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RealReflect

D10.3: REPORT ON LIGHT SIMULATION IN ARCHITECTURE

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Abstract

This document reports on the evaluation and validation of global illumination computation for lighting in architectural environments. The rendering of the architectural images is carried out using the WP07 high quality renderer developed within the project. The main purpose is to report on validation for the lighting of rendering architectural environments. For the validation two methods are used. First, a set of simple scenes with known reference values is used. Second, two models of existing real scenes are rendered and compared with the corresponding photographs of the reality.

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Chapter 1

Introduction

The objective of this document is to present the validation procedure carried out for the rendering software developed within the project in the context of rendering of architectural environments. The design of light distribution by placing light sources and apertures (windows) in a building is a common procedure in the lighting engineering. The main goal of this industry is design of the surface material, positioning, and the type of luminaries in order to get a plausible illumination. There are numerous specific goals for lighting engineering design: artistic, aesthetic, energetic, ergonomic, or any combination of these. In particular, the combination of aesthetic, ergonomic, and energetic demands on lighting with the utilization of daylight is of increasing importance for both office and home buildings. Traditionally, the lighting engineering was based on experience, adhoc formulas, and experimental tests in scale models. This paradigm was changed significantly with the evolving utilization of computers in engineering tasks. Today, the cost and time profitability of the computer lighting simulation makes the lighting engineering based on global illumination computation indispensable part already in the early phase of architectural design. The energy savings due to the efficient lighting design is supported on various levels and institutions, since the power consumption for lighting purposes is significant part of the total power consumption. For example, "Solar Heating and Cooling Programme (SHC) Task21" of "International Energy Agency" [IEASHC21] is an initiative to advance the daylighting technologies and promote daylight conscious building design.

For all these reasons the correctness of lighting computer programs is recently gaining importance. The correctness of rendering gave the birth to so called predictive rendering in computer graphics [STAR2005],[Greenberg97]. A several mostly commercial and free software packages including Dialux, Genelux, Integra Inspirer, Lightscape, and Radiance are in use. However, the capability, fidelity, and accuracy of these software packages has been practically unknown to their users. Therefore there is an increasing effort in some technically sound validation of the software packages for the purposes of lighting design, which is described in more detail in the following chapter. The proposed validation tests consists of simple scenes with described light sources, where the reference illumination (often computed analytically) is given for a set of points and the simulation should compute it. The reference value should match with the computed value with some acceptable level of error. We provide the numerical results for these tests achieved for the WP07 rendering package of REALREFLECT project.

Further, we show the more intuitive way of global illumination software validation, which is however more subjective. It uses the same methodology as the deliverable D10.2. A model of an existing real scene is rendered given a viewpoint and lighting conditions. The rendered image can be compared with the photograph of the scene. In the ideal case the match is perfect, but as was shown in previous studies, this is quite infeasible in practical situations [Drago01], since even small inaccuracies of geometric details can become quite important depending on the viewpoint and lighting conditions. In addition the comparison is highly subjective and it is based on a very simple psychovisual experiment with human observers, since standard techniques for comparing images pixel by pixel cannot be applied.

We use two scenes, one relatively simple and one relatively complex. We would like to stress that the accurate re-modeling of the real scenes for validation purposes of global illumination software packages is unfortunately in its infancy or the data are not publicly available.

The first (simple) scene was developed in the scope of project by common effort of ICIDO and VRA on the demand of REALREFLECT project. A model of a real office building in ICIDO facilities was remodeled by VRA. Then the light sources and surface reflectances were assigned by ICIDO. We call this scene "ICIDO office" in this text.

The second (complex) scene was developed under supervision of Karol Myszkowski in his previous study of predictive rendering in year 2001. We call this scene "Aizu Atrium" in this text. Withing the scope of REALREFLECT project the geometric data was completed by BTF data for majority of surfaces for this model. BTF data were measured by the University of Bonn.

In total, we give 205 numerical results of comparison and three pairs of images rendered versus captured photographs of real scenes.

The simple tests verify mostly the high quality renderer (WP07 package), the rendering of two architectural scenes also the rest of the REALREFLECT pipeline as a whole. This includes the BTF data acquisition[D10.1] and functionality of tone mapping operator[D10.4].

The document is further structured as follows. The chapter 2 gives the details of validation using TC.3.33 tests. The chapter 3 shows the details for scene "ICIDO office". The chapter 4 shows the details for scene "Aizu Atrium". The final chapter summarizes the validation effort for architectural scenes within REALREFLECT project.

Chapter 2

Validation Tests by Preliminary Proposal of CIE TC.3.33 Committee

The proposed test suite TC.3.33 [TC.3.33] has been designed by CIE (COMMISSION INTERNATIONALE DE L'ECLAIRAGE) with the objective of assessing lighting computer programs that are used in lighting engineering, namely in the design of lighting for architectural environments. This is also objective of this report.

