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A Computational Tool for the Evaluation of the Visual Accessibility of Architectural Spaces

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eines Diplom-Ingenieurs

unter der Leitung von
Univ.Prof. Dipl.-Ing. Dr.techn. Ardeshir Mahdavi
E 259-3 Abteilung für Bauphysik und Bauökologie
Institut für Architekturwissenschaften

eingereicht an der
Technischen Universität Wien
Fakultät für Architektur und Raumplanung

von
Dawid Wolosiuk
Matr. Nr: 1127262
Schönbrunner Straße 85/52, 1050-Wien

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Kurzfassung

Ein großer Teil der weltweiten Population ist irgendwann im Leben einer teilweisen Seheinschränkung (Alter, Erkrankungen) ausgesetzt. Leider werden Seheinschränkungen - obwohl weite Teile der Bevölkerung davon betroffen sind - im Zuge von "Universal Design" nicht oder nicht hinreichend berücksichtigt. Es liegt die Vermutung nahe, dass dies mit einem Kenntnismangel bei Akteuren und Stakeholdern, wie den gesetzgebenden Stellen, Planern und Ausführenden zusammenhängt. Obwohl es inzwischen eine große Anzahl von potenten, computergestützten visuellen Performance-Simulations-Werkzeugen gibt, scheint es es nur wenige Entwicklungs- bzw. Adaptierungsbemühungen hinsichtlich solcher Werkzeuge zu geben, die sich mit den Belangen von Menschen mit Seheinschränkungen auseinandersetzen. Um diese Lücke zu überbrücken, dokumentiert diese Master-These die Ergebnisse aktueller Entwicklungsbemühungen in diesem Gebiet, welche simulationsgestützte, visuelle Performance-Evaluierung unter Berücksichtigung der Bedürfnisse von Menschen mit Seheinschränkungen zum Ziel hatten. Ein grundsätzliches Problem besteht darin, dass "Visueller Komfort" zur Berücksichtigung in der Planung sowohl Expertise in dem Gebiet, wie auch anspruchsvolle Simulationswerkzeuge erfordert. Existierende visuelle Simulationswerkzeuge haben darüber hinaus in Teilbereichen Schwächen bei der graphischen Benutzeroberfläche oder bei den vorhandenen Möglichkeiten der zielgerichteten (fragestellungsgerichteten) Ergebnisauswertung. Das im Zuge der Entwicklungsbemühungen erstellte Simulationstools adressiert diese Aspekte: Im Rahmen eines browser/web-basierten Environments können Designvarianten sehr intuitiv analysiert und hinsichtlich spezieller, wesentlicher Performancekriterien (z.B. Kontrast) mühelos detailliert evaluiert werden. Diese Master-These beschreibt die generelle Struktur der Simulationsumgebung, sowie die Implementierungsdetails. Anhand von anschaulichen Beispielen wird darüber hinaus der Workflow, sowie die

Simulationsdatenverifikation, welche anhand einer Wiener U-Bahn-Station durchgeführt wurde, präsentiert.

Summary

Partially sighted people constitute a large part of the population. It can be argued that specific requirements of this population in view of universal design have not been sufficiently addressed. There is a long list of visual simulation applications that can support the building design process. However, to the author's knowledge there is a lack of visual performance simulation tools that would be suited to specifically address the needs of visually impaired people. This thesis presents a developed tool for the assessment of the visual performance of spaces, especially with regard to the requirements of above-mentioned group. Implementation of building regulations related to visual accessibility in a reliable manner (during design process) requires expert knowledge and use of sophisticated visual simulation software. Furthermore the existing lighting simulation software lacks in adequate means for performing comprehensive results analysis. Toward this end, the tool attempts to facilitate accurate evaluation of visual conditions in proposed designs and provide a full set of adequate means for a complete visual performance assessment. The thesis describes the general structure and implementation details of the designed tool. It also documents an illustrative example of the tool usage, and simulation results verification, based on a case study of an underground metro station.

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Parts of the text in this thesis are adopted from papers, written in relation to the projects, and co-authored with Prof. Ardeshir Mahdavi and project-team members.

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Chapter 1

Introduction

1.1 *Motivation*

In the last decades, the general awareness with regard to the topic of universal design (or design for all) has been steadily increasing. As a consequence, more attention is being paid to the requirements of all segments of population (specifically including those with certain perceptual and/or motoric limitations). Documents like the UN-Convention on the Rights of Persons with disabilities (UN 2007) were created and ratified by majority of countries. Nonetheless, additional efforts toward improving pertinent regulations, design practices, and relevant technologies are still needed. Specifically, the field of visual accessibility in a built environment has not received the same level of consideration as some other areas of universal design. Partially sighted people (over 246 million worldwide, WHO 2012) primarily orient themselves based on their residual eyesight. Unfavorable lighting conditions as well as poorly illuminated environments (due to inadequate choice of materials, colors, luminaires, etc.) are likely to drastically reduce their orientation and mobility. The optimization of materials and lighting solutions represents a highly critical measure toward creating environmental circumstances in which the remaining eyesight can be optimally utilized. The international and national standards for barrier-free design (e.g. ISO 2011; DIN 2009; SIA 2009; ASI 2013; BSI 2009) provide information about the requirements of visually impaired people as well as threshold levels for some of the relevant indicators (e.g. luminance contrast and average illuminance). However, further recommendations

are needed regarding other relevant indicators (glare avoidance, light distribution uniformity, etc.).

1.2 Objectives

This research effort was aimed primarily at the development of effective means toward supporting the design and implementation of visually accessible solutions in the built environment. Thereby, a central objective was to enhance the mobility of people with sight restriction. Through our project, we intended to provide an empirical basis for the requirements of visually impaired people, with focus on lighting and interaction of lighting with architectural surfaces. The final project effort was an attempt to develop a computational tool for architects and engineers that provides all necessary means for complex evaluation of visual accessibility criteria of projects. The development of this tool was also primary objective of this thesis.

1.3 Thesis structure

The Thesis is structured in terms of X Chapters including current introduction chapter.

Chapter 2: Provides basic information about ViDeA research project.

Chapter 3: Provides general information regarding lighting simulation and relevant visual accessibility indicators.

Chapter 4: Presents visual accessibility simulation tool created as a part of the ViDeA project. The application and its components are described in detail.

Chapter 5: Contains illustrative example of the tool usage. Example is based on a case study of an underground metro station.

Chapter 6: Conclusion includes the contributions together with future research and a listing of publications written in relation to the thesis and the project.

Chapter 2

The ViDeA Project

2.1 *Project structure*

The simulation tool which is the main focus of this thesis was developed as a part of the ViDeA research project. Figure 1 illustrates the basic structure of the project and its components.

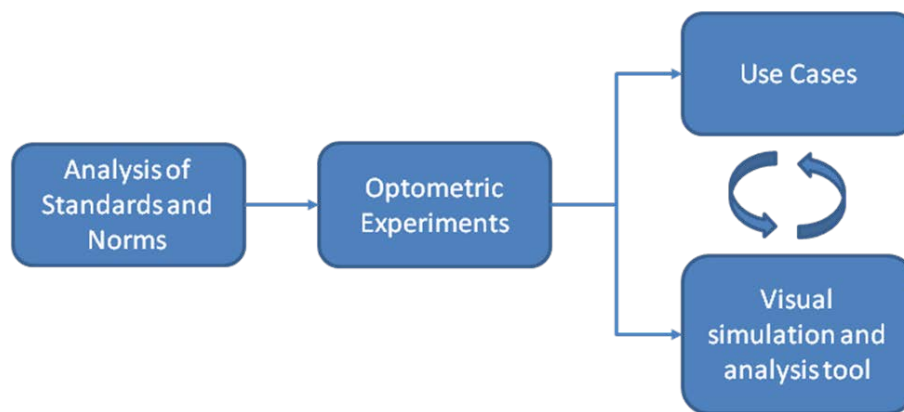


Figure 1. The ViDeA research project structure

The starting point of the project was a study of the international and national standards and norms related to barrier-free design. Purpose of this analysis was to gather current accessibility indicators thresholds and concurrently to identify the paucities of relevant indicators.

The subsequent project part was conduction of optometric experiments where participants with both “full” and impaired vision were considered. The experiments were to provide important information about the requirements of sight restricted people as related to existing visual accessibility factors present in the standards, as well as testing and setting

new thresholds for the non-present factors (classified as relevant in the course of visual accessibility assessment of a space).

A number of use cases were selected in order to assess the findings of the optometric experiments and help finding main sources of visual obstacles in the real-world conditions. Use cases involved interactive pass-troughs of people with visual impairments through spaces and facilities in the transportation sector (e.g. public stations and traffic hubs), backed up by a series of relevant on-site measurements (luminance camera pictures, materials scattering measurements).

The final ViDeA project task, concurrently the main focus of this thesis, was development of a visual simulation and light analysis tool. The tool was intended to allow for systematic evaluation of designed space in terms of visual accessibility. The findings of preceding project stages concluded with optometric expertise provided the functional requirements and knowledge base for the designed tool.

