OLED100.eu
Project Report

Three aesthetical perception case studies

July 2009

This public report is part of the **OLED100.eu** project:
Organic LED Lighting in European Dimensions
funded under the IST priority (contract nr 224122)
of the European 7th Framework Programme

For more information about the project, please visit: http://www.oled100.eu

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1 Management Summary

OLEDs offer a large variety of design options. This refers to really free design parameters such as shape, size and emissive colour, but also to technology enforced parameters such as off-state appearance and busbar structures.

In this deliverable architectural and aesthetical research has been performed to identify most suitable market entry parameters. Especially for size and shape, existing standards and common building materials have been evaluated. It turned out that a suitable OLED tile size could be 15 cm x 15 cm pitch size and multiples thereof.

This edge length was transferred to other tile shapes such as hexagons and triangles.

Several room models were built with a ceiling illumination completely made of OLEDs. The variations were shown to test persons who had to rank the modifications according to their personal taste.

In general, it can be concluded that larger tiles are preferred over smaller tiles. At high luminance levels the shape of the tiles does not seem to be important, but at moderate luminance levels ornamental shapes and clusterings are rejected in office or working environment while in residential environments they are more accepted.

For the off-state appearance, a milky diffuse surface is accepted better, especially in office environment where a more neutral appearance is required. However, this result is not very reliable since there were challenges in setting up a realistic room simulation.

For the emissive white colour of the OLED, cool white (6500 K) has been clearly rejected, even for office environment where 4000 K was the favoured colour temperature. For residential environment the acceptable range was from warm white (3000 K) to neutral white (4000 K) which is good news for OLED technology because OLEDs show their best luminous efficacy at low colour temperatures.

2 Introduction

2.1 About OLED100.eu

OLED100.eu, an integrated research project, has brought together a consortium of experts from leading industry and academic organizations to accelerate the development of organic light-emitting diode (OLED) technologies in Europe. It has received €12.5 million funding from the European Community's Seventh Framework Programme to form the technological basis for efficient OLED applications for the general lighting industry in Europe.

The OLED100.eu programme follows the successful OLLA (Organic LEDs for Lighting Applications) programme, which started in 2004 and was completed successfully in June 2008. OLLA created the basis for organic lighting by developing white OLEDs with efficacies of 50.7 lm/W at an initial brightness of 1000 cd/m2 and with lifetimes well above 10.000 hours. With OLED100.eu, Europe is continuing to invest in the development of organic lighting technologies and moving to specifications required for general lighting applications. The consortium will focus on five main goals:

- High power efficacy (100 lm/W)
- Long lifetime (100.000 h)
- Large area (100x100 cm2)
- Low-cost (100 Euro/m2)
- Measurement standardization / application research

OLEDs are a new and attractive class of solid-state light sources and they are emerging as a compelling candidate to replace conventional lighting systems for large area illumination. Organic LEDs generate a diffuse, non-glaring illumination with high color rendering. They are flat, thin, and have the potential to serve as efficient large area light sources. OLEDs are instant-on, can be dimmed and can be produced on substrates of basically any shape. This high level of flexibility in terms of design and application make them highly appealing for designers, manufacturers and consumers. Furthermore, as a highly efficient light source, OLEDs have the potential to achieve substantial energy savings. This latest EU research consortium provides important support to ensure Europe plays a leading role in OLED technology.

Partners in the OLED100.eu consortium include:

- Bartenbach LichtLabor GmbH, Austria
- European Photonics Industry Consortium (EPIC), France
- Evonik Degussa GmbH, Germany
- Fraunhofer Institute for Photonic Microsystems (IPMS), Germany
- Microsharp Corporation Limited, Great Britain
- Novaled AG, Germany
- Océ Technologies B.V., The Netherlands
- OSRAM Opto Semiconductors GmbH, Germany
- Philips Technologie GmbH, Business Center OLED Lighting, Germany

- Philips Technologie GmbH Forschungslaboratorien, Germany
- Physikalisch-Technische Bundesanstalt (PTB), Germany
- Saint-Gobain Recherche S.A., France
- Siemens AG, Germany
- Technische Universität Dresden, Institut für Angewandte Photophysik, Germany
- Universiteit Gent, Belgium

Additional project information is available on our website www.oled100.eu or in the OLED100.eu-Newsletter, which can be downloaded from our website.

2.2 Purpose of the Document

With regard to the integration of Organic Light Emitting Diodes (OLEDs) into future lighting scenarios it is not only necessary to meet pure technical specifications such as luminous efficacy, lifetime or CRI requirements. Since OLEDs are large and flat light sources, they are offering some degrees of freedom in product design. As two examples, the lateral dimensions and the geometrical shape can be adjusted to specific application needs. However, in view of efficient production of OLED lighting tiles it is desirable to keep the variety of products quite low in order to produce with high throughput.

Thus, it is very important to ensure the market acceptance of future OLED designs at an early stage. This can be done focusing on two aspects. The first aspect is an architectural one, it deals with existing standards and norms in terms of built-in dimensions of current lighting fixtures (e.g. for ceilings) and other building materials such as wall or floor tiles which can be substituted by light emitting OLED tiles. The second aspect deals with pure aesthetics and needs to identify a mainstream taste among end users. If this mainstream taste can be technically transferred into product design, a high market acceptance can be easily anticipated.

Flatness and freedom of shape are definitely two features of OLED light sources. Besides these two features, OLEDs can exhibit further design properties which may – or may not – be considered as product features. These must be checked with regard to customer acceptance as well.

The properties under consideration are the off-state appearance and the so-called busbar structures. A typical so-called bottom emitter OLED as shown in figure 2.1 (light is emitted through the bottom substrate) appears like a mirror in the off-state. This effect is caused by the highly reflective metal cathode at the top of the OLED stack.

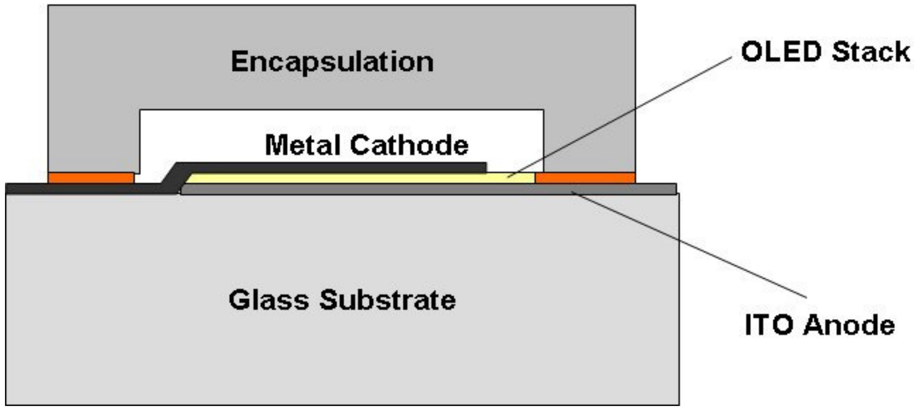


Fig. 2.1 Structure of a typical bottom emitter OLED device. The ITO (indium tin oxide) anode and the OLED stack are transparent. In on-state light is coupled out through the substrate. In off-state the reflective metal cathode causes the mirror effect.

By applying additional thin structures to the substrate for the purpose of better light extraction – thus higher luminous efficacy – the mirror effect vanishes and is replaced by a diffuse white appearance. One can imagine also other effects, e.g. black off-state by means of a circular polariser or coloured mirror by means of a colour filter. Since polariser and colour filter are reducing the luminous efficacy and since improved light extraction is a major research field in WP2 of OLED100.eu, the diffuse white appearance is considered to be of highest technical relevance. However, if the market (applications, end users) would favour a mirror appearance as a feature of aesthetic value, this must be considered in product design. The difference between the two most relevant off-states is shown in figure 2.2.

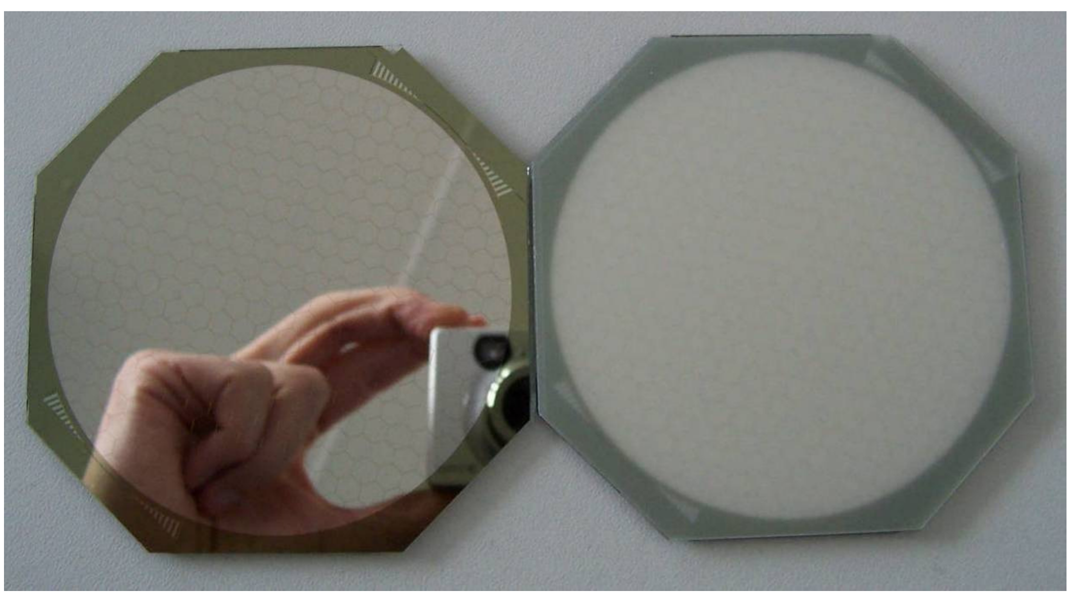


Fig. 2.2: Two OLEDs of same type with two different off-states. The mirror-like appearance is shown on the left side and the diffuse white appearance with a standard light extraction film is shown on the right side.

In order to find the best solutions and human preferences for the above listed design topics, perception and taste studies were performed. This report shows the results of tests conducted with approximately 60 subjects and draws conclusions on OLED tile designs which can be understood as design recommendations.

Originally, the DoW for the OLED100.eu project stated two separate studies on tiling architecture and off-state appearance. However, it turned out that the off-state topic was difficult to realise in a specific test setup. The best approach was very similar to the one used in the tiling architecture study. Since this test setup enabled quite easily the change of another parameter, i.e. the colour temperature of the OLED, it was decided to add this topic to the studies. The colour temperature of the OLED is also important for product design because currently OLEDs show the best luminous efficacy at low colour temperatures. Thus, it is very interesting to identify preferences for that parameter as well.

The report is structured as follows.

The third chapter covers the tiling architecture aspects, i.e. size and shape. The first section gives an overview of various norms and standards for common building materials such as ceiling lights, wall tiles, etc. A market survey is included showing the most common dimensions offered by various suppliers worldwide. The first section also includes some generic considerations on aesthetics. Based on these combined findings a test setup was derived which is explained in the second section. Several variations of tile size, tile shape and tile arrangement are realised in a room model which were presented to the subjects for a comparative ranking. Several side parameters such as luminance level of the OLED or the room interior were varied in order to identify an impact on the taste classification. Finally, the results of the questioning are presented accompanied by a detailed explanation of the analytical methods applied to the collected data. They are carefully evaluated by standard statistical methods and significant differences in preference are highlighted.