The committee TC.3.33 of CIE has been working on the definition of the tests since 1999. The final text of the CIE standard should be available in 2006 or 2007. However, since this is too late for REALREFLECT project, we have opted to use the preliminary version of tests similarly to a few companies active in illumination engineering software [Maamari03b]. This preliminary unofficial version of the test description proposal was issued on 18th September, 2002. See the detailed results for Inspirer product [Integra03] of Integra Ltd. for the achievements of tests for an established commercial software based on radiosity. The methodology of reporting the results of the tests was adopted from [Integra03].

The tests are defined using analytical or experimental references. It typically includes a very simple interior scene, such as a box, equipped with internal or external lighting, and defined set of reference values or invariants that should be achieved by computation. The reference values is for example illuminance at the exactly defined points on the surfaces or flux preservation for light coming through an aperture in the roof or the wall of a simple scene.

In the following sections, we briefly describe individual tests one by one and the results achieved within REALREFLECT, namely for high quality software renderer developed within WP07.

2.1 Test01 - Luminous flux penetration through aperture

In daylighting simulation it is often important to correctly implement the transmission of the incident luminous flux on the aperture into the interior of the building. This corresponds to the flux conservation. The aperture is for example a wall or roof window. The test is designed to compute the total flux incident on the aperture and also the flux coming to the interior surfaces of a simple scene. The correctly working software should get the values of flux the same for interior of the scene and for the aperture.

2.1.1 Description of Test01

The geometry of the scene is a square room of dimensions 4m x 4m x 3m, with either a roof or a side wall opening at the center of the roof or the wall. The thickness of the wall and roof is 0.2m. The roof opening is sized 1m x 1m, 2m x 2m, 3m x 3m, or 4m x 4m (full opening). The wall opening size is 2m x 1m, 3m x 2m, or 4m x 3m (full opening). The lighting simulation should be computed with interior surfaces having no reflectance (total absorption).

The external illumination can follow any sky model. We have decided to use overcast CIE sky model type 1.

2.1.2 Results for Test01

In order to compute total flux we have generated randomly but with uniform distribution a set of 10,000 points on the internal surfaces of the scenes. We have computed the illuminance for every point and by multiplying with the total surface area of the internal surface we got a total flux. The numerical results achieved are in the Table 2.1.

Opening type	**Analytical**	**Simulation**	**Error**[*Percent*]
Roof Opening 1x1	3.14	3.18	1.29
Roof Opening 2x2	12.51	12.54	0.23
Roof Opening 3x3	28.07	28.17	0.36
Roof Opening 4x4	49.59	49.93	0.67
Wall Opening 2x1	3.20	3.17	0.97
Wall Opening 3x2	9.53	9.48	0.60
Wall Opening 4x3	18.85	18.85	0.02

Table 2.1: Test01: Luminous flux penetration through aperture.

2.2 Test02 - Directional transmittance of clear glass tau

The correct processing of transparent materials such as glass is very important for the designers of illumination in architectonic environments. The tests aims at verification of the correctness of direct lighting through glazed windows.

2.2.1 Description of Test02

The geometry of the scene is a square room of dimensions 4m x 4m x 3m, with a roof opening 1m x 1m at the center of the roof. The thickness of walls and roof is 0.2m. The interior surfaces have zero reflectance. At the top of the opening is positioned a perfectly specular glass.

The external illumination is a directional parallel light source (simulating the sun in reality), aimed at the aperture covered by glass with an incident angle at range: 0, 10, 20, 30, 40, 50, 60, 70, 80, and 90 degrees.

2.2.2 Results for Test02

In order to compute total direct flux we have generated randomly but with uniform distribution a set of 100,000 points on the internal surfaces of the scenes. More points than for test01 were required since the directional properties of light reflection from the parallel light source narrow the incoming area to possibly a small region on the internal surfaces. We have computed the illuminance for every point and by multiplying the average total illuminance with the total surface area of the internal surface we have obtained a total flux. The numerical results achieved are shown in the Table 2.2.

Theta	0	10	20	30	40	50	60	70	80	90
Analytic t(theta)	0.879	0.880	0.880	0.876	0.087	0.848	0.802	0.683	0.423	0.028
Simulated t(theta)	0.959	0.936	0.912	0.805	0.694	0.575	0.411	0.243	0.073	0.000
Analytic t(theta)/t(0)	1.00	1.001	1.001	0.997	0.986	0.964	0.912	0.777	0.482	0.033
Simulated t(theta)/t(0)	1.00	0.977	0.952	0.840	0.724	0.600	0.429	0.253	0.076	0
Error [Percent]	0.0	2.39	4.88	15.70	26.57	37.75	51.57	67.44	84.23	inf

Table 2.2: Test02: Directional transmittance of clear glass.

2.3 Test03 - Functionality of luminaries with intensity distribution files

The most luminaries provided by industry are understood as far field photometry. For the purposes of software are described by a format following gonimetric diagram such as IESNA (LM-63-1995) or ELUMDAT. The purpose of this test is to check the correct interpretation of these formats, namely interpolation of a value between the points defined over a hemispherical grid. The direct illumination is computed and compared with reference values.

2.3.1 Description of Test03

The geometry of the scene is a simple quadruple surface 4m x 4m placed horizontally. The light source is positioned in the center of the quadruple 3m above the surface.