2.2 *Optometric experiments*

In the course of the ViDeA project a series of optometric experiments was conducted to obtain better information regarding the special requirements of visually impaired people. The main group of participants included 98 people of various age and with different levels of visual impairment and a group of 37 people with “full” vision. The optometric test setting was specifically created for this purpose (see Figure 2). Various tests were performed under 8 different adaptation luminance levels (between 0.1 and $320 \text{ cd}\cdot\text{m}^{-2}$) to determine visual acuity, contrast threshold, contrast threshold depending on glare and glare sensitivity. The targeted adaptation luminance level was realized via a uniformly lit visual field. The visual tasks were displayed on a high quality screen.

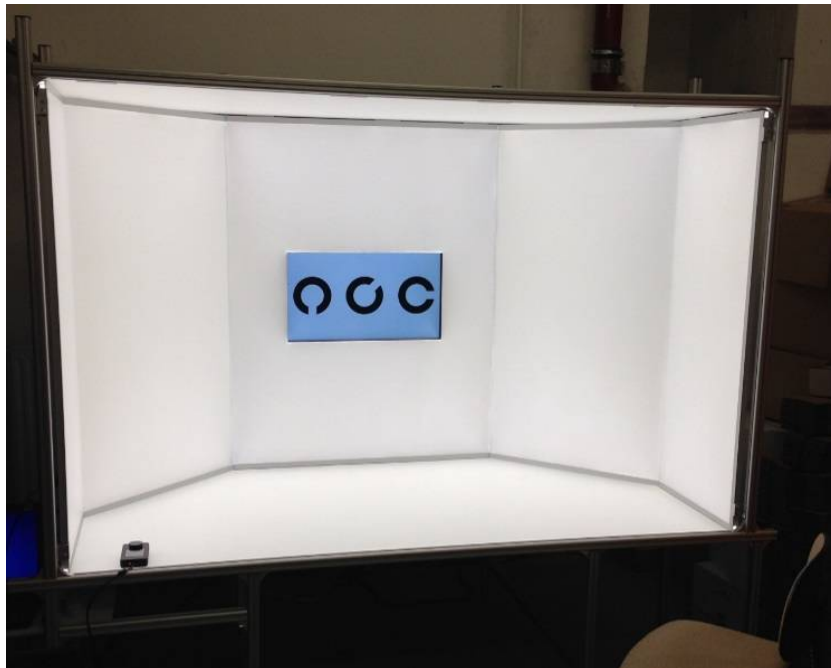


Figure 2. Experimental setup

The overall luminance of the screen and the luminance of the surrounding were nearly identical. The results of the experiment highlight the dependency of visual acuity and contrast sensitivity on surrounding luminance and glare. This circumstance has not been yet considered in the current standards. The findings in a form of threshold levels for certain visual indicators were included in a developed tool.

2.3 *Use cases*

A group of 39 persons with visual disabilities took part in interactive pass troughs of 5 different transport hubs. The participants were equipped with glasses with integrated video camera which allowed for direct documentation of their impressions on ability to orient themselves, evaluate the light situation or name the source of any visual obstacle.



Figure 3. Train station platform pass through

The use cases were also supplemented with a series of luminance camera images documenting crucial moments of the walk-through path for further analysis.

Chapter 3

Background

3.1 *Lighting simulation*

Computer simulation is a common research tool used to replicate the dynamic behavior of system using certain mathematical model in a form of computer algorithms. In this sense the lighting simulation is an attempt to replicate the behavior of the light in a 3D space in order to predict the illumination levels at the point of interest. In more detailed sense the lighting simulation can be understood as tracking of energy flow of light in a system (as a system we can understand a 3D scene) after it interacts with surfaces of certain physical properties in order to deliver quantitative predictions of illumination levels in a certain space.

There are many software products able to perform comprehensive light simulations of a varying complexity. The difference between them lies primarily in the type of solving algorithm (model) used to calculate illumination levels. Radiosity and Ray-tracing are the two most common algorithms used in light simulation software as their solver engine.

3.1.1 Radiosity method

In the radiosity method (or finite element method) all of surfaces in the scene are divided to a grid and the energy transfer between each grid cell of different surfaces is calculated (see Figure 4). Typically the radiosity does not account for specular reflections and assumes the surfaces to be ideally diffusive (Lambertian). This method is view independent, meaning that absolute values are calculated for all 3D elements of a simulated scene (Witzel 2013).

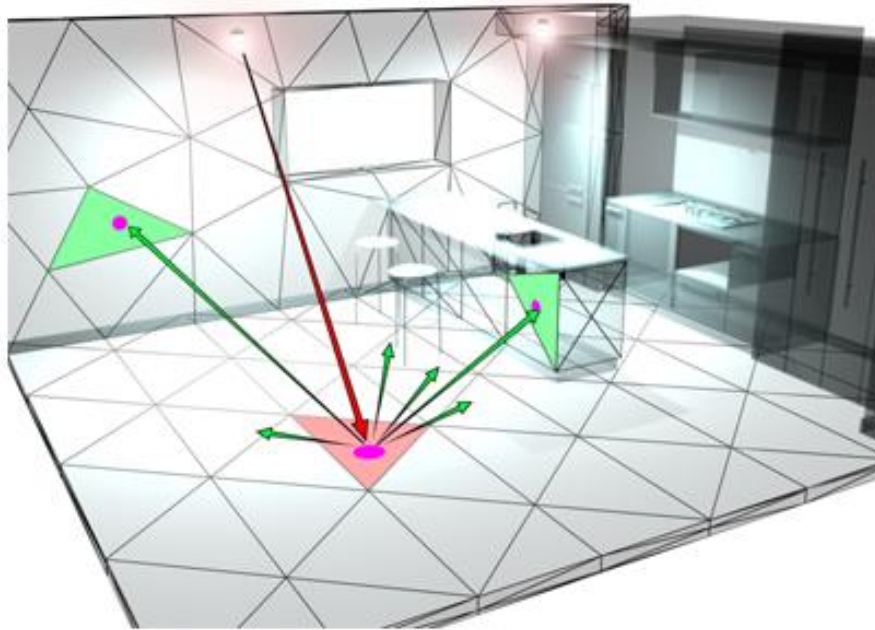


Figure 4. Radiosity - patched surfaces interaction (Source:3dmax-tutorials.com)

3.1.2 Ray-tracing method

On the contrary the ray-tracing is entirely view dependent method. Depending on the origin of calculation, two variations of this method can be distinguished, namely forward and backward ray-tracing.

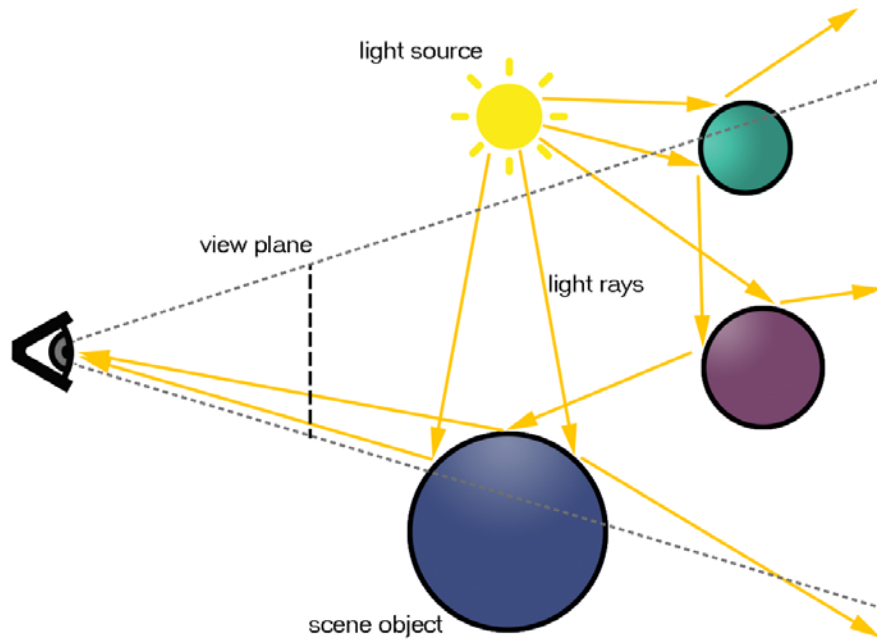


Figure 5. Forward ray-tracing

Background

The forward ray tracing implicates that the calculation originate at the light source from which the light rays (light particles - photons) carrying certain amount of energy are casted and followed until (after reflecting off different surfaces) they reach the view position ("eye") where the image is finally formed (see Figure 6).