In the fourth chapter the off-state appearance is covered. After a short introduction highlighting the challenges, the test setup and the results are presented in a comparable way to the tiling architectural study.

In the fifth chapter the impact of the colour temperature is presented in the same manner. After a short literature survey is given in the first section, the test setup is described in the following section and finally the results are presented.

A discussion of the results is undertaken in the sixth chapter followed by a summary.

3 Tiling Architecture

3.1 Literature Research and Architectural Suggestions

3.1.1 Introduction

The organic light emitting diode „OLED“, differs from all previously available lamps. That applies not only for the technology of the generation of light, which is not mentioned in this report, but also for its characteristic form as a flat surface.

Most types of lamps generate light as a ‘spot’, except for the fluorescent lamp which can be described as a linear light. Except for electroluminescent films – which are not suitable for general illumination due to low efficacy – the creation of area emitters is only possible by means of clustering point or linear light sources in combination with diffusers, light guides or other optical aids.

For technical reasons, the OLED cannot be produced as an endless expanse, but rather as a finite element which can be used in tiled arrangements. In order to create larger areas, this would be cumulatively designed.

In the following sections, a concrete recommendation for a modular OLED-system will be compiled. Forms, dimensions and surface structures will be determined. The starting point is dimensional stipulations which are generally valid in civil engineering and which conform to international standards. In doing so, aesthetic and practical aspects will be differentiated.

An overview of general types of components available on the market which are based on the above mentioned scale of proportions provides evidence of which module dimensions are most often used.

Subsequently, possible dimensions for a basic module will be derived which would be compatible with existing scale of proportions and component systems.

In order to enhance the creative freedom, this basic module will be supplemented with further module forms which allow for a number of arrangement design variations.

The grid patterns and samples which arise create an image even when switched off, which influence the aesthetic character of a room. Certain creative and perception psychology fundamentals are needed in order to understand their effect in a spatial area.

The aspects mentioned in the report are only conditionally adjusted to the photometric requirements and possibilities and are therefore confined to requirements of the market and are aesthetic in form as perception psychology approaches. It deals with a recommendation, which in further stages, must be discussed and adjusted to basic light and production regulations, in order to be able to define a final product.

3.1.2 Measurements

For decades, it has been attempted to define relative and absolute dimensions in architecture as a determination in civil engineering. Scales of proportion have been developed in many cultural areas independent of each other, the earliest known definitions came from Egypt, Greece and the Roman Empire.

The intention was to find the most possible harmonic proportions as dimensions for objective beauty. The initial relationship thread started with the human being. The original measurement units were oriented on biological body measurements, e.g., inch, foot, acre, etc.

Practicable considerations such as economic efficiency, by means of standardised scales of proportion, were to be taken into consideration much later.

For the first time, dimension correlations from Vitruv (approx. 1st century B.C.) were gathered. An especially harmonic ratio proved to be the "Golden Cut", with the ratio of 1:1.62. Hereby, two quantities follow the golden cut, if the ratio between the sum of those quantities and the larger one is the same as the ratio between the larger one and the smaller.

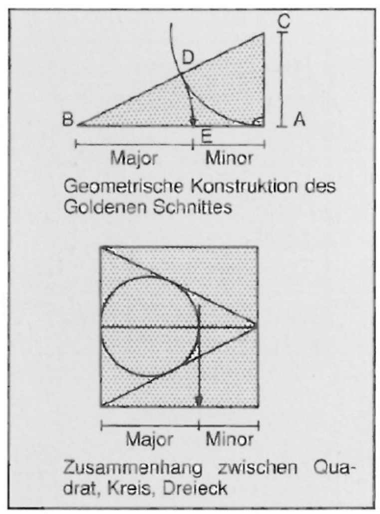


Fig.3.1: Geometric construction of the "golden cut"; correlation between square, circle and triangle

In the Renaissance, primarily Vignola, Palladio and Scamozzi all tried to develop a theory of proportion, which would define absolute beauty. Their findings had a strong influence on the design of buildings at that time and in the following centuries. Also, the work of Albrecht Dürer is of importance, whose 'relationship between measurements' derives from the human body (figure 3.2), and by means of various stages up to 1/40, the size of the body is composed.

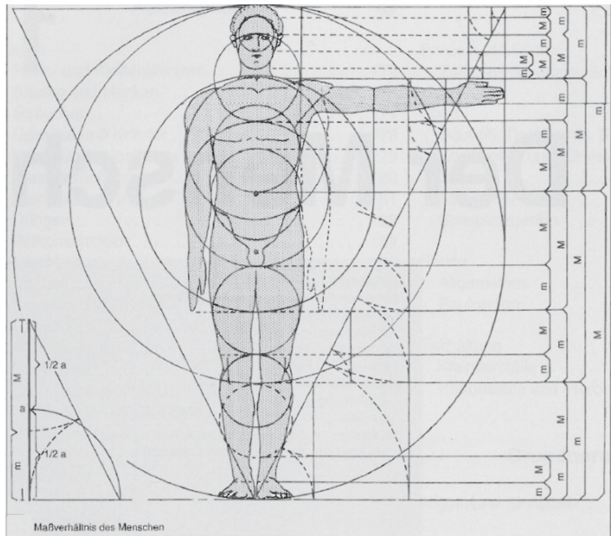
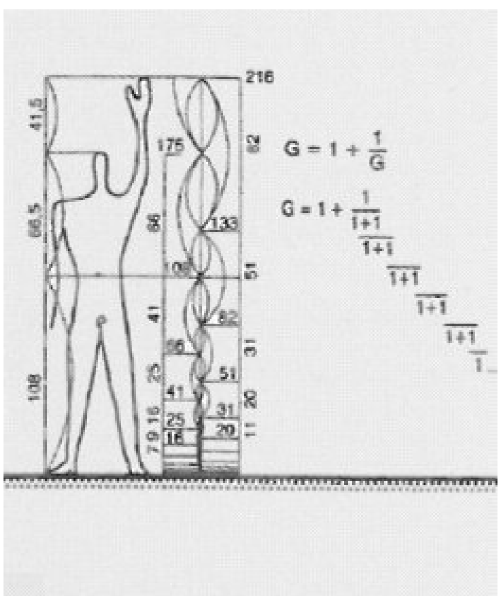


Fig.3.2: "Relationship between measurements", Albrecht Dürer

Until the beginning of the 20th century, the above mentioned theories of proportion were not developed any further, but rather copied. It was the architect Le Corbusier who developed a new scale of proportion – the "Modulor" (figure 3.3 (b)), which was based on the "Golden Ratio Progression" by Fibonacci and relied on the average size of a European as 175 cm. The scaling progression continues with 108.2 – 66.8 – 41.45 – 25.4, where the smallest proportion equates to exactly 10 inches (figure 3.3 (a)). Later he took a basis of 6 English feet = 182.88 cm as an initial dimension, from which the "red progression" derives.



Rote Reihe: Ro		Blaue Reihe: Bl	
95 280,7 cm	952,80 m		
58 886,7 cm	588,86 m	117 773,5 cm	1177,73 m
36 394,0 cm	363,94 m	72 788,0 cm	727,88 m
22 492,7 cm	224,92 m	44 985,5 cm	449,85 m
13 901,3 cm	139,01 m	27 802,5 cm	278,02 m
8 591,4 cm	85,91 m	17 182,9 cm	171,83 m
5 309,8 cm	53,10 m	10 619,6 cm	106,19 m
3 281,6 cm	32,81 m	6 563,3 cm	65,63 m
2 028,2 cm	20,28 m	4 056,3 cm	40,56 m
1 253,5 cm	12,53 m	2 506,9 cm	25,07 m
774,7 cm	7,74 m	1 549,4 cm	15,49 m
478,8 cm	4,79 m	957,6 cm	9,57 m
295,9 cm	2,96 m	591,8 cm	5,92 m
182,9 cm	1,83 m	365,8 cm	3,66 m
113,0 cm	1,13 m	226,0 cm	2,26 m
69,8 cm	0,70 m	139,7 cm	1,40 m
43,2 cm	0,43 m	86,3 cm	0,86 m
26,7 cm	0,26 m	53,4 cm	0,53 m
16,5 cm	0,16 m	33,0 cm	0,33 m
10,2 cm	0,10 m	20,4 cm	0,20 m
6,3 cm	0,06 m	7,8 cm	0,08 m
2,4 cm	0,02 m	4,8 cm	0,04 m
1,5 cm	0,01 m	3,0 cm	0,03 m
0,9 cm		1,8 cm	0,01 m
0,6 cm usw.		1,1 cm usw.	

Fig.3.3: (a) Scaling progression; (b) Modulores values for red ("Rote Reihe") and blue progression ("Blaue Reihe") according to Le Corbusier; 226 cm in the blue progression is approximately a person with arm stretched upwards

The „blue progression“ is based on the initial dimension of 226 cm (a person with arm stretched upwards), which proves to be more practicable in civil engineering due to its larger proportions. As all of these scales of proportion are based on creative criteria such as rhythm, proportion, symmetry or hierarchy, one can summarise this under the term of “harmonic proportion systems”.

3.1.3 Raster and Decoration

In cave paintings in France, the first coloured areas in a square raster showed up. Since then, the raster is the most common principle of arrangement. It is usually used for flat surfaces, although cubes, tetrahedrons and octahedrons can be continued in a spatial raster as well. In the flat surface, the possibilities of arranging shapes are reduced to three basic principles: the square/rectangle raster, the triangle raster and the band raster. Each of the three rasters can be displayed with points, lines or surfaces, so that nine different (but related to each other) decoration areas are created [WEI1].

In former times, the principles of arrangement were called rapport, rhythm repetition or pattern. These days, they are simply called a raster, which is familiar with everyone. Forms which should fit into such a raster must firstly go through a transformation process by abstraction or geometrics otherwise they would not be suitable. This transformation process means as a rule, that the forming of something is developed from a form. [WEI1].

The last citations clarify the creative effect, which the lining up of repeated elements can have. Regardless of their apparent simplicity with geometric basic patterns, the raster can become a decisive element in the spatial appearance. With the example of a floor or ceiling raster, it is clear how strongly the perspective, estimation of distance, axial alignment of the room etc. are influenced.

Accordingly, this aspect should be acknowledged when designing the OLED, as the OLED surface is made up of many repetitive elements. Furthermore, it is not only the illuminating surface but also the joining which makes a deciding impression on the overall appearance. Its dominance depends on a technically necessary or also a creatively desired joint width.

3.1.4 Standards and Module Arrangement

3.1.4.1 DIN 4172 „Scale of Proportions for Structural Engineering“

With the introduction of the meter as a standard for measuring units and the building industrialisation in the 19th century, additional measuring systems were established, as buildings could be constructed by a sequence of mass manufactured building components which were based on recurring measurements.

Due to this, creative criteria as a basis for scales of proportion stepped into the background and were replaced by requirements for the practical operation and the aim of standardisation of the measurements utilised in the entire construction trade.

One of the most important industrially manufactured building components was the brick, the original length of which was based on the span of the hand (25 cm), and the width was based on the size of the grip (10-15 cm). With introduction of the metric system, the so-called octametric system forced its way through for determination of brick measurements. This was based on an eighth of a meter.