The luminaire is simulated by a light source following the cosine distribution. The grid is defined by 15 degrees between vertical angles (theta) and exhibits the axial symmetry (phi). The maximum intensity is 1000 candela (theta=0). The total output luminous flux is then 3142 lumen.

The reference values are computed by evaluating the ideal cosine distribution of luminaire. There are 10 measurement points for which the direct illumination is computed and compared.

2.3.2 Results for Test03

The reference value for the test is computed by ideal cosine distribution. The numerical results achieved are shown in the Table 2.2.

Points	Analytical E	Simulated E	Error[*Percent*]
A	111.111	111.111	0.00
B	105.214	104.345	0.83
C	90.020	89.465	0.62
D	71.100	70.672	0.62
E	99.735	99.369	0.37
F	85.636	84.992	0.75
G	68.064	67.751	0.46
H	74.360	73.820	0.73
I	59.981	59.853	0.21
J	49.392	49.005	0.78

Table 2.3: Test03: Description of luminaries with intensity distribution files.

2.4 Test04 - Shape factor

The indirect illumination thanks to the inter-reflection on the diffuse surfaces is one of the most important features achieved by global illumination software. The core of such a computation is correct determination of a fraction of luminous flux leaving a perfectly diffuse surface incident upon another (differential) surface. This is the subject of the test04, where the reference values are computed by analytic formulas, and where the direct illumination from the area light source is computed at a few points. Although the direct computation is computed, the test checks the basic assumption for correct computation of indirect illumination.

2.4.1 Description of Test04

The geometry for the scene is a box room of size 4m x 4m x 3m, with an area diffuse light source at the center of the ceiling and size 1m x 1m. The surfaces inside the room have zero reflectance to exclude the indirect illumination contribution.

The single luminaire at the ceiling has total output 10,000 lumen.

Ten reference values of illuminance (lux) are defined by a position in the room. Five of them are defined on the floor, six of them on the wall.

2.4.2 Results for Test04

The numerical results with computed errors are shown in the Table 2.4 and Table 2.5.

Point	1	2	3	4	5
E analytical	341.1	324.1	279.9	223.6	169.1
E simulated	341.3	324.5	280.1	223.9	169.0
Error[*Percent*]	0.050	0.11	0.076	0.12	0.050

Table 2.4: Test04: Illuminance variation on the floor.

Point	6	7	8	9	10	11
E analytical	109.9	147.4	194.6	242.8	260.6	187.4
E simulated	110.0	147.5	194.6	243.4	260.8	187.4
Error[*Percent*]	0.086	0.043	0.001	0.228	0.056	0.002

Table 2.5: Test04: Illuminance variation on the wall.

2.5 Test05 - Surface reflectance

The correctness of indirect illumination itself is the main subject of this test. The goal is to compute only indirect illumination reaching the points on the surfaces for which the reference values of illuminance are known.

2.5.1 Description of Test05

The geometry of the scene is again a box room of size 4m x 4m x 4m, with all the surfaces covered by ideally Lambertian material with specified albedo. The albedo in the test has the values as follows: 0, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0.

The luminaire is a point light source with uniform distribution located at the center of the ceiling. The output flux is 10,000 lumen.

The illuminance should be computed as the average illuminance. This is in our case implemented similarly to Test01 and Test02 by positioning the points uniformly on the all surfaces and computing average illuminance from all the points.

2.5.2 Results for Test05

The numerical results with computed errors are shown in the Table 2.6 and Table 2.7.

Reflectance	0.00	0.05	0.1	0.2	0.3	0.4
E analytical [lx]	0.00	5.48	11.57	26.04	44.64	69.44
E simulated [lx]	0.02	5.51	11.61	26.12	44.77	69.61
Error[*Percent*]	inf	0.57	0.42	0.32	0.30	0.26

Table 2.6: Test05: Average indirect illuminance variation with surface reflectance.

Reflectance	0.5	0.6	0.7	0.8	0.9	0.95
E analytical [lx]	104.2	156.3	243.1	416.7	937.5	1979.2
E simulated [lx]	104.5	156.1	239.1	382.3	644.7	855.2
Error[*Percent*]	0.44	0.13	1.64	8.25	31.22	56.79

Table 2.7: Test05: Average indirect illuminance variation with surface reflectance.

2.6 Test06 - Sky component with unglazed openings under the CIE general sky type 16 (overcast sky)

The correct computation of the illumination from the outdoor light sources such as sun and sky are of a crucial importance for designers and lighting engineers that use global illumination software. The ratio of illuminance obtained from sky in a building to the illuminance from unobstructed sky is usually referred to as daylight factor. The daylight factor is given as percentage. The measurements of daylight factor for sake of better accuracy and reproducibility are taken under conditions of overcast sky, where small variance of exitant luminance from sky can be achieved. These conditions are achieved by using CIE sky model type 16 (overcast) or by uniform sky model. The reference values can be obtained by relatively complex analytical formulas.

2.6.1 Description of Test06

The geometry of the scene is a square room of dimensions 4m x 4m x 3m, with either a roof or a side wall opening at the center of the roof or the wall. The thickness of the wall and roof is zero. The roof opening is sized 1m x 1m, 2m x 2m, 3m x 3m, or 4m x 4m (full opening). The wall opening size is 2m x 1m, 3m x 2m, or 4m x 3m (full opening). The lighting simulation should be computed with interior surfaces having 0 percent reflectance.