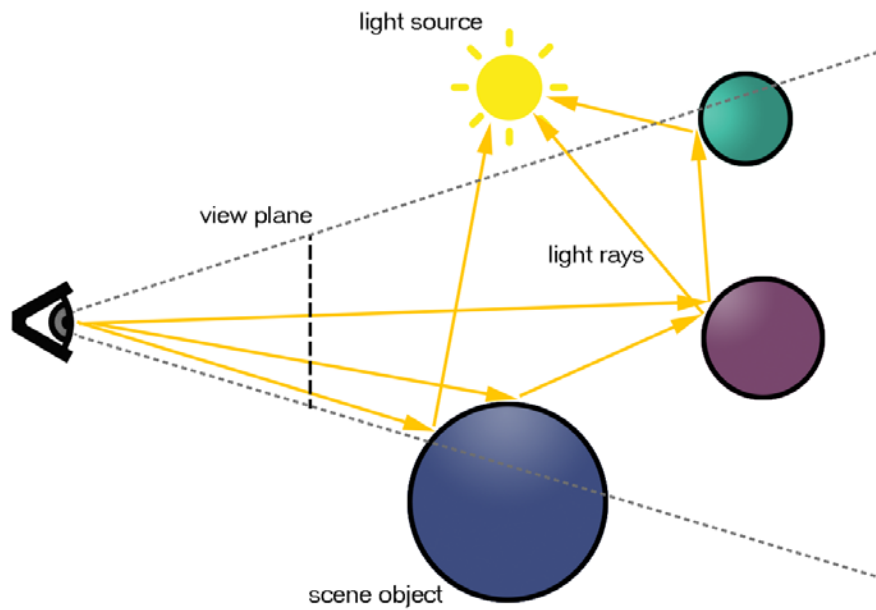


Figure 6. Backward ray-tracing

Knowing the physical properties of a surface the value of radiant flux can be determined at each point of reflection. This method can be highly inefficient, as many of the rays never reach the viewer position, hence never contribute to the final image (see Figure 5). More effective method is the backward ray tracing, as only the rays originating from view position and contributing to the final image (view plane) are traced (See Figure 6). This method helps to save valuable computational resources.

3.2 ***Visual accessibility indicators***

This section provides an overview of visual indicators, selected in collaboration with the project partners, which were qualified as crucial for accessibility evaluation.

Luminance

Luminance is the one of the most important and useful quantity in lighting science as it is primary related to sight. Hence it is required for evaluation of number of visual performance or visual comfort indicators, as the ones selected for this research project and to be included in the tool.

Luminance is defined as a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It is expressed in SI units of lumens per steradian (candelas) per square meter.

$$L = \frac{I}{A_{proj}} \quad (1)$$

L ... luminance [$\text{cd} \cdot \text{m}^{-2}$]

I ... luminous intensity [cd]

A_{proj} ... projected source area [m^2]

Luminance contrast

The luminance contrast is an indicator of whether the difference in brightness between objects is sufficient to ensure their recognizability. There are several definitions of luminance contrast with different possible value ranges. Thus when providing the contrast values, one has to specify the definition to which it refers. It is an important indicator, since the experiments shown there is significant difference in contrast requirement for people with visual impairments.

Michelson contrast

Michelson contrast is often referred to as modulation. It measures relation between the spread and the sum of two luminances. It is typically applied to periodic patterns (Rea 2000). It is defined as:

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

L ... luminance [$\text{cd} \cdot \text{m}^{-2}$]

L_{max} ... maximum luminance [$\text{cd} \cdot \text{m}^{-2}$]

L_{min} ... minimum luminance [$\text{cd} \cdot \text{m}^{-2}$]

Weber contrast

This is the most commonly used and one of the oldest definitions of contrast. Represents the ratio between luminance of the target (object) to its adjacent background (Rea 2000). It is defined as:

$$C_W = \frac{(L_t - L_b)}{L_b} \quad (3)$$

L_t ... task luminance [$\text{cd} \cdot \text{m}^{-2}$]

L_b ... background luminance [$\text{cd} \cdot \text{m}^{-2}$]

Depending if the background is brighter or darker than the target luminance, it can be in range of -1 to infinity. In another version of this contrast definition, where information on target and background is of secondary importance, Weber contrast is defined as:

$$C_W = \frac{(L_g - L_l)}{L_g} \quad (4)$$

L_g ... greater luminance [$\text{cd} \cdot \text{m}^{-2}$]

L_l ... lesser luminance [$\text{cd} \cdot \text{m}^{-2}$]

Bowman- Sapolinski contrast

The luminance contrast of two surfaces related to the reflectance property of the material is described as (AS 2009):

$$C_s = 1.25 \times \frac{(Y_2 - Y_1)}{Y_1 + Y_2 + 0.25} \quad (5)$$

Y_1 ... luminous reflectance of the darker surface

Y_2 ... luminous reflectance of the brighter surface

Reflectance difference factor

Reflectance difference factor is another selected performance indicator that can be found in different accessibility related norms (in ISO 21542 (ISO 2011), in ÖNORM B 1600 (AS 2013) and BS 8300 (BSI 2009)). It is a difference in the degrees of material reflectance (in a scale of 0-1). It is a simplified indicator that is view independent (specular component of material is omitted) and gives some initial idea of object recognizability.

$$LRV_{dif} = |LRV_1 - LRV_2| \quad (6)$$

LRV ... material reflectance

Illuminance/ Luminance uniformity

Uniformity is the ratio between minimum and mean level of illuminance in the area of interest (DIN 2011). For visually impaired people it is relevant to have a uniform illumination on the ground, since quick adaptation to different brightness levels is an issue and takes time.

$$U_0 = \frac{E_{min}}{E_{avg}} \quad (7)$$

E_{min} ... minimum illuminance [lux]

E_{avg} ... average illuminance [lux]

The above-mentioned uniformity indicator includes value of single point measurement. In order to counter the argument that the resulting value is highly error prone (as it may depend on individual point), a number of

more statistically relevant algorithms were developed. For example, by Mahdavi et al. (Mahdavi 1995):

$$U = \frac{E_{avg}}{(E_{avg} + E_{SD})} \quad (8)$$

E_{avg} ... average illuminance [lux]

E_{SD} ... standard deviation of illuminance

Unified Glare Rating (UGR)

The UGR (Unified Glare Rating) developed by the International Commission on Illumination is an estimate of discomfort glare produced by lighting system in a given environment. It is defined as (CIE 1995):

$$UGR = 8 \log \left(\frac{0,25}{L_b} \cdot \sum \frac{L^2 \omega}{p^2} \right) \quad (9)$$

L_b ... background luminance [$\text{cd} \cdot \text{m}^{-2}$]

L ... luminance of the luminous parts of each luminaire in the direction of the observer's eye [$\text{cd} \cdot \text{m}^{-2}$]

ω ... is the solid angle of the luminous parts of each luminaire at the observer's eye [sr]

ρ ... Guth position index for each luminaire (displacement from the line of sight)

Chapter 4

Visual performance assessment tool

As mentioned in the project description, one of the tasks was a development of visual accessibility assessment tool for architects and engineers. The following chapter focuses on development process and implementation details.

4.1 *Initial requirements*

The first step of development was the identification of major functionality goals that the tool was expected to meet. Initially three major goals were identified:

- Provide means to augment designed space (3D model) with relevant properties (material properties, lighting)
- Provide means to perform physically accurate light simulation
- Provide means for comprehensive visual accessibility evaluation of a designed space (indicators)

Having the requirements defined, basic software architecture and workflow was decided upon to form a general structure of the designed tool. The structure, as well as details on embedded software choices is discussed in the following part.

4.2 General structure

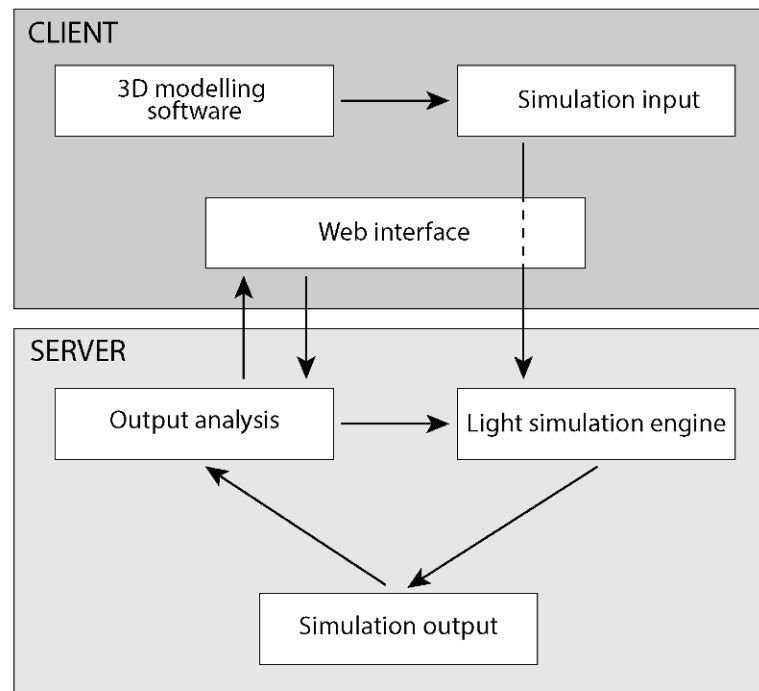


Figure 7. ViDeA tool workflow

The tool workflow chart is split into two major blocks, namely “Client” and “Server” groups (see Figure 7). The client side represents user related activities that are performed on the local machine and analogically the server part represents the group of automated processes performed on a remote dedicated server.