In 1852, the brick length of 25 cm = 10 inches, or the so-called “Reichsformat” was established and was replaced in 1945 by the “Bundesformat (federal format)” with 24 cm, taking the grout into account.

The present basic size for bricks is 12.5 cm.
The basis for the scaling sequence is:

10 – 5 – 2.5 – 1.25 – 0.625 – 0.3125

and the scale:

100: 4 = 25.00 cm
100: 8 = 12.50 cm
100:12 = 8.33 cm
100:16 = 6.25 cm

As a brickwork construction belongs to a particular building method, in 1955 the DIN 4172 which is one of the oldest scale of proportions which still exists, was established, which still applies for component measurements and semi-finished products for structural engineering.

As a rule, one of the most important definitions belongs to the construction preferred values which are displayed in figure 3.4. They are values for the basic dimensions and the ensuing individual dimensions, building shell dimensions and exterior dimensions.

Preferred Values For Structural Work				Preferred Values For Individual Measurement	Preferred Values For Finishings			
a	b	c	d	e	f	g	h	i
25	25/2	25/3	25/4	25/10=5/2	5	2x5	4x5	5x5
				2,5				
				5	5			
			6 1/4	7,5				
		8 1/3		10	10	10		
	12 1/2		12 1/2	12,5				
				15	**15**			
		16 2/3		17,5				
			18 3/4	20	20	20	20	
				22,5				
25	25	25	25	25	25			25
				27,5				
			31 1/4	**30**	**30**	**30**		
		33 1/3		32,5				
				35	35			
	37 1/2		37 1/2	37,5				
		41 2/3		40	40	40	40	
			43 3/4	42,5				
				45	45			
50	50	50	50	50	50	50		50
				52,5				
			56 1/4	55	55			
		58 1/3		57,5				
				60	**60**	**60**	**60**	
	62 1/2		**62 1/2**	**62,5**				
				65	65			
		66 2/3	68 3/4	67,5				
				70	70	70		
				72,5				
75	75	75	75	75	75			75
				77,5				
			81 1/4	80	80	80	80	
		83 1/3		82,5				
				85	85			
	87 1/2		87 1/2	87,5				
		91 2/3		90	90	90		
			93 3/4	92,5				
				95	95			
				97,5				
100	100	100	100	100	100	100	100	100

Fig. 3.4: Preferred values in construction and building, red figures denote most common pitches

3.1.4.2 Standard 18000 Modular Coordination in Construction Engineering

Due to its improved divisibility, a decimal system was developed which is based on increments of 10.

Due to the integer multiplication of the basic module of M = 10 cm, multi modules ensued from which several preferential dimensions proved to be reasonable:

3M = 30 cm, 6M = 60 cm und 12M = 120 cm.

Additional dimensions were indicated with 2.5M = 25 cm, 5M = 50 cm und 7.5M = 75 cm.

Depending on the construction method utilized, the following preferential dimensions ensued:

Brickwork construction:
    15M, 30M, 45M (floor plan) and/or 5M, 10M, 15M (vertical section)
Frame construction:
    12M, 72M, 84M, 96M (a multiple of the 12M succession)
Interior work, furniture:
    3M to 12M

A long time ago, this scale of proportions was reflected in the DIN 18000, which defined an international standard for the dimensioning of construction components. It aimed for a limitation of the range of building components and parts, for higher productivity, for easy combination and replacement of building components, thus a simplification of the design work. However, it has not completely established itself in brickwork construction as opposed to the octametric series of measurements, as no improvement in material can be achieved.

With a high quantity of pre-fabrication, as in construction of elements, the module arrangement has definite advantages due to its easy divisibility.

3.1.4.3 Future Developments

From an economic point of view, new developments in the manufacture of building components together with the help of computer supported methods, allows for the fabrication of individual elements with viable expenditure. Therefore, new scope for creative freedom is established.

Even now there are structural shapes coming into being where standard building components can hardly be implemented. By means of Computer Aided Design (CAD) and computer supported production methods, such as Computer Numerically Controlled (CNC), Computer Aided Manufacturing (CAM) and individual pre-fabrication, can these designs be transformed into reality (e.g. complex spatial structures, which are not based on the right angle, can be displayed and optimised for the fabrication of building components).

These developments make it possible for a certain independency from the valid scale of proportions. Nevertheless, a large portion is planned in accordance with these proportions as it is often reverted back to the standard building components. In addition, the European region is essentially regarded as built-up, that means that the main building construction already exists, many of which having been completed in accordance with the abovementioned scale of proportions.

3.1.5 Building Components

This section deals with a description of typical commercial building materials and their typical dimensions in order to derive - from the most commonly used plate widths - an OLED-module size which could be compatibly integrated in various trades. Much background information can be found in the "Dry Construction Manual". [BEC1]

3.1.5.1 Building Materials for Planking and Lining

A wide variety of materials is used for planking and lining. Table 3.1 gives an Overview of various components and common dimensions.

Table 3.1: Survey of various building materials and their most common dimensions

	Width / mm	**Length / mm**	**Remark**
Plaster Boards	1250	< 4000	DIN 18180
	600	< 3500	DIN 18180
Plaster fibre boards	100	150	
	124.5	200	
	124.5	250	
	124.5	254	
	124.5	300	
Chipboards	1850	4100	
	2080	2710	
	2050	2750	
	2050	5300	
Wood fibre panels	1250	2500	
Plywood	1250 o. 1500	2500 o.3000	
	1200 o. 1525	2400 o.3050	
	1850	2200 o.2500	
	1250	2200	
Oriented Strand Boards	1250	2500	
Cement Coated Polystyrene Structural Panels	600	1250 o. 2500	
Metallic Cladding	600	600	
	625	625	

3.1.5.2 Ceiling Systems

Ceiling systems are mechanical support structures which can be found in many variations. Most common are systems with raster patterned surfaces. They are made of metal substructures which support various shapes and sizes of ceiling tiles. One can also find "open" systems which are not made up of joined ceiling tiles, but rather of suspended „grid" plates with a specific height of the grid bars. The latter ones can exhibit shapes like squares or honeycombs. The raster patterned ones can be divided into several principles, such as T-systems, Z-systems, clipping systems, linear grid systems or others, They are usually all following the requirements of the DIN 18168 and some are shown in figure 3.5.

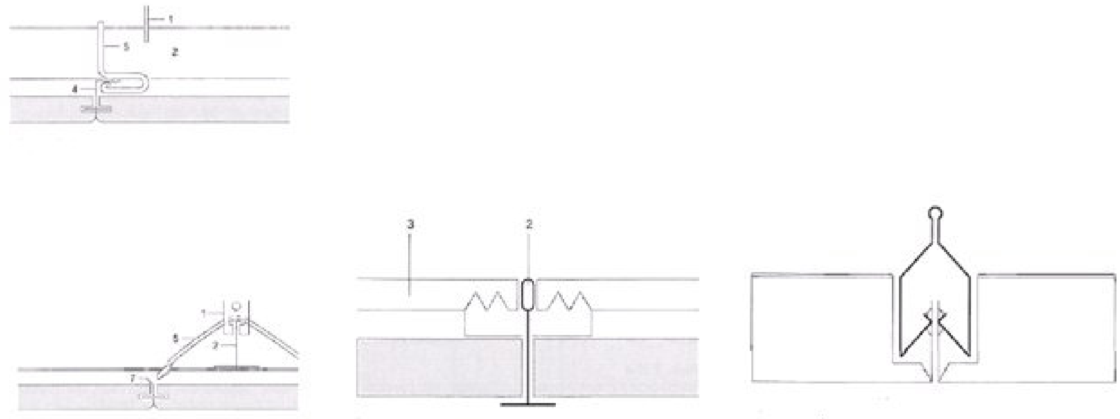


Fig. 3.5: Schematic cross-sections of a Z-system (left), a T-system (middle) and a clipping system (right)

The number of different pitches used in these systems is quite low. One can really identify highly common dimensions such as 60 cm x 60 cm or 62.5 cm x 62.5 cm. Sometimes, 50 cm x 50 cm can also be found.

3.1.5.3 Tiles

Different from ceiling systems floor and wall tiling is much more diversified in terms of dimensioning. Shape-wise, there is still a preference for square tiles, but any other shape can be found as well. The edge length is usually smaller than pitches of ceiling systems described in the previous section. While 60 cm which is fairly typical there, for tiles 60 cm is a kind of maximum dimension rarely used.

Wall tiles most commonly have a size of 150 mm x 150 mm with a grout width of 2 or 3 mm, and 98 mm x 98 mm tiles with 2 mm grout. Corresponding edge tiles are 50, 75 and 100 mm high [ERH1]. The material is usually glazed stoneware available in a wide range of shape and colour where no standards exist or the standards have been withdrawn [WEL1].

Floor tiles are also available in nearly all sizes. The previous standard DIN 18155 is not longer valid. However, a preferred size is 10 cm x 10 cm [WEL1].

Besides single colour tiles also mosaic tilings are quite common which are made of different colours. Typical sizes range from 2 cm x 2 cm up to 7.5 cm x 7.5 cm, also rectangular structures can be found such as 2 cm x 4.2 cm or hexagonal ones like 1.75 cm x 2 cm [ERH1, WEL1].

3.1.5.4 Glass Construction

The future use of transparent OLEDs can be imagined as glass-like ceilings or windows. The integration of photovoltaic (PV)-cells into the outside shells of buildings can act as a reference here and give some inspiration for OLED future applications. As opposed to free-standing add-on systems by which the solar cells are embedded in EVA and Tedlar foil and attached to the back side of a glass panel, PV installations, which are integrated into the building, are protectively situated in the voltage-free middle layer of symmetrical laminated glass. Due to the low energy demands for manufacturing these, and the good service life, most polycrystalline cells are used with an edge length of 10 cm, 12.5 cm and 15 cm which are freely arranged inside a module [WUR1]. Examples are shown in figures 3.6 and 3.7

Fig. 3.6: Integrated solar module on the glass shell construction of the Academy for Further Education, Herne, 1998, Arch.: Jourda & Perraudin Architects with HHS Planer

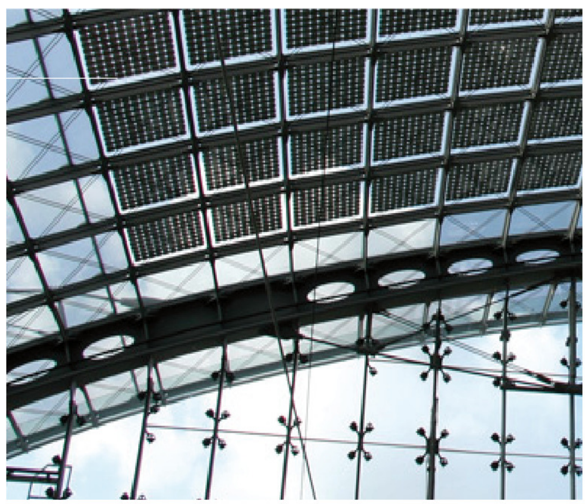


Fig. 3.7: Photovoltaic module integrated into glass at the Berlin Central Station (Lehrter Station), 2006, Gerkan Marg und Partner

3.1.5.5 Overview of the Market

This section provides a very rough and incomplete market survey on big raster and light ceiling manufacturers and their most common products. Table 3.2 lists the product offerings of various suppliers and table 3.3 gives some sales figures of Central European metal ceiling manufacturers.