We have decided to use overcast CIE sky model (type 16), following the intensity distribution according to the formula:

$$L = L_{base} * (1 + 2.cos(theta)/3.$$

The two set of points are defined on the floor level. The first set of 10 points is defined for the opening at the center of the roof, the second set of 8 points for the opening at the center of the wall.

2.6.2 Results for Test06

The achieved numerical results with computed errors are shown in the Table 2.8 and Table 2.9.

2.7 Test07 - Direct illuminance with unglazed roof openings under CIE general sky type 5 (uniform sky)

The direct illuminance from sky inside the room where the light has to come through the aperture is also the subject of this test, similar to test06. The reference solution is computed for uniform sky illumination by analytical formula.

	Point	A	B	C	D	E	F	G	H	I	J	Avg. Error
Roof 1x1	DF analytical	3.6	3.4	2.6	1.9	2.8	2.2	1.6	1.8	1.3	1.0	
	DF simulated	3.7	3.3	2.6	1.9	2.9	2.3	1.7	1.9	1.4	1.1	
	Error[*Percent*]	4.0	2.6	0.2	0.1	5.1	6.3	7.6	4.9	8.7	9.0	4.85
Roof 2x2	DF analytical	12.9	11.8	10.5	8.1	10.9	9.6	7.4	7.8	6.1	4.8	
	DF simulated	13.6	12.4	10.4	8.0	11.4	9.6	7.4	8.2	6.38	5.1	
	Error[*Percent*]	5.1	5.4	0.9	1.3	4.9	0.1	0.4	4.5	4.6	5.9	3.31
Roof 3x3	DF analytical	25.1	23.5	20.6	17.6	22.0	19.3	16.5	17.0	14.5	11.7	
	DF simulated	26.3	24.7	21.6	17.6	23.1	20.3	16.6	17.9	14.7	12.2	
	Error[*Percent*]	5.0	4.9	4.9	0.2	5.0	5.1	0.6	5.3	1.6	4.7	3.73
Roof 4x4	DF analytical	37.3	35.6	32.3	27.8	34.0	30.8	26.6	28.0	24.2	21.0	
	DF simulated	39.3	37.4	33.9	29.2	35.7	32.4	27.9	29.5	25.4	22.0	
	Error[*Percent*]	5.3	5.2	5.1	5.0	5.0	5.2	4.9	5.2	5.1	5.0	5.1

Table 2.8: Test06: Daylight factor variation with roof opening.

	Point	A	B	C	D	E	F	G	H	Avg. Error
Wall 2x1	DF analytical	0.8	1.2	1.8	2.7	4.2	6.1	6.9	2.4	
	DF simulated	0.9	1.4	2.0	3.1	4.9	7.2	8.8	4.9	
	Error[*Percent*]	16.1	12.6	12.7	15.7	15.6	18.8	28.7	104.6	28.1
Wall 3x2	DF analytical	2.2	3.2	4.6	6.7	9.9	14.3	18.3	10.2	
	DF simulated	2.5	3.6	5.2	7.7	11.5	17.1	23.4	17.9	
	Error[*Percent*]	14.5	11.6	12.8	14.8	16.6	19.8	27.6	8.9	15.8
Wall 4x3	DF analytical	3.9	5.3	7.4	10.2	14.3	19.6	25.7	30.5	
	DF simulated	4.4	6.1	8.4	11.8	16.8	23.7	32.8	43.9	
	Error[*Percent*]	13.4	14.2	13.7	16.1	17.3	20.8	27.7	44.1	20.9

Table 2.9: Test06: Daylight factor variation with wall opening.

2.7.1 Description of Test07

The geometry of the scene is a square room of dimensions 4m x 4m x 3m, with either a roof or a side wall opening at the center of the roof or the wall. The thickness of the wall and roof is zero. The roof opening is sized 1m x 1m, 2m x 2m, 3m x 3m, or 4m x 4m (full opening). The lighting simulation should be computed with interior surfaces having 0 percent reflectance.

We use uniform CIE sky model (type 5), which results in uniform value of exitant luminance over the whole hemisphere (this is different to overcast sky).

The two set of points are defined on the floor level. The first set of 5 points is defined on the floor, the second set of 6 points on the wall.

2.7.2 Results for Test07

The achieved numerical results with computed errors are shown in the Table 2.10, Table 2.11, Table 2.12, and Table 2.13.

Opening 1x1	Point	A	B	C	D	E		Avg. Error
	E analytical	762.0	724.0	625.0	500.0	378.0		
Floor	E simulated	761.9	716.4	626.9	509.1	379.4		
Points	Error[*Percent*]	0.01	1.05	0.31	1.83	0.36		0.71
	Point	F	G	H	I	J	K	Avg. Error
	E analytical	246.0	329.0	435.0	543.0	582.0	419.0	
Wall	E simulated	243.4	331.9	434.9	541.7	577.2	418.0	
points	Error[*Percent*]	1.04	0.87	0.02	0.23	0.82	0.24	0.54

Table 2.10: Test07: Direct illuminance with roof opening 1x1m for CIE sky type 5 (uniform sky).