The standard workflow of the tool begins on the client's side where a 3d model is generated or imported to CAD software. With a help of software's GUI (Graphical User Interface) and other means like software extensions it is semantically enriched. Thereby, semantic properties of the constitutive elements of space (visual reflectance and scattering properties of surfaces, specification of the electrical lighting system) are specified. This data set together with user-specified viewing positions constitutes the input for an advanced lighting simulation engine. This input is uploaded to the server through a dedicated web interface. Simulation results in a number of rendered images for specified positions

and 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 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 numeric indicator values are compared with pertinent threshold levels, which are determined via optometric experiments (mentioned in project description) and literature.

4.2.1 3D modeling software

There was a list of primary and secondary criteria for selection of 3d modeling software. Many aspects of functionality, from basic built-in tool range to advanced development potential, had to be considered. After considering a range of CAD suits like AutoCAD, Rhinoceros 3D or Archicad, the Trimble SketchUp (Trimble, 2014) was selected.

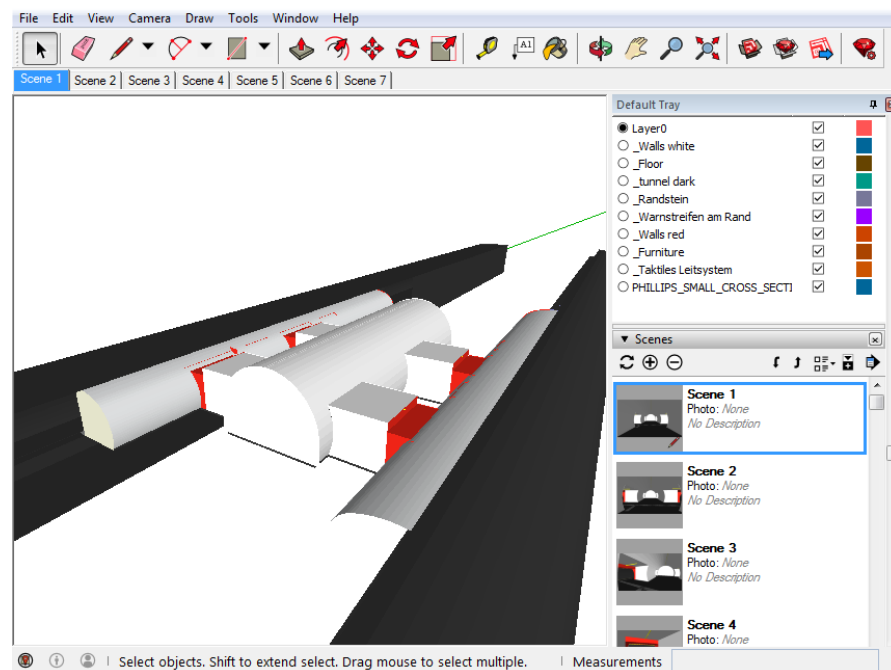


Figure 8. Trimble SketchUP - interface

Trimble SketchUp is a popular freeware 3d modeling software, well established in the community. Due to its functionality and ease-of-use it is

one of the most popular entry level 3d modeling and visualization program. In addition to offering basic modeling tool set, there also exists a large base of software plug-ins created by the community. These plug-ins extend functionality of SketchUp in various ways. The possibility of software extendibility was one of the most important features that were looked for, when 3d software was being selected for the tool. It is because in order to generate a comprehensive input for the lighting simulation engine, the geometry had to be additionally enriched with a list of semantic properties, as well as it had to be saved in engine's compatible format.

In SketchUp the extensions are made utilizing built-in Application Programming Interface (API). The core API's programming language is RUBY. It can be supplemented with html, css and java scripts for interface design. Utilization of these popular high-level languages, together with available detailed API's documentation, all helps software engineer to mitigate plug-in development process. In conclusion the SketchUp was chosen for its built in features that match tool's requirements (e.g.: object layers, advanced camera controls) and above all a possibility of functionality customization through extensions.

4.2.2 Light simulation engine

In order to make comprehensive visual accessibility evaluation of a designed space possible, primarily a physically accurate lighting simulation is needed. To author's knowledge none of the existing light simulation software products that exist on the market met the requirements. They either lack in functionality to evaluate relevant indicators (selected in the course of project) or they lack in accuracy due to limited simulation engine capability. In addition the majority of these software products are proprietary so any interference in software code to extend functionality was not possible. It was evident that a completely new solution involving utilization of advanced ray-trace based simulation engine and design of applicable graphical user interface was needed.

It was decided that lighting simulations in ViDeA tool are going to be carried out by the RADIANCE software.

RADIANCE

RADIANCE (Ward 1994) is a highly sophisticated light visualization system, capable of performing physically accurate simulations. It is extremely versatile due to a division into multiple smaller programs that can be individually controlled. It has been many times validated and its accuracy has been proven. It's rendering engine is based on backward ray-tracing model supplemented with ability to calculate diffuse inter reflections between objects to solve the global illumination (simple ray-trace algorithms are not capable of doing it and usually assume constant ambient value). It makes radiance able to simulate the light behavior in complex environments. There are very little limitations to geometry and materials that can be simulated (Jacobs 2012, Ward 1998). These features make RADIANCE one of the most popular simulation engine used for scientific and engineering purposes. It is also known to be built-into several lighting simulation software suits.

It was chosen to be a part of the developed tool as there is no other comparable software that would give such implementation flexibility and simulation accuracy.

4.3 Implementation details

The ViDeA tool software architecture can be split into two major parts. First is the simulation input generation part, performed locally on client's machine. It involves 3D modeling software aided by a custom software plug-in. Goal of this part of the tool is to give a user all of the means required to augment designed 3D space with relevant properties and define lighting conditions (see Figure 9). Second part is the web application that runs on a remote server. It is responsible for the control of light simulation engine routines, presentation of the results and provision of relevant analytical tools. The connecting element is a simulation package, which as an end product of input generation, becomes a starting point of the simulation and analysis part.

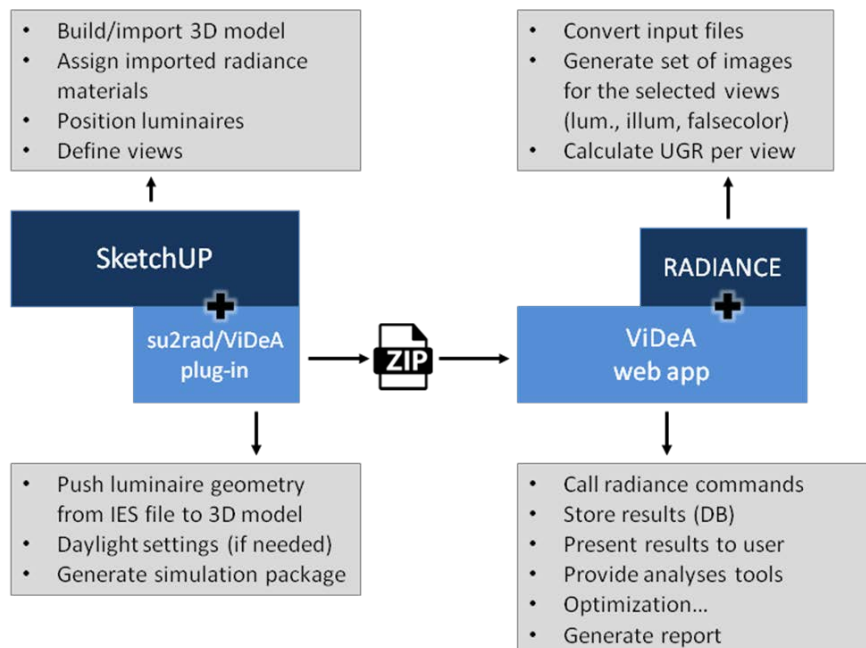


Figure 9. Implementation details overview

4.3.1 Simulation input generation (client)

As mentioned in previous section, following an initial assessment of the ViDeA tool's requirements in view of 3d modeling, the Trimble SketchUp 3D modeling software was selected. It provides 3D geometry modeling and import capabilities, provides 'layers' function for grouping entities with similar properties and it is open for development. SketchUp software provides two options for developers to extend its functionality. The first is writing plug-ins, using the built-in Ruby API for interaction with the active model within the software. The second is building upon the SketchUp SDK utilizing C API for direct manipulation of the model files from outside of the software.

A Ruby API-based plug-in was developed as a part of the ViDeA tool. Its primary purpose is to give the user the possibility to augment 3D models with all necessary data required to conduct a comprehensive light simulation with the a state of the art physically-based RADIANCE lighting simulation and rendering system.

As a starting point, the existing "su2rad" exporting plug-in was adapted (Bleicher 2015). This plug-in is intended for users already familiar with RADIANCE. It functions as a bridge between SketchUp and RADIANCE software. It benefits from SketchUp's Graphical User Interface (GUI) to facilitate access to initial simulation settings, assignment of RADIANCE compliant materials to groups of 3d objects (per layer, per color), and export of stored camera positions for rendering. It consists of a logic part (utilizing SketchUp Ruby API) and a user interface (implemented in HTML/JS combination).