Especially the sales overview reveals some interesting facts. For the metal ceiling tile manufacturers who were surveyed in Germany, the percentage of square tiles as opposed to rectangle tiles is approx. 50% to 50%.

The dimensions of the rectangle panel ceiling formats vary considerably and generally depend on the manufacturer and on the project.

As far as the square tiles are concerned, the formats of 600 mm and 625 mm are dominant. According to the ceiling manufacturers, the format 600 mm tiles are implemented mainly in the EU and the format 625 mm tiles are prevalent in German-speaking countries.

Table 3.2: Rough overview of popular raster dimensions offered by big raster and light ceiling manufacturers

Manufacturer	**Origin**	**Product Name**	**Pitch Dimensions / mm²**
Pagolux	Europe	Aluraster 5/33, K-Raster	600 x 600
			625 x 625
		Conturraster	600 x 600
			1200 x 1200
			625 x 625
			1250 x 1250
		C-Raster	1200 x 1200
			1250 x 1250
		C-Raster ST	967 x 967
		Aluminiumraster	625 x 625
Durlum	Europe	Etincell, Geocell, Quadra	600 x 600
			1200 x 600
			625 x 625
			1250 x 625
		Getincell	1200 x 600
			1250 x 625
		Getincell Line	600 x 600
			625 x 625
		Lumeo	1200 x 1200
			1400 x 1400
			1500 x 1500
Vesmetall	Europe	VES-K8	600 x 600
			700 x 700
			625 x 625
			1250 x 625
Pinta-Acoustic	Europe	Ceiling grid system	2 ft x 2 ft
			4 ft x 4 ft
		Contour tiles	2 ft x 2 ft
Colorado Ceilings	Europe	all	2 ft x 2 ft
			4 ft x 4 ft
Sinotile	China	Ceiling grid	595 x595
			603 x 603
			1200 x 600

Manufacturer	Origin	Product Name	Pitch Dimensions / mm²
Rondo	Australia	DUO	600 x 600
			1200 x 600
			1350 x 600
Rentex	Europe	Glaslichtdecke	900 x 900
			1100 x 1100
			1300 x 1300
			1400 x 1400

In Germany, around 1.2 million m² metal ceilings are sold each year and hence approximately 600,000 m² of 625 mm tiles.

Nonstandard geometrics, e.g. triangle formats, are produced upon request for particular projects and are therefore rarely accounted for in an overall consideration.

In view to future OLED design a first conclusion can be drawn that individual module dimensions should be established on the basis of the common ceiling format of the 600 mm square tile for implementation in office buildings and administration buildings. These individual OLED's would then also fit into the commonly implemented 625 mm tile. The recommended dimensions for the OLED are therefore square shape with pitch dimensions of either

600 mm x 600 mm, 300 mm x 300 mm or 150 mm x 150 mm. The single OLED tile should be a little smaller to reserve space for mechanical fixing.

Table 3.3: Annual Sales of some metal ceiling manufacturers in Central Europe

Manufacturer	Product / mm	Sales / m²/a	Comment
Armstrong	600		
	625	100k	
	Panel	150k	
Dampa	600	400k	
	625		
	Panel	100k	
Dipling	600		Panel ceiling tiles nearly all in 312x625 format
	625	40k	
	Panel	60k	
Dobner	600	Unusual	Panel ceiling tiles mostly 200's
	625	Common	
	Panel	5k	
Lindner	600	~ 1kk	International Market: Nearly all in 600x600
	625		
	Panel		
Richter	600	Mostly in Italy	

Manufacturer	Product / mm	Sales / m²/a	Comment
	625	Mostly in D, CH	
	Panel		
Suckow & Fischer	600	~ 1kk, mainly large panels	625 in Germany, 600 in rest of Europe
	625		
	Panel		
Fural	600	108k	
	625	12k	
	Panel	180k	

3.1.6 Tiling Architecture Requirements

3.1.6.1 Dimensions

In order to create a continuous surface area with OLEDs, where each “OLED tile” would have defined dimensions, it is necessary to be able to line these up together without joints. Due to their flatness, it would seem to be logical to select a simple geometric basic form with a defined aspect ratio.

From an aesthetic point of view, one of the previously mentioned harmonic, scale of proportions, aspect ratio and/or proportions, could desirably emerge.

Due to the industrialised building trade and its dominant additional scale of proportions, a basic module should be established which is based on the current valid standards and be varied, in order to enable a combination of multiple forms. Thus, the various spatial and technical requirements can be met with simple combination of components already available on the market. As an example, a square raster ceiling is given as it is implemented these days, above all, in office buildings and public buildings. The suspension systems are produced according to the Module standard DIN 18000 and/or DIN 4172 (German-speaking countries), as are the suitable tiles which could be replaced by OLED-surfaces.

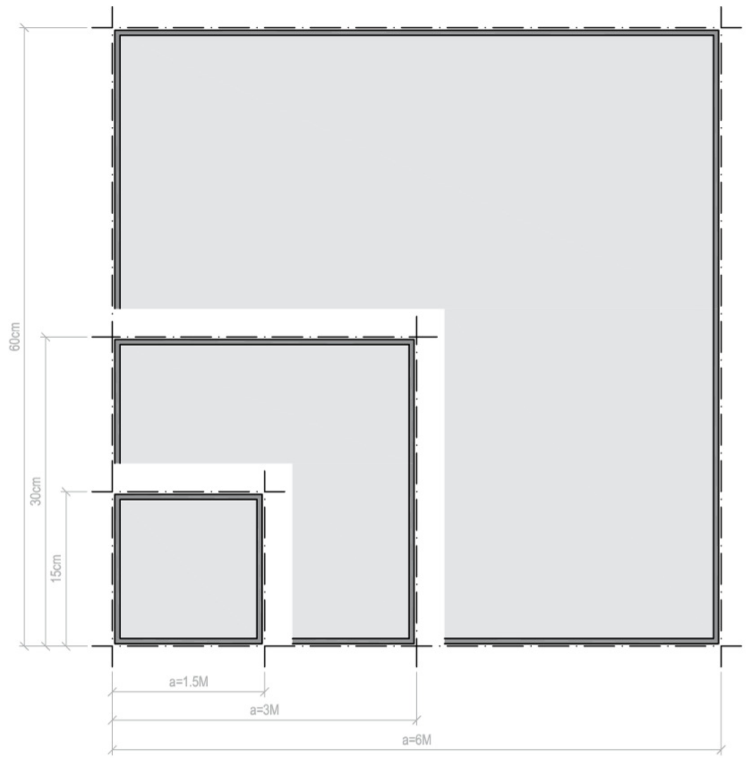


Fig. 3.8: Guidelines for OLED module pitches of 1.5M and multiples thereof

If one considers the components for interior fitting which are available on the market – one of the most important areas for implementation of the OLED – it can be deduced, that as a rule, the preferred axial dimensions of 3M, 6M and 12M would be produced.

The lateral lengths of the OLED-basic module should therefore be consistent with the smallest preferred dimension of 3M or a denominator thereof.

From these considerations and the current possibilities of technical realisation, a square basic module with an axial dimension of 1.5M = 15 cm represents the most sensible technical approach. Upscales with double and four times lateral dimensions are indicated in figure 3.8.

In order to be able to ensure the power supply to the module, a circumferential conductive band is necessary, which would be connected with the control gear. This conductor path would not itself illuminate, that means, the resulting illuminating surface is smaller than 15 cm x 15 cm. As an example, the width of the conductive frame is 0.5 cm and the gap between two OLED tiles which is needed for connection and mechanical fixture is 0.1 cm, the edge length of the light emitting surface would result in 13.8 cm.

For addition, surface dimensions are possible which are in accordance with the abovementioned preferred dimensions. Therefore, a surface layout according to the current valid standard DIN 18000 would be possible, which could cover the many standard applications.

The aim of further development should be, to be able to produce OLED modules, which feature axial dimensions of 3M, 6M, 12M etc, as for the addition of smaller modules, additional support materials or a support raster would be necessary. These dimensions all can be fitted into either 60 cm x 60 cm rasters or 62.5 cm x 62.5cm rasters as shown in figure 3.9.

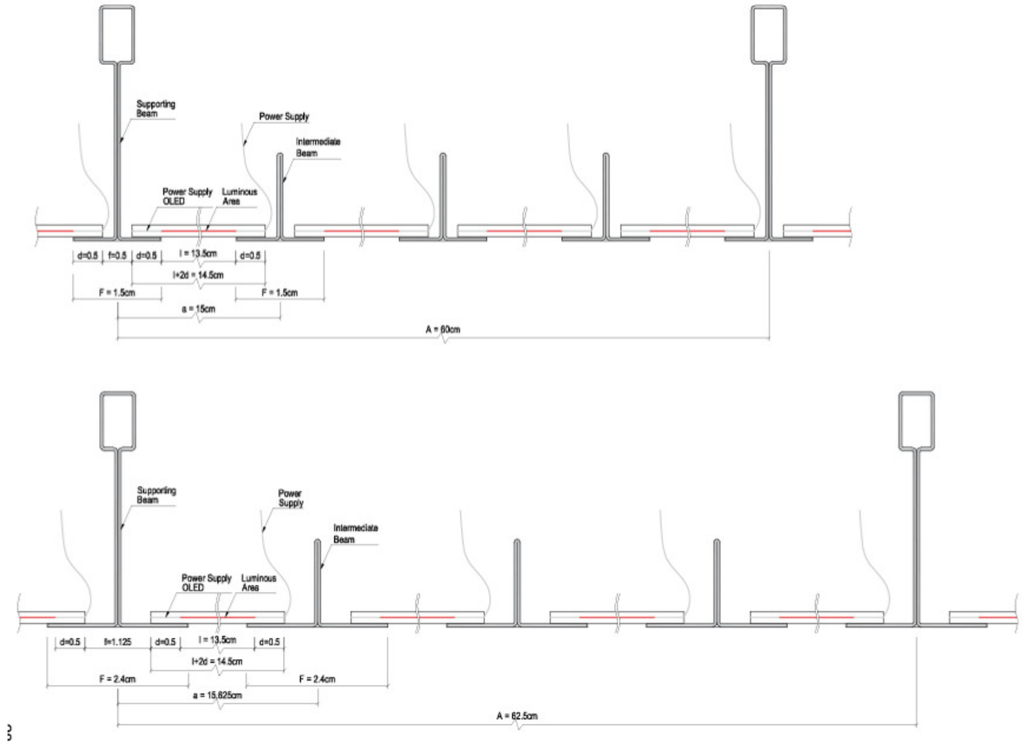


Fig. 3.9: 15 x 15 cm² OLED module fitted into 60 cm² pitches (top) and 62.5 cm² pitches (bottom)

3.1.6.2 Derivatives from Square Shape

The square OLED module can meet the requirements of many applications which form the basis of an orthogonal room. However, building is not restricted to the right angle. Thus, polygonal or organic based forms and dynamic height developments are being combined to complex spatial structures, which allow further basic forms of the OLED, in order to be integrated better into the architecture.

As, unlike common lighting systems, the OLED will become a part of the surrounding room surfaces and detaches itself from the luminaire, as a creative object which is additionally positioned in a room. It is luminaire and material in one. Its modular form creates a structure and therefore a characteristic appearance, which when used as a planar application can also have a considerable influence on the room even when it is switched off.