Opening 2x2	Point	A	B	C	D	E		Avg. Error
	E analytical	2756.0	2642.0	2336.0	1922.0	1494.0		
Floor	E simulated	2745.5	2628.7	2335.6	1914.7	1486.1		
Points	Error[*Percent*]	0.38	0.50	0.02	0.38	0.53		0.36
	Point	F	G	H	I	J	K	Avg. Error
	E analytical	903.0	1207.0	1608.0	2076.0	2407.0	1950.0	
Wall	E simulated	900.7	1198.0	1601.2	2070.3	2396.2	1952.1	
points	Error[*Percent*]	0.26	0.74	0.43	0.28	0.45	0.11	0.38

Table 2.11: Test07: Direct illuminance with roof opening 2x2m for CIE sky type 5 (uniform sky).

Opening 3x3	Point	A	B	C	D	E		Avg. Error
	E analytical	5351.0	5184.0	4714.0	4031.0	3259.0		
Floor	E simulated	5347.8	5166.3	4703.4	4016.0	3242.9		
Points	Error[*Percent*]	0.05	0.34	0.23	0.37	0.49		0.30
	Point	F	G	H	I	J	K	Avg. Error
	E analytical	1759.0	2322.0	3084.0	4071.0	5155.0	5285.0	
Wall	E simulated	1764.5	2313.1	3081.9	4064.3	5154.5	5272.7	
points	Error[*Percent*]	0.31	0.38	0.07	0.16	0.01	0.19	0.19

Table 2.12: Test07: Direct illuminance with roof opening 3x3m for CIE sky type 5 (uniform sky).

Opening 4x4	Point	A	B	C	D	E		Avg. Error
	E analytical	7993.0	7814.0	7290.0	6475.0	5469.0		
Floor	E simulated	7968.4	7796.9	7274.6	6465.3	5450.6		
Points	Error[*Percent*]	0.31	0.22	0.21	0.15	0.34		0.25
	Point	F	G	H	I	J	K	Avg. Error
	E analytical	2559.0	3288.0	4249.0	5502.0	7096.0	9025.0	
Wall	E simulated	2553.2	3274.7	4240.8	5488.7	7082.4	9012.1	
points	Error[*Percent*]	0.22	0.40	0.19	0.24	0.19	0.14	0.23

Table 2.13: Test07: Direct illuminance with roof opening 4x4m for CIE sky type 5 (uniform sky).

2.8 Test08 - Direct illuminance with glazed roof openings under CIE general sky type 16 (overcast sky)

The direct illuminance from sky inside the room where the light has to come through the glazed aperture is the subject of this test. The test is actually very similar to the test07, however, the aperture is covered by 6mm thick glass. The reference solution is computed for overcast sky illumination by analytical formula.

2.8.1 Description of Test08

The geometry of the scene is a square room of dimensions 4m x 4m x 3m, with either a roof or a side wall opening at the center of the roof or the wall. The thickness of the wall and roof is 200mm. The roof aperture covered by 6mm thick glass is sized 1m x 1m, 2m x 2m, 3m x 3m, or 4m x 4m (full opening). The lighting simulation should be computed with interior surfaces having 0 percent reflectance.

We use overcast CIE sky model (type 16).

A single set of 6 reference points is defined on the floor level.

2.8.2 Results for Test08

The achieved numerical results with computed errors are shown in the Table 2.14, Table 2.15, Table 2.16, and Table 2.17.

Opening	Point	A	B	C	D	E	F	Avg. Error
1x1	SC analytical	1.8	2.6	3.1	1.4	2.0	1.0	
	SC simulated	2.0	3.0	4.2	1.5	1.9	1.0	
	Error[*Percent*]	10.8	16.6	35.2	7.5	5.5	0.9	12.7

Table 2.14: Test08: Direct illuminance with glazed roof opening 1x1m for CIE sky type 16 (overcast sky).

Opening	Point	A	B	C	D	E	F	Avg. Error
2x2	SC analytical	7.3	9.6	11.2	6.3	8.9	4.6	
	SC simulated	6.3	13.0	10.8	6.0	10.7	4.7	
	Error[*Percent*]	13.3	35.3	3.4	4.0	19.9	2.7	13.1

Table 2.15: Test08: Direct illuminance with glazed roof opening 2x2m for CIE sky type 16 (overcast sky).

Opening	Point	A	B	C	D	E	F	Avg. Error
3x3	SC analytical	15.9	19.3	21.8	14.1	17.2	10.9	
	SC simulated	15.6	23.6	24.8	14.7	19.5	9.4	
	Error[*Percent*]	1.8	22.1	13.8	4.1	13.5	13.4	11.5

Table 2.16: Test08: Direct illuminance with glazed roof opening 3x3m for CIE sky type 16 (overcast sky).