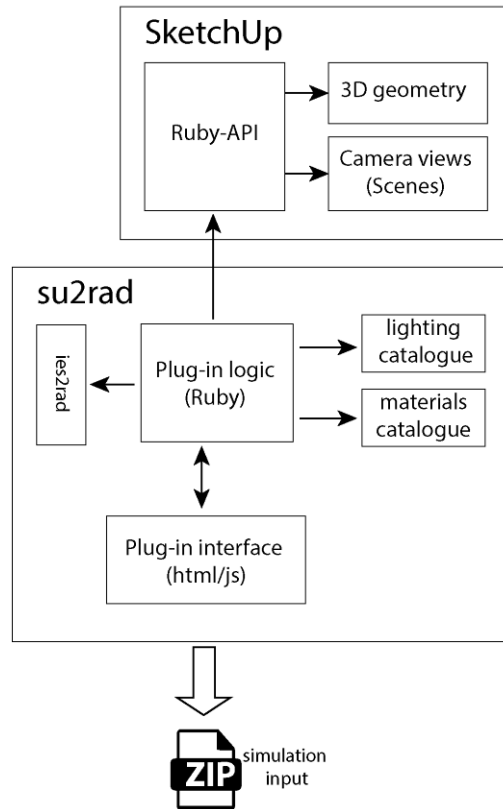


Figure 10. Plug-in architecture

The original plug-in was altered to correspond to the project goals. The ViDeA extension enables the user to import light source geometry extracted from an IES photometric data file (IESNA 2002) and position it in a 3D model (see Figure 10). A Ruby/java script scans the dedicated directory for the relevant IES files to create a list of the available luminaires. It harmonizes the extracted geometry for use with SketchUp and converts luminaires' photometric data into the RADIANCE-compliant format. Moreover, the developed plug-in allows to easily exchange imported luminaire instances against other options from the luminaire data base. The plug-in also enables user to import RADIANCE compliant materials list stored in a text file and add them to the SketchUp's built-in materials list. This allows the use of the native "paint bucket" tool for custom RADIANCE materials assignment. Finally the plug-in also appends additional views and rendering settings that are required for calculation of the visual performance indicators.

4.3.2 Lighting simulation and analysis (server)

The outcome of the original "su2rad" plug-in is a set of simulation input files, organized and structured in directories. To perform lighting simulation, render selected scene views, and extract the relevant data, the user has to leave the plug-in GUI and execute desired set of RADIANCE routines of varying complexity using the operating system's command-line interface (CLI). This requires a valid RADIANCE installation on the user's machine, familiarity with CLI, and very good knowledge of the software. To remove these requirements, a web-application was created (see Figure 11).

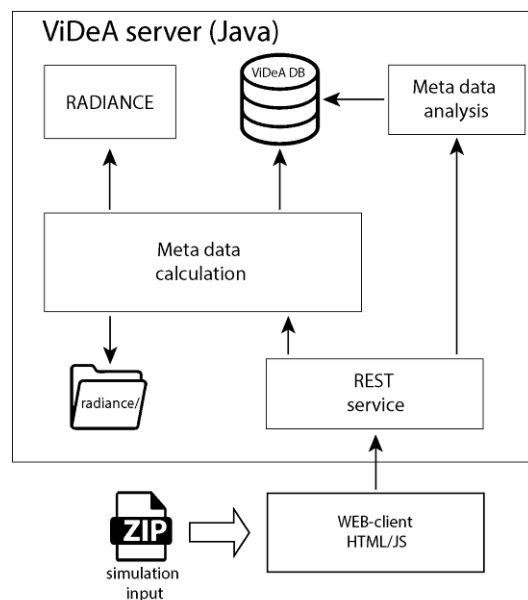


Figure 11. Web application architecture

It is intended to present the user with numeric and visual results of the simulation, display warning information in case the values are outside recommended ranges, as well as provide the necessary tools for interactive analysis of rendered views.

The compressed input zip file (exported with customized su2rad plug-in) is uploaded to the server via a dedicated web-client interface. Subsequently, several command-line routines are initiated to:

- Extract input files
- Initialize simulation
- Render all of the saved and views
- Render fisheye views for UGR calculation
- Calculate visual performance indicators
- Process the derived values
- Store simulation details, file structure, results in a database for rapid queries

To perform analysis of the selected rendered view, an R-tree data structure is generated from the meta-data obtained for each pixel of the image. R-trees are multi-dimensional tree data structures that provide efficient spatial access to their elements (Guttman 1984). The interface offers the possibility to select a point, segment, or surface of interest in the image. Determining which pixels are inside of the user's selection is a 'point in polygon' problem that is solved in two steps. First all pixels inside the polygon's bounding box are fetched from the previously generated R-tree. Next they are tested with a ray casting algorithm (Roth 1982), based on the Jordan curve theorem (Berg et al. 1975), to exclude pixels not belonging to the polygon. Several descriptive statistical values are calculated based on the selected pixel's 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.

Chapter 5

Illustrative example

5.1 *Simulation 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 recreation of 3d space
- Photometric profiles of electric lighting
- Luminance images
- Optical properties of the building materials

The blueprints as well as photometric lighting profiles (in form of IES files) were supplied by the project partners. 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.

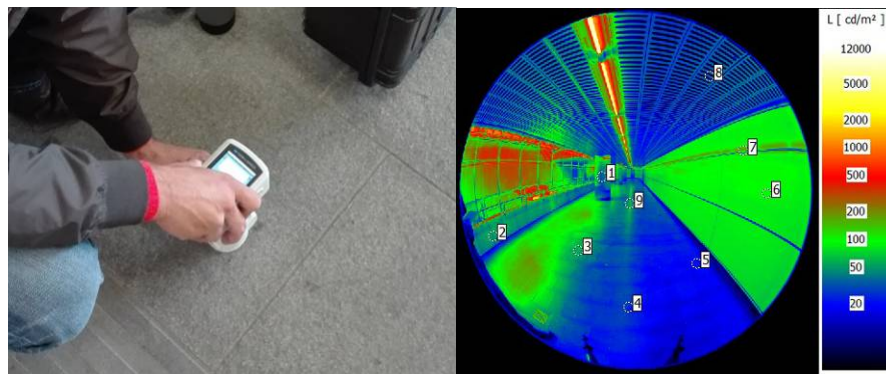


Figure 12. Measurement of building materials scattering properties and one of the luminance camera images

Illustrative example

Using a portable spectrophotometer, a series of on-site measurements was performed to determine the average reflectance of building materials. The collected data had to be converted to radiance compliant format (CIE XYZ tristimulus system to reflectance on RGB channels).

5.2 3D scene modeling



Figure 13. 3D model of the Schottenring metro station

The 3D model of the station was recreated from provided blueprints in Archicad (BIM software) and saved in a SketchUp compliant format (see Figure 13). Given the added functionality in the modified “su2rad” plug-in, luminaire source geometries (extracted from IES file) were imported to the 3d model and then duplicated and positioned according to the plan documentation(see Figure 14).

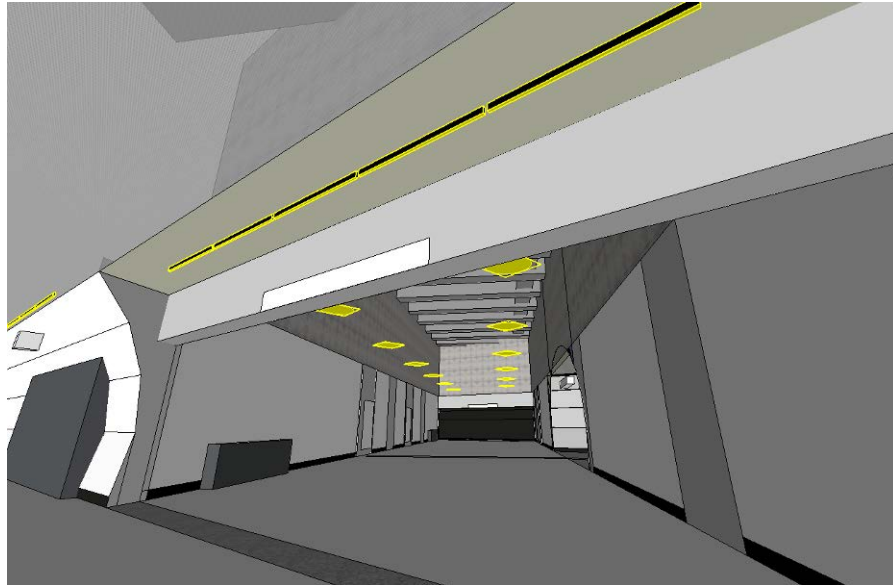


Figure 14. Positioned IES luminaires

In the next step, the 3d model had to be semantically enriched by associating previously collected materials' visual properties to surfaces. This was done using another new plug-in' feature that allowed adding the on-site collected materials (in radiance compliant format) to the native SketchUp's materials collection, thereby enabling the use of the built-in "paint bucket" tool in material application process (see Figure 15).