In order to increase creative freedom and to enable an optimum integration into the architecture, one can suggest further geometric basic forms (figure 3.10), which can be combined with each other.

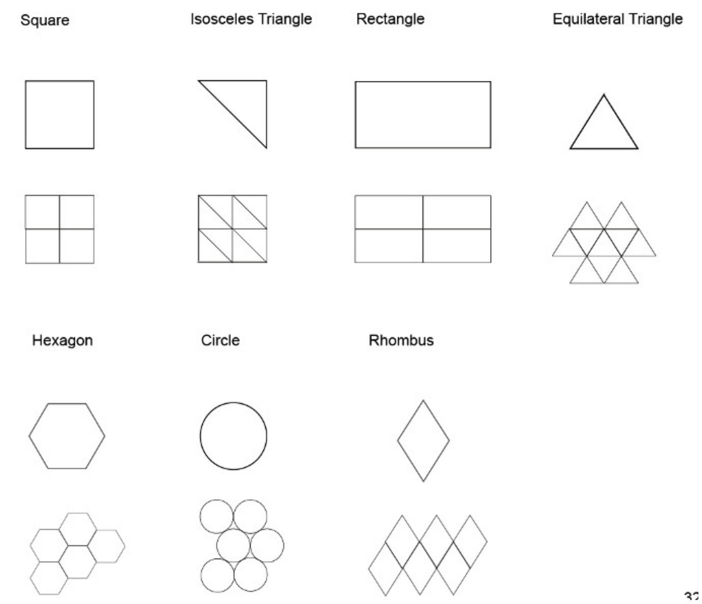


Fig. 3.10: Basic geometric shapes

3.1.7 Tiling Architecture

For determination of the dimensions of further module forms, a square basic module with edge lengths of 1.5M = 15 cm is taken, which will also be used to define the edge length of all other modules. From this, the deviations for every individual module shape can easily be concluded. The resulting cluster architectures are presented for some example shapes in figures 3.11 to 3.17.