Opening	Point	A	B	C	D	E	F	Avg. Error
4x4	SC analytical	24.9	29.8	32.5	22.9	27.3	19.2	
	SC simulated	23.4	31.9	39.8	23.0	33.7	21.9	
	Error[*Percent*]	6.1	6.9	22.6	0.6	23.3	13.9	12.3

Table 2.17: Test08: Direct illuminance with glazed roof opening 4x4m for CIE sky type 16 (overcast sky).

2.9 Test09 - Direct illuminance with unglazed wall openings under CIE general sky type 5 (uniform sky)

The lighting coming from the window located at the vertical wall is a common situation in office buildings. This tests aims at verification of such conditions under the assumptions of the open window (no glass).

2.9.1 Description of Test09

The geometry of the scene is a square room of dimensions 4m x 4m x 3m, with a side wall opening at the center of the wall. The thickness of the wall and roof is not considered (it is zero). The wall opening has size 2m x 1m or 4m x 3m (full opening). The lighting simulation should be computed with interior surfaces having 0 percent reflectance.

We use uniform CIE sky model (type 5), which results in uniform value of exitant luminance over the whole hemisphere.

The two set of points are defined on the floor level. One set of 4 points is defined on the floor, the second set of 4 points is defined on the ceiling, and the third set of 7 points is specified on the wall.

2.9.2 Results for Test09

The achieved numerical results with computed errors are shown in the Table 2.18, Table 2.19, Table 2.20, Table 2.21, Table 2.22, and Table 2.23.

2.10 Summary for TC.3.33 tests

In this section we give a summary of the results for nine tests from TC.3.33 suite test as proposed in year 2002. We use ranking for total of 211 values. The results of error ranking are given in the Table 2.24, the table contains the cumulative sum for a sequence of limit error values.

Opening 2x1	Point	A	B	C	D	Avg. Error
	E analytical	216.81	193.08	93.76	46.67	
Floor	E simulated	218.48	193.33	93.19	47.26	
Points	Error[*Percent*]	0.77	0.13	0.61	1.26	0.69

Table 2.18: Test09: Direct illuminance with wall unglazed opening 2x1m for CIE sky type 5 (uniform sky), floor points.

Opening 2x1	Point	L	M	N	O	Avg. Error
	E analytical	14.0	28.13	57.93	65.04	
Floor	E simulated	14.4	29.38	58.24	61.62	
Points	Error[*Percent*]	2.86	4.44	0.54	5.25	3.27

Table 2.19: Test09: Direct illuminance with wall unglazed opening 2x1m for CIE sky type 5 (uniform sky), floor points.

Opening 2x1	Point	E	F	G	H	I	J	K	Avg. Error
	E analytical	105.93	115.42	97.03	77.26	56.35	34.63	31.78	
Wall	E simulated	104.84	102.66	99.44	81.40	66.18	48.50	31.30	
Points	Error[*Percent*]	1.03	11.10	2.48	5.37	17.44	40.04	1.50	11.30

Table 2.20: Test09: Direct illuminance with wall unglazed opening 2x1m for CIE sky type 5 (uniform sky), wall points.

Opening 4x3	Point	A	B	C	D	Avg. Error
	E analytical	1230.2	686.8	371.7	208.3	
Floor	E simulated	1227.6	683.9	371.4	207.8	
Points	Error[*Percent*]	0.21	0.43	0.09	0.40	0.28

Table 2.21: Test09: Direct illuminance with wall unglazed opening 4x3m for CIE sky type 5 (uniform sky), floor points.

Opening 4x3	Point	L	M	N	O	Avg. Error
	E analytical	369.1	206.1	111.5	62.5	
Roof	E simulated	355.8	197.6	107.5	60.7	
Points	Error[*Percent*]	3.60	4.08	3.57	2.84	3.52

Table 2.22: Test09: Direct illuminance with wall unglazed opening 4x3m for CIE sky type 5 (uniform sky), floor points.

Opening 4x3	Point	E	F	G	H	I	J	K	Avg. Error
	E analytical	472.6	438.5	415.4	388.0	356.4	320.8	239.1	
Wall	E simulated	474.1	438.3	414.4	386.8	354.0	319.5	238.1	
Points	Error[*Percent*]	0.33	0.04	0.24	0.32	0.68	0.40	0.42	0.35

Table 2.23: Test09: Direct illuminance with wall unglazed opening 4x3m for CIE sky type 5 (uniform sky), wall points.

Further we would like to note that in the description of tests in the document [TC.3.33] is also described test10, that concerns direct illuminance with glazed wall openings under CIE general sky type 16. Unfortunately, the description of the test10 was so scant that we were not able to reproduce the test itself. In general the reproduction of the tests was tedious manual process requiring modeling and preparing auxiliary files with reference values or additional data.

From all the results for tests and ranking it follows clearly that the implemented model of glass (transparent material) does not follow the model used by illumination engineering. This is the source of large errors for test02 and test08. For the tests without using glazed apertures the results are more than satisfactory, reaching usually error below 1 percent and typically 1 to 3 percent. Such an error is acceptable since the error of 1 percent is on the level of luminance perceptibility by human subject. This is also the case for professional software products used exclusively in lighting engineering such as [Integra03], although many packages including Integra Inspirer works only for diffuse surfaces and hence it is optimized to this surface type. This is inferior to our approach used in WP07 that uses density estimation with final gathering and non-diffuse definition of surface reflectances.