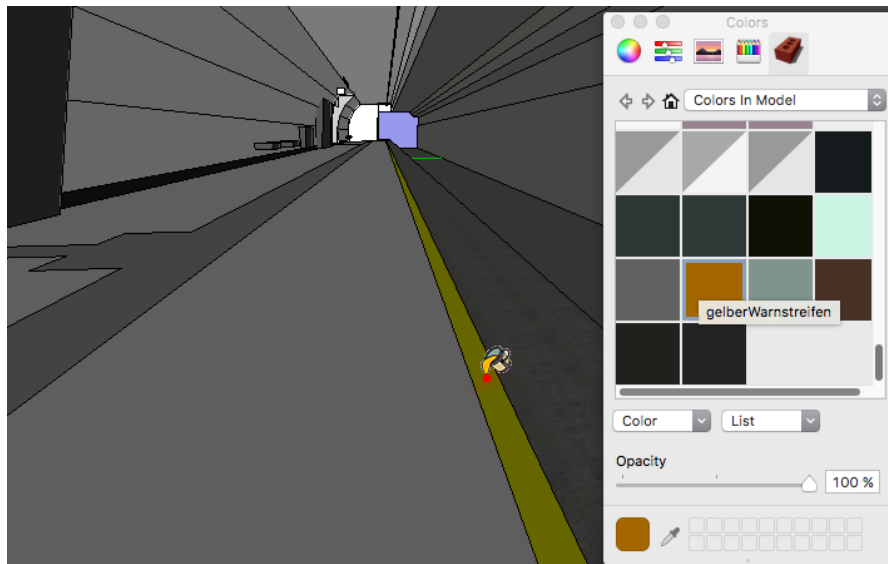


Figure 15. Imported Radiance materials application

Illustrative example

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 (see Figure 16).

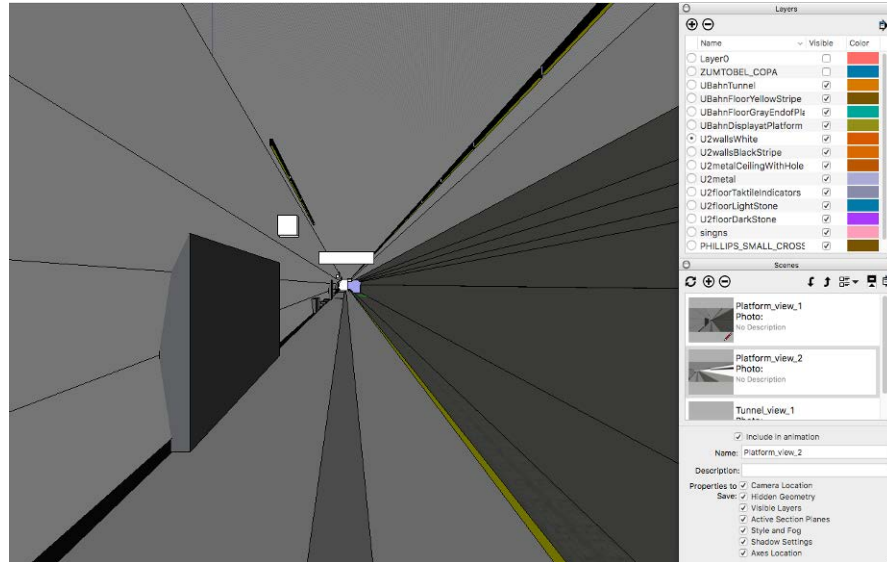


Figure 16. One of the camera views selected for evaluation

Using plug-in interface the entire scene geometry together with additional data was exported and saved as a single compressed ZIP file.

5.3 Web application

Lighting simulation is carried out automatically after upload of a ZIP file via ViDeA web interface (see *Figure 17*) to the dedicated server. User is informed on the simulation progress via progress bar. The end product of the simulation is a set of rendered views with pre-calculated view dependent visual indicators (UGR, mean luminance and illuminance, light distribution uniformity), ready for further analysis.

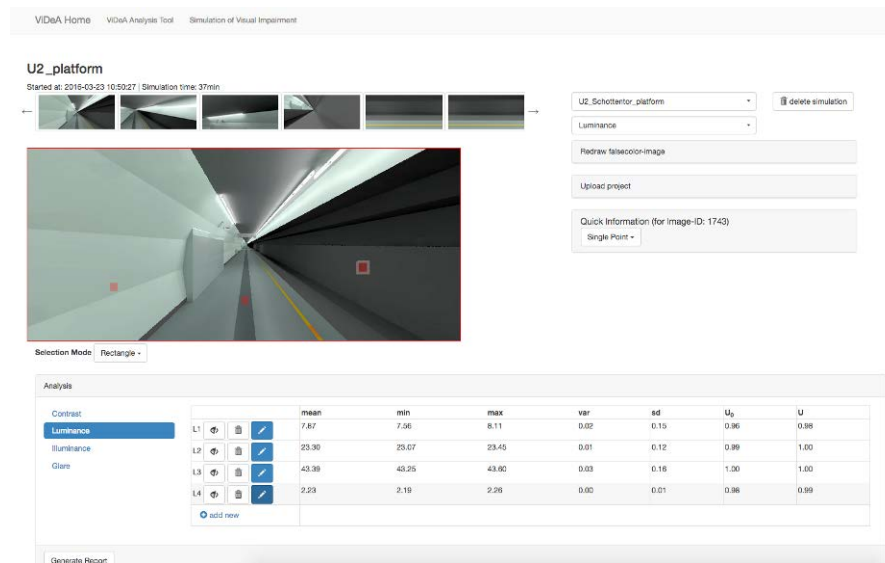


Figure 17. ViDeA tool web application interface overview

Rendered views appear in top left part of the interface. Views of interests can be selected from thumbnail array (*Figure 18*).

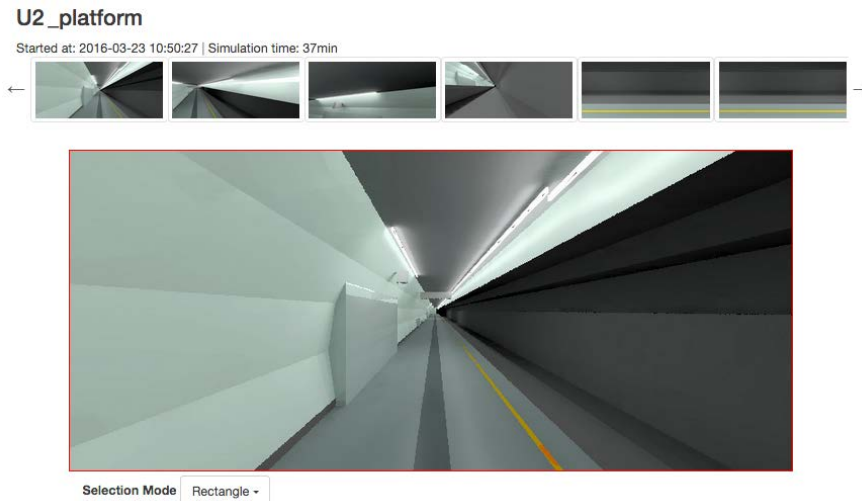


Figure 18. Rendered view selection

The selected thumbnail is enlarged, detailed per-pixel photometric data loaded and the image is ready for detailed analysis. Initially ‘Quick info’ tab (see Figure 19) can be used to investigate metadata layers (luminance or illuminance value, material name, material reflectance, distance from camera etc.) stored for each pixel of a rendered image by point clicking on it.

Quick Info (for Image-ID: 1743)		
Single Point ▾		
Position	(513, 316)	Pixel
Luminance	23.98	cd/m ²
Distance to camera	3.53	m
RGB	0.19, 0.12, 0.00	
Material	gelberWarnstreifen, rho=0.37, <input type="button" value="Select"/>	
Surface	f_685_0	

Figure 19. “Quick info” tab example – for a selected point of an image

The analysis tab located at the bottom of the interface is used for inspection of contrast ratios, luminance and illuminance of selected regions in the image. User can store multiple analyzed image areas together with calculated indicators and statistical data (see Figure 19).

Illustrative example

Analysis

Contrast

Luminance

Illuminance

Glare

			mean	min	max	var	sd	U ₀	U	
L1				7.87	7.56	8.11	0.02	0.15	0.96	0.98
L2				23.30	23.07	23.45	0.01	0.12	0.99	1.00
L3				43.39	43.25	43.60	0.03	0.16	1.00	1.00
L4				2.23	2.19	2.26	0.00	0.01	0.98	0.99

[+ add new](#)

Generate Report

Figure 20. Luminance analysis table

The 'generate report' button at the bottom gives possibility to generate a PDF report of the current simulation. Report gathers all rendered views and matches them with analyzed data.

5.4 *Simulation results and verification*

To evaluate the tool performance, two selected rendered views and luminance camera images were put under comparison. Average luminance values of corresponding segments of the images were analyzed in LKM labSoft (luminance photos, LKM 2017) and ViDeA tool (renderings).