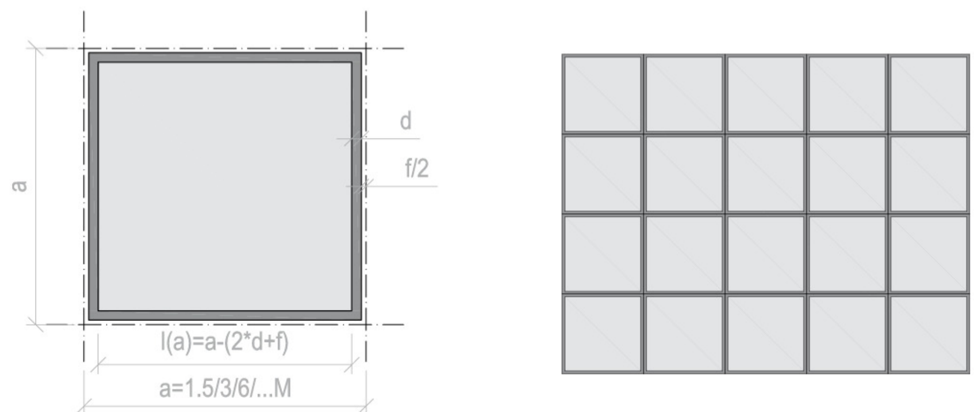


Fig. 3.11: Square tile clustering

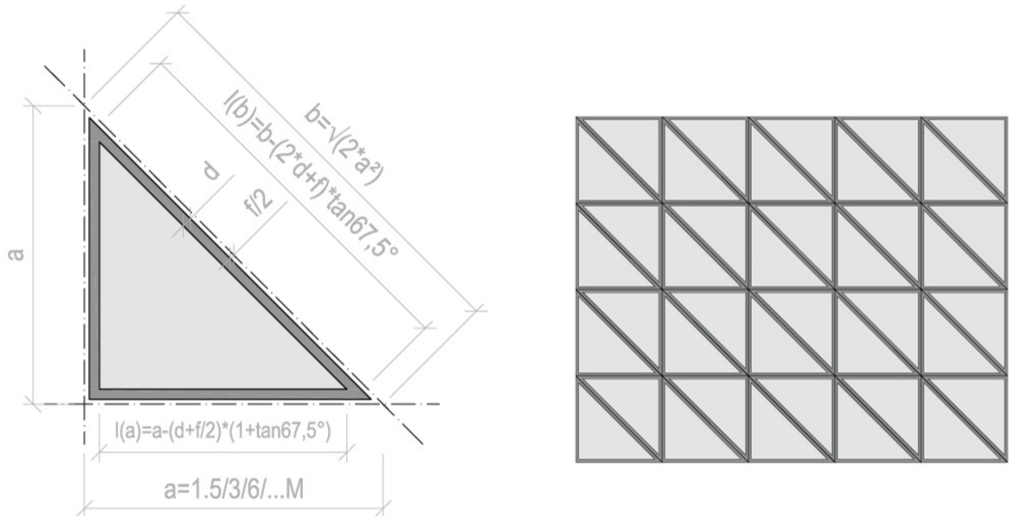


Fig. 3.12: Isosceles triangle tile clustering

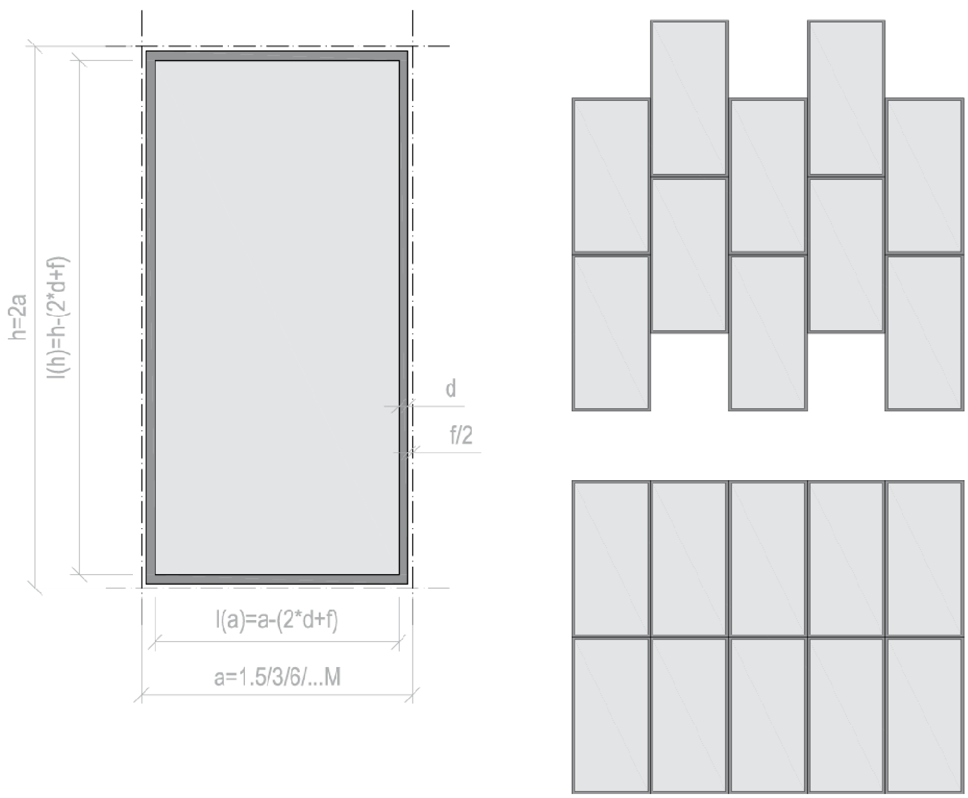


Fig. 3.13: Rectangle tile clustering

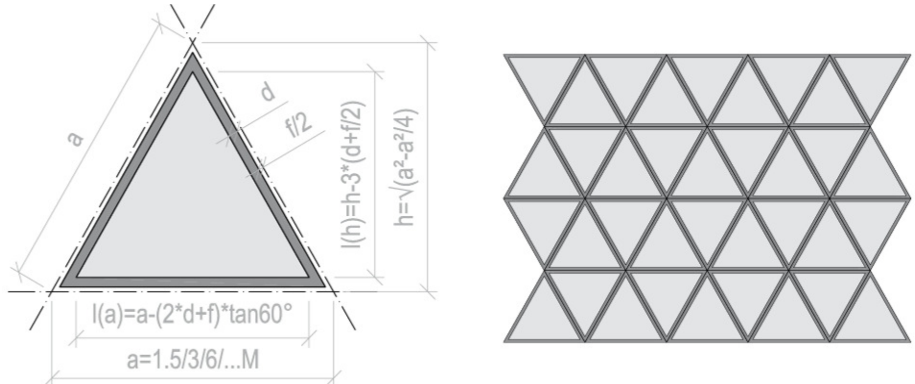


Fig. 3.14: Equilateral triangle tile clustering

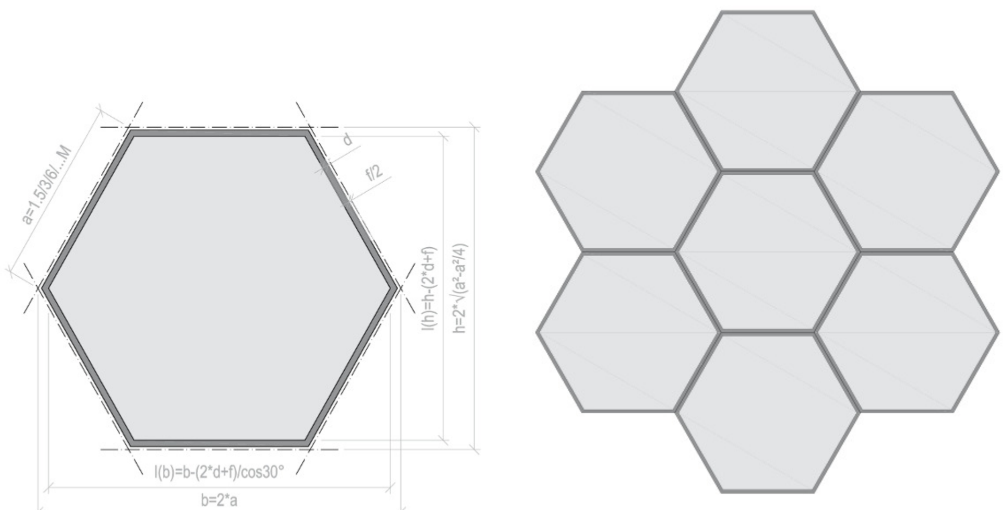


Fig. 3.15: Hexagon tile clustering

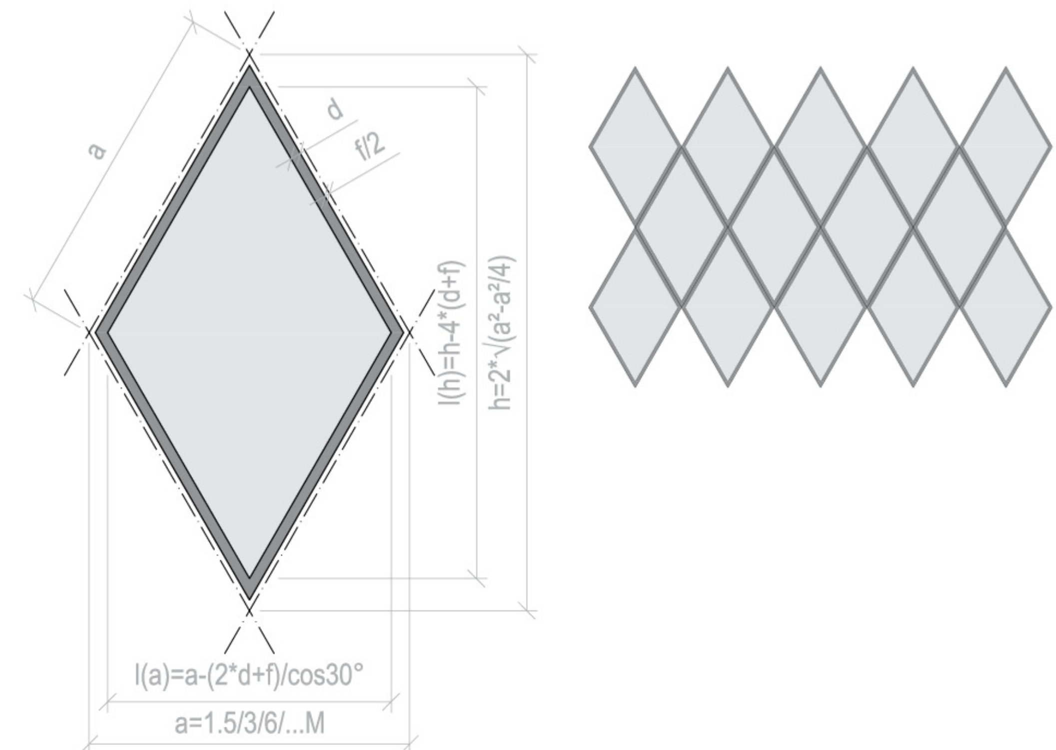


Fig. 3.16: Rhombus tile clustering

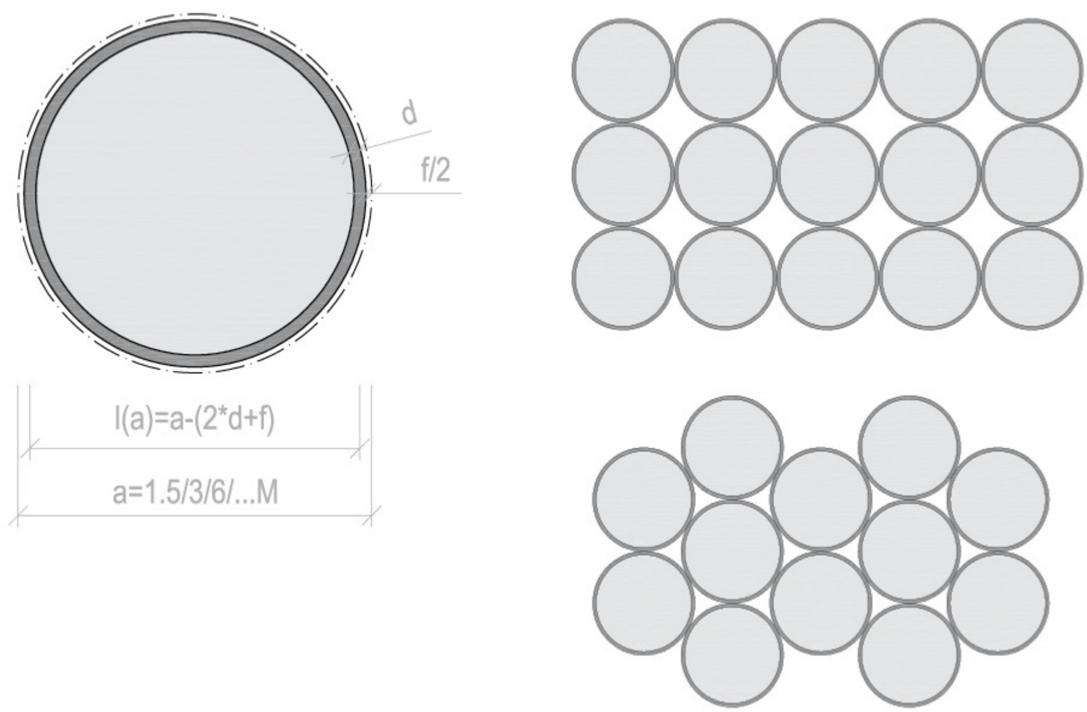


Fig. 3.17: Circular tile arrangement

The edge lengths of the individual modules are intentionally chosen as the same for all, in order to be able to combine the different module forms. The outcome is a multitude of different forms, together with simple forms up to complex structures and patterns which one can define as raster or decoration. Various arrangements of different shapes can be imagined. A quite common structure is presented in figure 3.18.

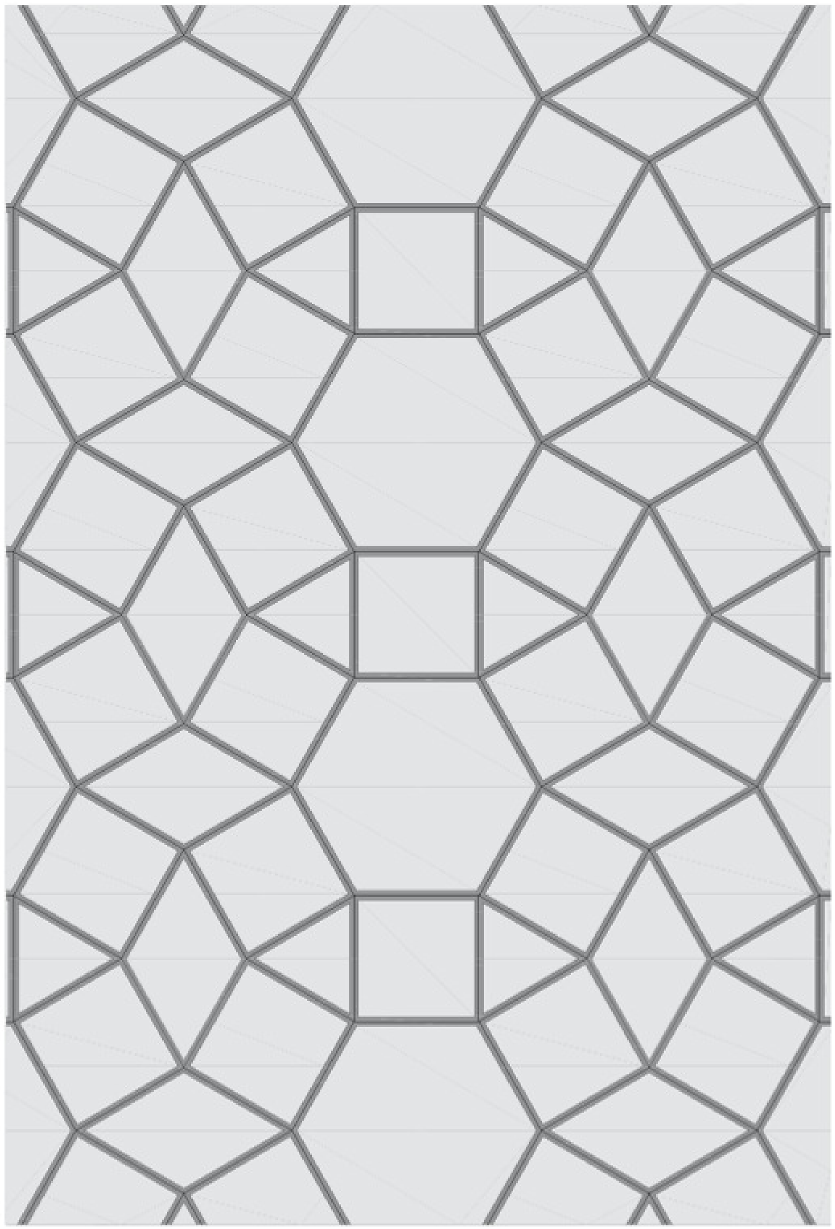


Fig. 3.18: Multi-shape tile clustering

3.2 Aesthetical Perception Case Study

3.2.1 General Description

As one can see from the previous chapter, there are a number of different possibilities for the geometric (tiling) of OLEDs. During the course of this study, it should be attempted to come to a general, valid conclusion with regard to “aesthetical appearance” and an evaluation or a sequence from “I don’t like it” to “I like it very much”, of different patterns. Basically, there is the possibility to evaluate different patterns consecutively, or to present several patterns at the same time. As this, to some extent, deals with very similar patterns and by comparison in a lesser quantity, a simultaneous presentation was chosen where several test persons could make an evaluation at the same time.

By evaluation of the proportions (tile size) of the OLED, it appears that a presentation in spatial surroundings is necessary, as no size evaluation without size comparison is possible. As the OLED is a light source, it would appear that an evaluation with the actual luminance is very important. In any case, luminance levels up to 1000 cd/m² should be investigated. These high luminance values can not be simulated on a computer screen and the resolution of a beamer is extremely restricted for fine structures. Due to this fact, it was decided to work with a model simulation in which it is possible to represent the spatial effect and the actual luminance. The compliance of previously simulated and subsequently actually implemented equipment is very convincing. Such photometric model simulations have been successfully carried out for decades at Bartenbach LichtLabor, with international architects and prominent clients.

In addition to the respective principal research questions, with 3 models (later referred to as Boxes 1 to 3) in each case with different OLED tiling variations, a further model with additional lighting components was tested. These components deliver directional light radiation and particularly increase the illuminance in a designated work area. The required illuminance for such a work table can be achieved with a lower ceiling luminance and the luminance distribution in the room is more uniform. Several studies have proven that this form of illumination can be advantageous in the areas of human performance and fatigue.

In this model (Box 4: Theoretical Luminance Model =TLM) it is therefore possible to adapt to the luminance in the room.

All illumination scenarios were carried out by using four scaled room models featuring either office or residential furniture. The scale (1 : 7.5) and placement of the four models allowed for simultaneous data collection with four test persons at one time.

The colour rendering should be more or less of a similar quality, and as with the case of the OLED spectrum and the light distribution, should radiate as widespread as possible. For these reasons, fluorescent lamps were used in the model simulations. The light distribution was adapted, using additional photometric components.

In the course of studies four different luminance levels and two different room setups were evaluated consecutively.

OLEDs can be applied at different places, e.g. on a ceiling or a wall, in an office or a corridor. Within each application, different luminance levels are needed. Therefore, four luminance levels were implemented in the room models.

- 100 cd/m² hereinafter referred to as “L1”
- 300 cd/m² hereinafter referred to as “L2”
- 1000 cd/m² hereinafter referred to as “L3”
- 0 – 2 cd/m² (off-state) hereinafter referred to as “L4” (see chapter 4)

The luminance level 100 cd/m² was chosen because it could be used for residential areas and corridors where it provides enough light for comfortable illumination, relaxation and orientation.

The medium luminance level 300 cd/m² delivers sufficient light for offices, when the whole ceiling will be replaced and equipped with OLED light tiles. The customarily required illuminance level of 500 lx for working areas can be achieved.

The higher luminance of 1000 cd/m² provides sufficient light for offices, even when just 30% of a usual office ceiling will be covered by OLED light tiles. This is also the development aim for "high" flux OLEDs in this project.