The invaluable contribution of implementing the preliminary tests of TC.3.33 is that several bugs and problems in the WP07 software renderer were identified and then corrected. The numerical results presented here are after the software modifications.

Error between CIE data and simulation results	Number of passed tests	Percent from total tests
less than 1 percent	100	46.9
less than 3 percent	117	54.9
less than 5 percent	139	65.2
less than 10 percent	158	74.1
less than 20 percent	191	89.7
more than 20 percent	22	10.3
total sum	213	100.0

Table 2.24: Summary for TC.3.33 tests using ranking.

Chapter 3

Test on Simple Scene ICIDO office

3.1 Introduction

The most general reason for nice lighting design in architectural interiors is that lighting conditions have been shown to have an impact on the fundamentals of human life: health, performance, and safety. The task of the lighting design is appropriate lighting with the minimum cost[vanBommel] [Boyce]. Note that daylight in addition to cheap cost provides a more pleasant atmosphere inside a building and superior quality of light to artificial lighting. It also provides the body with its only means of producing vitamin D and counteracts the effects of seasonal affective disorder.

3.2 Data Preparation

For the reasons stated above we have selected as the test case the office lighting located in ICIDO facilities. The daylight consists of 3 sources - two windows and one roof aperture created by staircase. In addition there are other luminaries, a signal light source and a logo of the company equipped with a back light, further traditional bulbs on the ceiling lamps.

The geometry of the ICIDO scene is relatively simple and it has been remodeled by VRA. In total it consists of about 200,000 triangles. The BRDF of materials were estimated by ICIDO and assigned to the surfaces, mostly Phong model was used. The light sources were measured by ICIDO and positioned in the scene. The exterior lighting was estimated as well. As a reference two HDR photographs of the real scene were taken by ICIDO using multi-exposure technique with the algorithm of Robertson [RB99].

3.3 Results

Tonemapped HDR photograph of the scene for the viewpoint I is shown in Figure 3.1. The corresponding tonemapped rendered image of the scene by WP07 renderer is shown in Figure 3.2. Similarly, for the second viewpoint (viewpoint II) the photograph is shown in Figure 3.3 and corresponding rendered image in Figure 3.4.

The quality of rendering with respect to the images can be judged by a reader of this document. Obviously, the reconstruction process of the geometry, surface reflectances, and luminaires was not perfect. Even small geometric differences that can be seen as unimportant at the first view are noticeable. For example, for the viewpoint I the positioning of camera is clearly slightly different. Further, the location of the round table with chairs is too far in the rendered image with respect to the photograph. The differences in the position of external lighting simulating the daylight causes the main spot of illuminance is shift from the right wall to the front wall.

Similarly for the rendered image with the viewpoint II the signal lighting was switched on in the top corner (middle of the image). Further, the ceiling in the location of the stairs has significantly different shape than in reality.

We have asked several human subjects what they think about images for view I and II without telling them what is a photograph and what is a rendered image. Surprisingly, for the viewpoint II it has appeared to be difficult for asked human subjects. The rendered image for viewpoint I a remaining noise, while the whole impression of the atmosphere is well preserved, but the noise was the clue to distinguish between a photograph and rendered image.

However, the human subjects have agreed that overall mood of the scene was preserved in the rendered images. The similar problems we have encountered were reported by similar studies such as [Pell01], [Drago01], [Ubb98], and [Eissa01].

Figure 3.1: Viewpoint I: Scene "ICIDO office" as taken HDR photograph (tonemapped for printing).

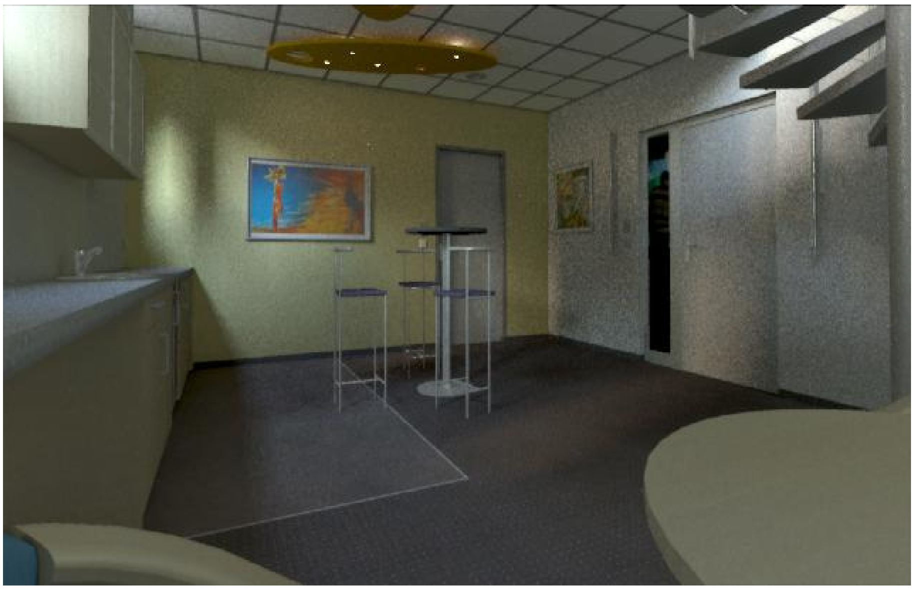

Figure 3.2: Viewpoint I: Scene "ICIDO office" as rendered by WP07 renderer (tonemapped for printing).