Figure 21 and 22 contrast the false color images obtained from the luminance camera with the computationally rendered images. Table 1 shows the resulting average luminance values for specific segments of the platform view images (see Figures 22 and 23). Table 2 shows the resulting average luminance values for specific segments of the passage view images (see Figures 24 and 25). Table 3 shows the resulting average luminance values for specific segments of the platform to track view images (see Figures 26 and 27).

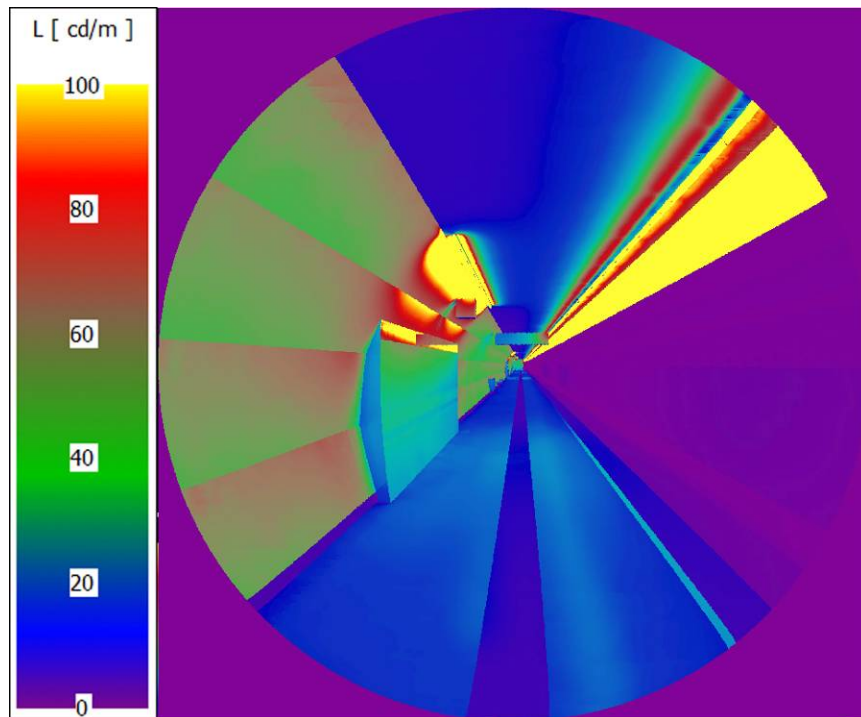


Figure 21. False color rendered image (Platform)

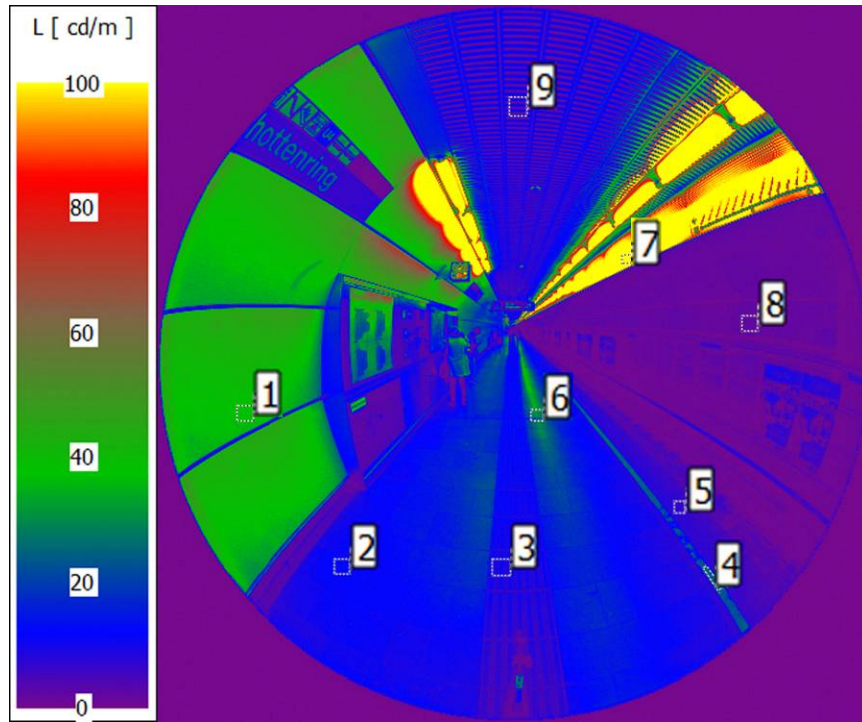


Figure 22. False color luminance camera photo (Platform)

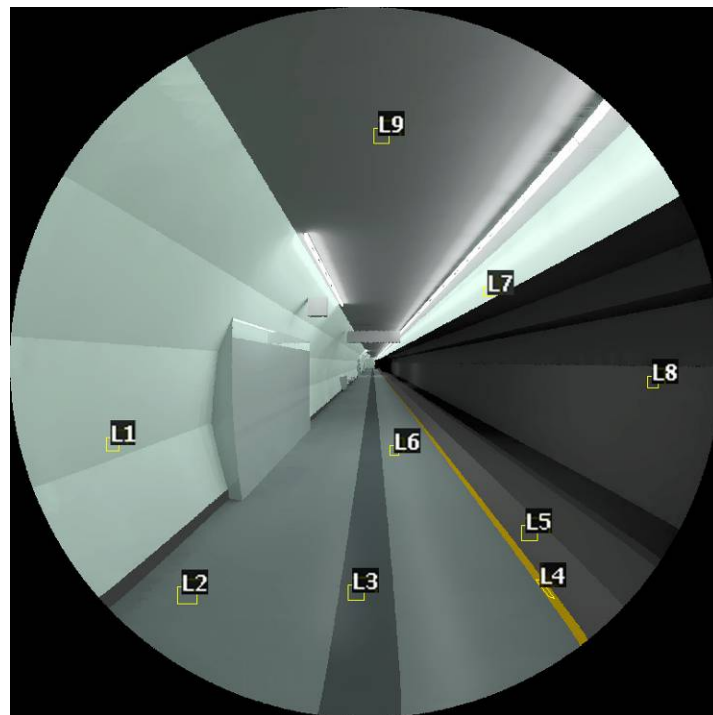


Figure 23. Rendered luminance image (Platform)

Table 1: Platform view luminance analysis, results comparisons

<i>Average Luminance [cd/m²]</i>		
<i>Region</i>	<i>Camera</i>	<i>Simulation</i>
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

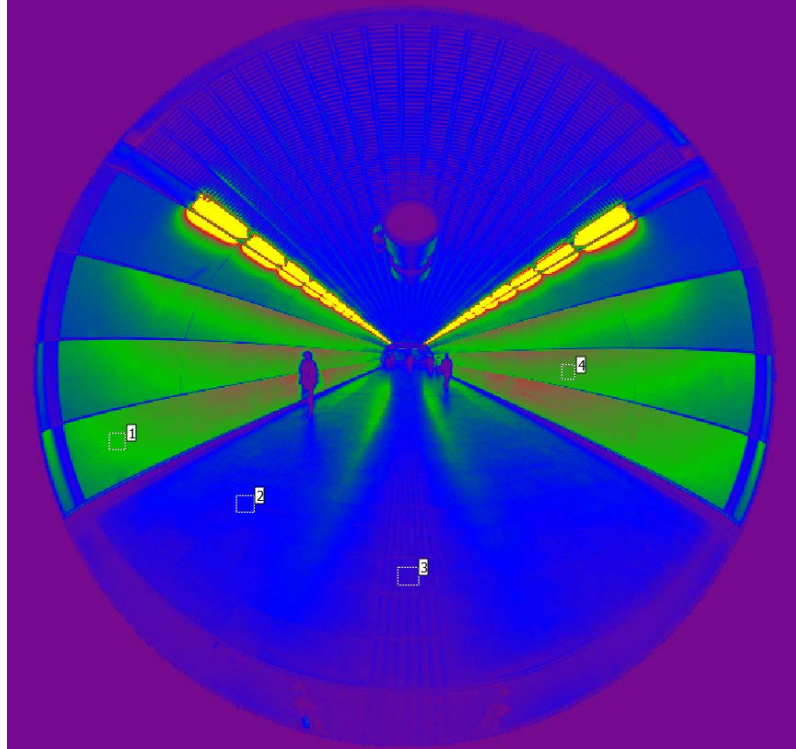


Figure 24. False color luminance camera photo (Passage)

