDeA research project. The project addressed the needs of visually impaired people by focusing on the specific requirements for creation of visually accessible spaces. Toward this end, the project partners carried out interviews and optometric experiments. Moreover, a systematic set of key visual performance indicators and associated computational routines was generated, which served as a base for the developed tool. The ViDeA tool aims at providing the necessary means to support designers in simulating and analyzing 3D scenes. To obtain detailed and high fidelity simulation results, a well-established simulation engine was deployed. A set of analytical tools was provided to facilitate the extraction of data necessary for a comprehensive visual performance assessment of the rendered scenes. The comparison of simulated and real-world numeric results presented in this paper, shows a promising correlation. This points to the potential of the developed environment as a design and retrofit decision support tool. The next developmental steps pertain to tool performance optimization. Specifically, computational efficiency is to be increased. Toward this end, recent developments in the use of advanced GPUs in the ray tracing process (Jones,

2014) and the associated rendering time reduction are to be harnessed.

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## Nomenclature

### Symbols

$E_m$	Average Illuminance (lux)
$L_b$	Background Luminance ( $E \cdot \pi^{-1}$ ) ( $\text{cd} \cdot \text{m}^{-2}$ )
$L_g$	Higher Luminance ( $\text{cd} \cdot \text{m}^{-2}$ )
$L_l$	Lower Luminance ( $\text{cd} \cdot \text{m}^{-2}$ )
$L_m$	Average Luminance ( $\text{cd} \cdot \text{m}^{-2}$ )
$L_{\max}$	Maximum Luminance ( $\text{cd} \cdot \text{m}^{-2}$ )
$L_{\min}$	Minimum Luminance ( $\text{cd} \cdot \text{m}^{-2}$ )
$\Omega$	Solid angle (sr)
$p$	Guth position index
$U_o$	Luminance uniformity

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