The illuminance on the centered table in Box 4 was the same as in the comparison models. Since it is mainly achieved by spot lights, and the resulting ceiling luminance was adjusted of 42 cd/m² for L1, 127 cd/m² for L2 and 420 cd/m² for L3, respectively. This corresponds to approximately 30 to 40% of the other models.

The figures 3.25 to 3.27 in the set-up description demonstrate the prevailing luminance levels. The photographs shown there are taken from the visual perspective of the test person (=TP). The position is chosen in order for the view of the ceiling from below could be evaluated.

3.2.2 Set-up

3.2.2.1 Parameter Variations

As described above the subjects had to perform their evaluation on a comparative basis. However, not all relevant parameters were presented at various levels. The matter of investigation in the architectural study was to test the acceptance of various tile sizes and tile arrangements. Thus, these parameters were presented in three different modifications next to each other. The 4th modification shown simultaneously presented one of the three scenarios illuminated under TLM conditions as explained above. However, since parameters like luminance and room equipment may influence the subjects' judgement, these parameters were altered as well. In all 4 model boxes the same luminance / illuminance and room equipment was shown at the same time. In the following the detailed variations are explained followed by the procedure and a comparative overview of all tested scenarios.

3.2.2.2 Scale Model

Construction of Scaled Room Model

The model rooms to be evaluated were equipped with OLED ceilings and were simulated by means of wooden models at a scale of 1 : 7.5. A box which was open at the front represented a neutral room and could, depending on the furnishings, be either an office or a living room. A light box attachment was situated above the room which was equipped with fluorescent lamps. The bottom of the light box was a large, white, diffuse area and by means of its diffuse radiation, simulates the OLED ceiling in the room. Underneath the plexiglass panel of the light box, a further mounting panel could be inserted. This mounting panel was equipped with a transparent film on which various patterns are printed, representing the different OLED tile shapes and sizes under investigation. The following layout and the cross-section (figures 3.19 und 3.20) display the model assembly and the drawing displays the room equipped as a living room.

Scale model: topview

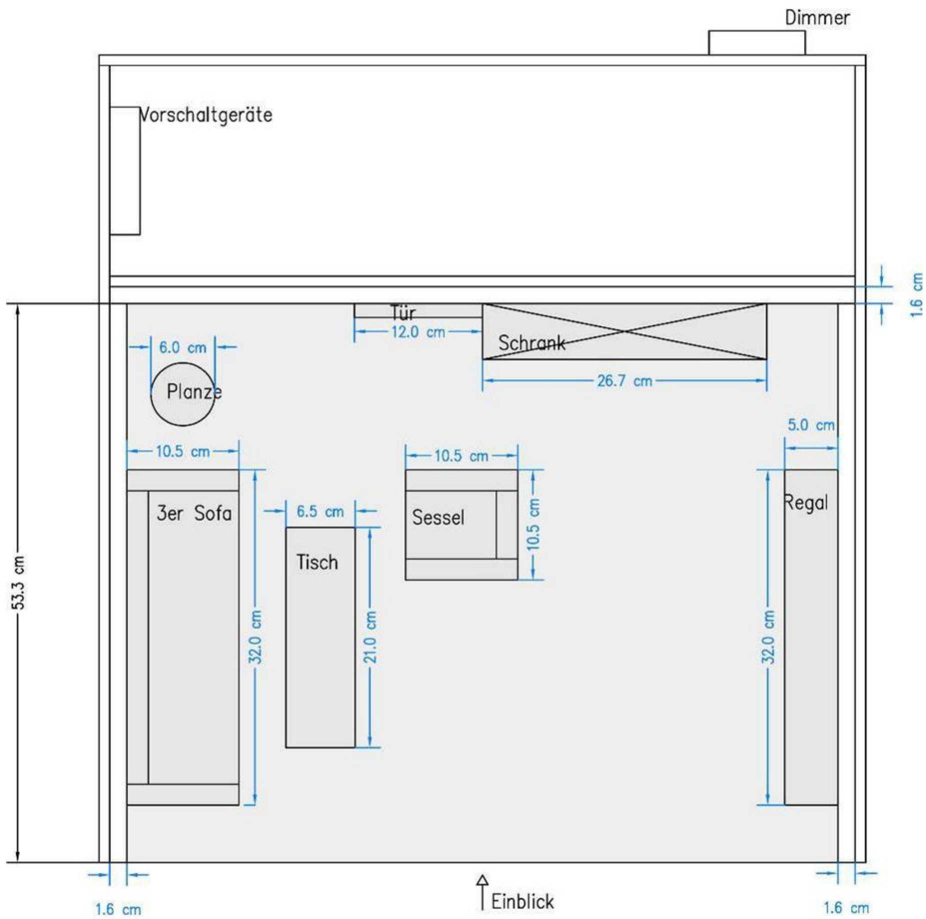


Fig. 3.19: Scaled room model top view (Dimmer = dimmer; Vorschaltgeräte = electronic control gear; Pflanze = plant; Tür = door; Schrank = wardrode; 3er Sofa = couch; Tisch = table; Sessel = chair; Regal = shelf; Einblick = subjects' view

Scale model: cross section 1

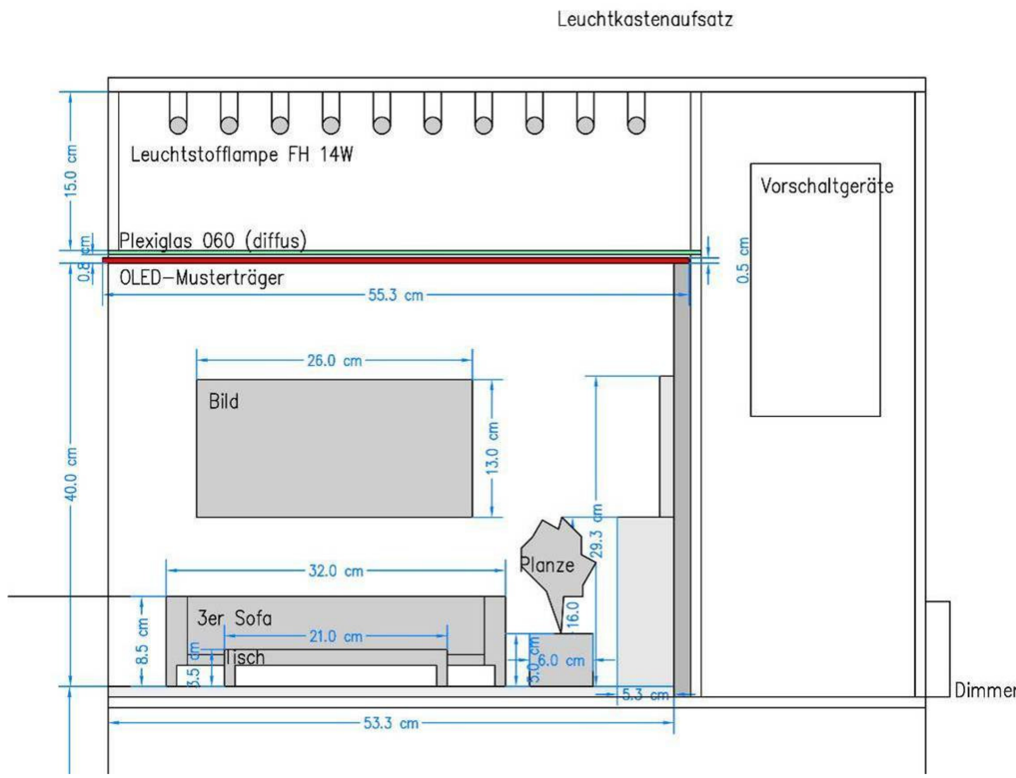


Fig. 3.20: Scaled room model cross section (Leuchtkastenaufsatz = light box; Leuchstofflampe = fluorescent lamp; Vorschaltgeräte = electronic control gear; Plexiglas 060 diffus = diffuse plexiglass ceiling; OLED Musterträger = transparent panel with OLED tile print; Bild = wall picture; Pflanze = plant; 3er Sofa = couch; Tisch = table

Foil Design

The following drawings depict the foil designs which were utilised for the simulation of the OLED ceiling. In figure 3.21 three different OLED pitches representing ceiling rasters of 60 cm x 60 cm, 30 cm x 30 cm and 15 cm x 15 cm are shown. The non-lighting gap between two tiles was set to 1 cm width (~ 1.35 mm in a scaled 1 : 7.5 model respectively).

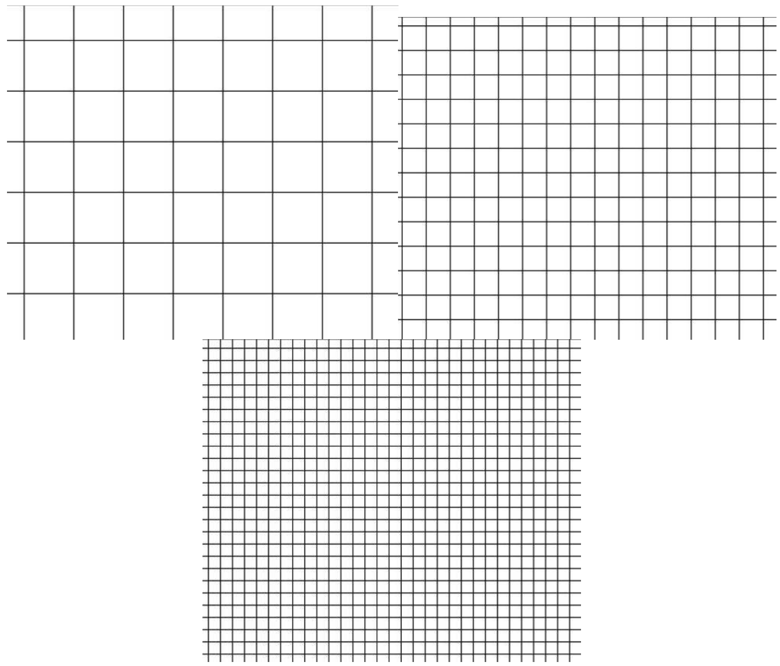


Fig. 3.21: Foil prints representing ceiling rasters of 60 x 60 cm² (left), 30 x 30 cm² (middle) and 15x15 cm² (right)

Figure 3.22 highlights three different OLED tile shapes and cluster arrangements based on an edge length of 15 cm. Besides mono-shape tilings like square and hexagon based pattern an ornamental tiling was realised composed out of squares and equilateral triangles. The non-lighting gap was kept same. Finally, it should be mentioned that the TLM model box was always equipped with 15 cm x 15 cm square tiles.