Figure 3.3: Viewpoint II: Scene "ICIDO office" as taken HDR photograph (tonemapped for printing).

Figure 3.4: Viewpoint II: Scene "ICIDO office" as rendered by WP07 renderer (tonemapped for printing).

Chapter 4

Test on Complex Architectural Scene Aizu Atrium

4.1 Data Preparation

The lighting is important not only for rooms of small size such as offices, but also for middle and large scale architectural environments. A representative of such spatial environment is a corridor at the university of Aizu. The project of remodeling a corridor of the university of Aizu was worked on by Frederic Drago and Karol Myszkowski [Drago01] in 2001. A moderately complex architectural environment containing about 2,000,000 triangles was modeled in 3D Studio MAX version 3 and completed by measured characteristics of luminaries including measured maintenance factor. Further, the BRDF for six dominant materials covering 95 percent of the surfaces in the whole scene were measured by Integra company. The rest of the surfaces BRDF was estimated. The data for this model is publicly available on Web page

http://www.mpi-inf.mpg.de/resources/atrium .

We have completed the model by BTF data for 4 material samples. The BTF data for these samples were measured by UBO facilities. The camera position and other parameters were only estimated only by hand.

4.2 Results

The tonemapped HDR photograph of the scene is shown in Figure 4.1. The tonemapped rendered image of the scene by WP07 renderer is shown in Figure 4.2. Notice that not all features of the scene were correctly re-modeled with respect to physical reality or they were lost during the data conversion. The floor pattern and the back wall in reality have a tiling structure that is not present at the rendered image. Also the set of light sources is different, small light sources headed at the top of the atrium are missing at the photograph. The closest sofa behind the stairs and the pot with the flower are also missing in the digital model. Unfortunately, we neither have not been able to complete the digital model with missing data nor to take new photographs of the real modified scene environment that would better match to the digital model. There is another visible problem with the camera that was used to take the real images, due to the non-linear distortions it does not follow well the pinhole camera used for rendering. By positioning the camera and changing viewing angle we were not able to achieve good match of geometric features of the rendered image and photograph.

However, the overall impression of the Atrium scene as rendered by WP07 renderer is preserved. This was also confirmed by several human subjects, although the match cannot be perfect due to the inconsistencies of the digital model and the real scene.

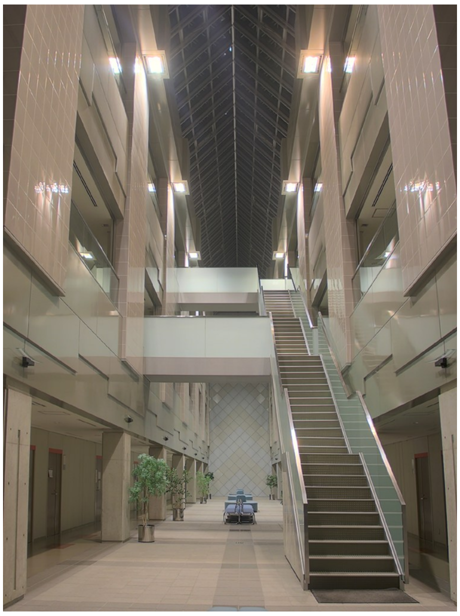

Figure 4.1: Scene "Aizu Atrium" as taken HDR photograph (tonemapped for printing).

Figure 4.2: Scene "Aizu Atrium" as rendered by WP07 renderer (tonempped for printing).

Chapter 5

Conclusions

In this report we have described two major validation procedures used for validation of WP07 renderer in the context of rendering architectural scenes.

First, the set of nine scene as the part of the preliminary proposal of CIE TC.3.33 committee was remodeled following the textual description. The software passed the tests with quite good results, in 50 percent of test cases the error is below 1 percent (inperceivable) and only in 10 percent of test cases the error is over 20 percent. The major problem with remaining moderate and large inaccuracies is the different model of the glass than the one assumed in the test by lighting engineering community.

Second, the model of the ICIDO office was remodeled including geometry, surface reflectances, luminaries, and camera viewpoint. The rendered images for two viewpoints were compared with HDR photographs taken after tone mapping. The results according to subjective evaluation are quite satisfactory.

Third, the model of the Aizu Atrium was completed by new data, converted to X3D with RR extensions and rendered. The similarity between the rendered image and HDR photograph of the real scene after tonemapping is acceptable.

In summary, we believe that the high quality renderer developed within REALREFLECT project follows the requirements of a predictive rendering for the purposes of architectural design with the capabilities equivalent or close to the existing commercial packages such as Integra Inspirer [Integra03]. An important unique feature of the renderer developed within the REALREFLECT project scope is its ability to use BTF data, which highly increases the perceived realism of rendered images.

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