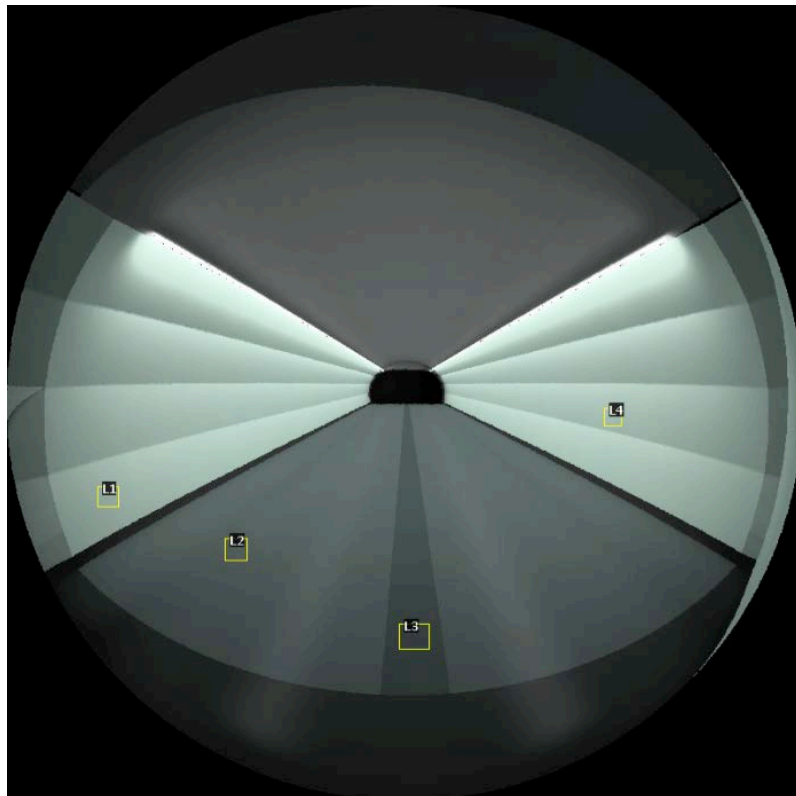


Figure 25. Rendered luminance image (Passage)

Table 2: Passage view luminance analysis, results comparisons

<i>Average Luminance [cd/m²]</i>		
<i>Region</i>	<i>Camera</i>	<i>Simulation</i>
1/L1	41.8	43.9
2/L2	13.6	13.3
3/L3	7.6	7.5
4/L4	52.6	53.9

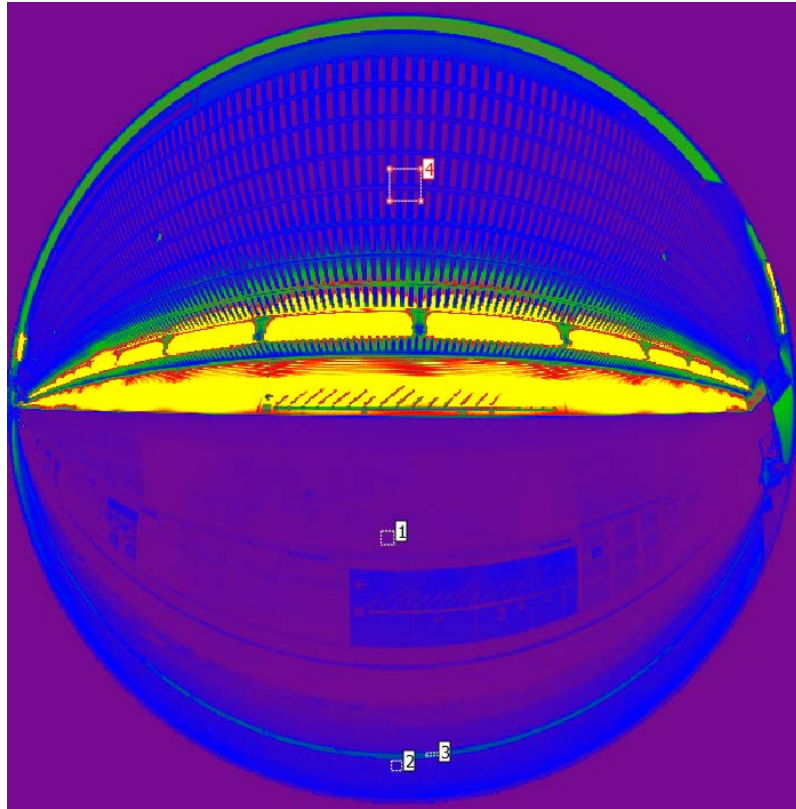


Figure 26. False color luminance camera photo (Track)

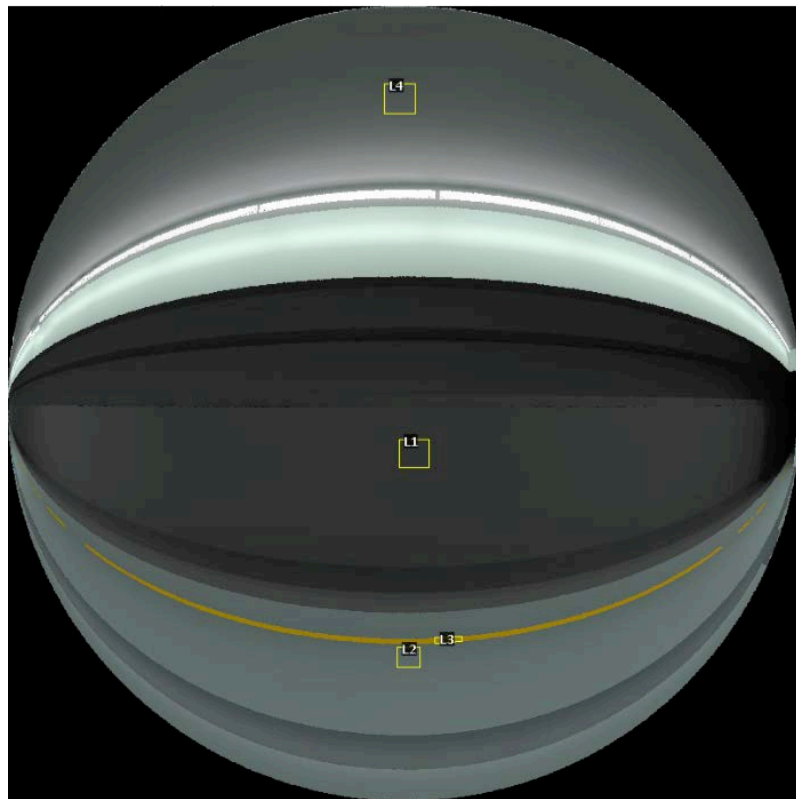


Figure 27. Rendered luminance image (Track)

Table 3: Track view luminance analysis, results comparisons

<i>Average Luminance [cd/m²]</i>		
<i>Region</i>	<i>Camera</i>	<i>Simulation</i>
1/L1	1,47	1,35
2/L2	10,2	10,6
3/L3	22,3	21,6
4/L4	7,91	7,81

5.4.1 Results discussion

The good correlation between the simulations and 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 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

Chapter 6

Conclusions

6.1 Contributions

The paucity of complex lighting simulation tool that would focus on the needs of visually impaired people was addressed. Based on identified technical and functional requirements a simulation tool was developed.

The validation of the tool done through a comparison of simulated and real-world numeric results presented in this thesis shows a promising correlation. These points to the potential of the developed environment as a design and retrofit decision support tool. The presence of analysis means specifically crafted to address visual accessibility benchmarking (both for people with normal and impaired vision) supports the design for all philosophy.

6.2 Future research

The next developmental steps pertain to tool performance optimization. Specifically, computational efficiency is to be increased. Toward this end, recent developments in utilization of advanced GPUs in ray tracing process (Jones 2014) and the associated rendering time reduction are to be harnessed. Such development would open new model optimization opportunities that could have been done without leaving the web application.

6.3 Publications

6.3.1 Journals

M. Maringer, D. Wolosiuk, N. Hauck, U. Pont, C. Vogelauer, E. Fürst, F. Buser, A. Mahdavi: "Toward visual accessibility in the built environment: The ViDeA Project"; Applied Mechanics and Materials (invited), Special Volume: Energy Saving and Environmentally Friendly Technologies - Concepts of Sustainable Buildings (2016), 428; 829 - 835.

6.3.2 Conferences

D. Wolosiuk, H. Hofstätter, A. Mahdavi: "The development and verification of a computational tool for the evaluation of the visual accessibility of architectural spaces"; Presented at: Building Simulation Applications - 3rd IBPSA-Italy Conference, Bozen, Italien; 2017-02-08 - 2017-02-10; M Baratieri, V. Corrado, A. Gasparella, F. Patuzzi (ed.); bu.press (publisher of the Free University of Bozen-Bolzano), 3. (2017), ISSN: 2531-6702; Paper ID 69, 6 pages.

M. Maringer, D. Wolosiuk, N. Hauck, U. Pont, C. Vogelauer, E. Fürst, F. Buser, A. Mahdavi: "Toward visual accessibility in the built environment: The ViDeA Project"; Presented at: envibuild 2015 - 10th International Conference Buildings & Environment 2015, Bratislava, Slowakei; 2015-10-15 - 2015-10-16; J. Hraska, M. Kalousek et al. (ed.); STU Bratislava - Eigenverlag, (2015), 8 pages.

D. Wolosiuk, H. Hofstätter, U. Pont, M. Maringer, M. Schuss, N. Hauck, A. Mahdavi: "Supporting Visual Design for All: The Videa Approach"; Presented at: 14th International Conference of the International Building Performance Simulation Association, Hyderabad, Indien; 2015-12-07 - 2015-12-09; V. Garg (ed.); (2015) 6 pages.

Chapter 7

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