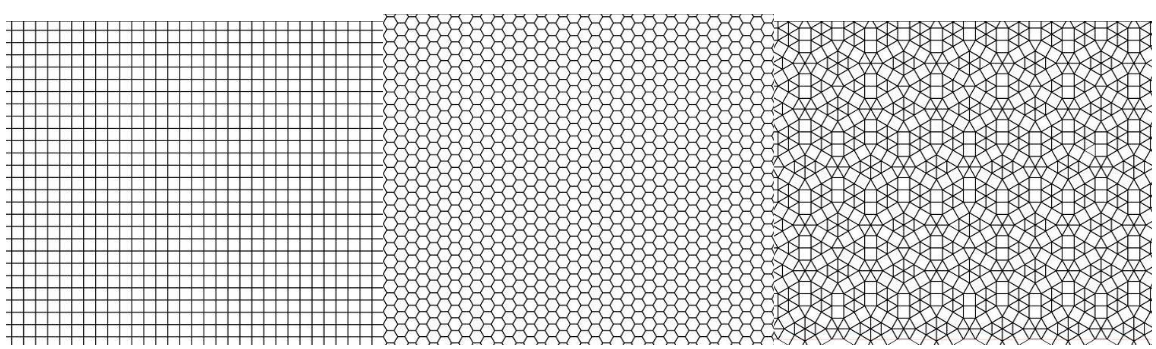


Fig. 3.22: Foil prints representing tiling architectures of square (left), hexagonal (middle) and ornamental (right) style

Room Types

In order to avoid interpretations and to achieve a neutral evaluation, both room types, the office and the living room, were retained in very plain and neutral colours and simple design. If the room were to be equipped with, for example, patterns or strong colors, this could influence the preference of a particular OLED tile size or form.

Both room types were equipped with a grey door and wooden cupboard on the back wall, a plant in the corner, and a set of flat shelves on the right wall. These elements remain fixed in the model. The walls were white and the floor was grey.

In order to change the room type, there were flexible elements which can be quickly exchanged. The office room (figure 3.23) has two tables with chairs which were situated in the middle of the room opposite each other.

The living room (figure 3.24) had a light brown couch which is situated against the left hand wall, together with a flat table and a chair which was located opposite to the couch.

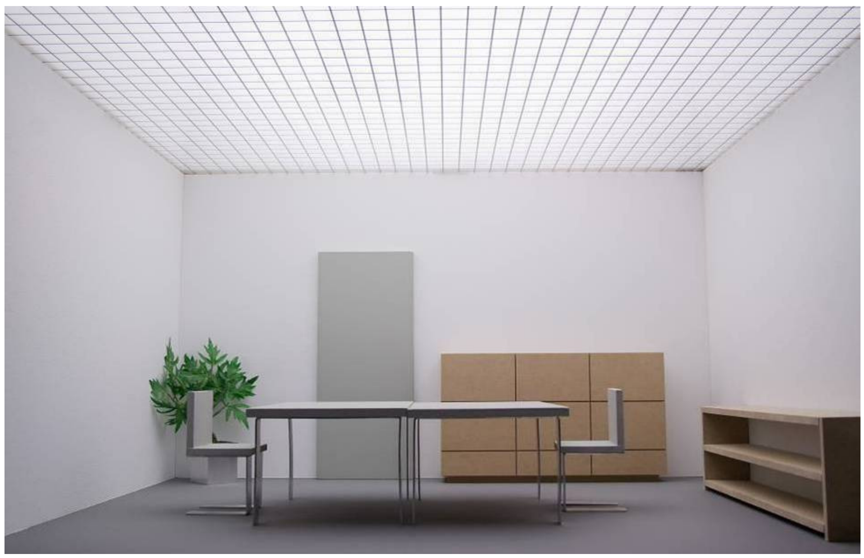


Fig. 3.23: Office room model with an OLED ceiling luminance of 300 cd/m², OLED tile size is 15 x 15 cm²

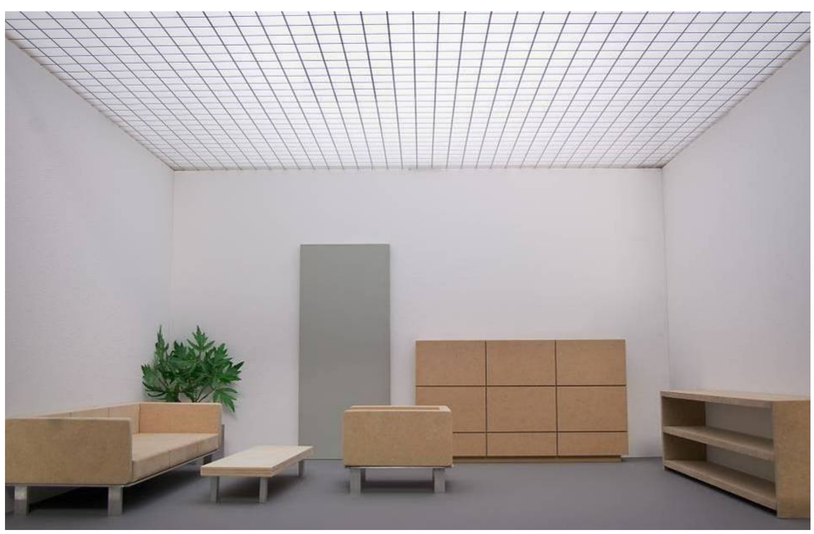


Fig. 3.24: Living room model with an OLED ceiling luminance of 300 cd/m², OLED tile size is 15 x 15 cm²

Lighting Situations

For documentation and adjustment purpose of the lighting situations some measurements were performed. The scenario shown in figure 3.24 above should serve as an example.

The same model was photographed again with an imaging luminance camera. Basically, this digital camera creates a picture similar to a black and white picture with many levels of grey in between, depending on the brightness. In order to facilitate readability of the levels of grey, similar grey-level values can be represented in colour. On a scale similar to a rainbow, one can directly read the measured luminance values.

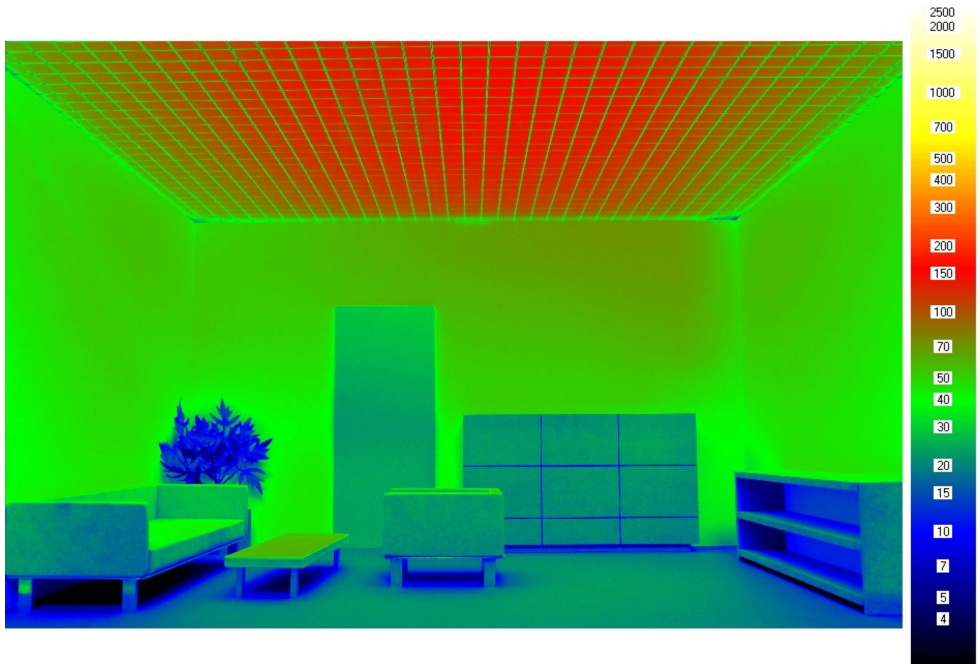


Fig. 3.25: Ceiling with an average luminance of 100 cd/m², colour coded luminance picture, the numbers on the scale are cd/m²

In figure 3.25 one can see that the ceiling is coloured red-greenish, thus having an average luminance of 100 cd/m². One can also identify that the brightness slightly decreases towards the edge. The reason is on the one hand, the multiple reflection of light in the room, and on the other hand, due to the implemented photometrics for the simulation of the OLEDs. In reality, the multiple reflection would have the same effect on the luminance of the OLED. The luminance was tuned that way, that the average luminance target was achieved after multiple reflections. In figure 3.26 one can see the false colour image at a measurement at 300 cd/m², and in figure 3.27 the false colour image at a measurement of 1000 cd/m2 is shown, respectively.

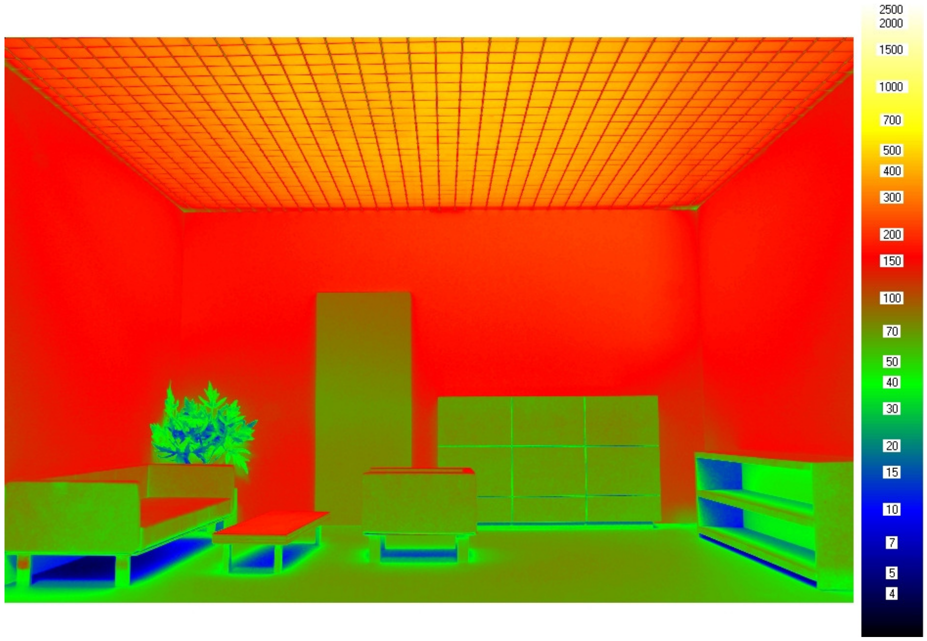


Fig. 3.26: Ceiling with an average luminance of 300 cd/m², colour coded luminance picture, the numbers on the scale are cd/m²

Fig. 3.27: Ceiling with an average luminance of 1000 cd/m², colour coded luminance picture, the numbers on the scale are cd/m²

3.2.2.3 Procedure

In all parts of the study, the test persons had to rank the aesthetic appearance of the 4 different scaled models (figure 3.28) starting from number 1, being the most preferred appearance, ranging to number 4, being the least preference. Equal rankings were not allowed.

Fig. 3.28: Four room models with different scenarios for comparative evaluation placed next to each other. In this case the colour temperature of light was altered which was subject of evaluation in another study. Details of this study are described in chapter 5.

All data was recorded by means of a questionnaire, which was completed by each test person. At the beginning of the test, personal details of the subjects were also noted, such as name, address, date of birth and gender and also whether they wore glasses or contact lenses. The study required a total of 1.5 to 2 hours, depending on how quickly the test persons reached their decision.

The ranking of preference took place as follows. The two test supervisors arranged the conditions on the model at random, while the test persons were seated facing the opposite direction. After alteration and naming of the (coded) condition, the test persons were instructed to stand up and move freely around the room looking into each model (compare to figure 3.29). Here, the entire interior of the model was to be taken into consideration, but the main attention was drawn to be given to the ceiling. After evaluation, the test persons sat down again with their back to the models, which was an indication to the test supervisor that the next condition could be adjusted. During the entire process, the test persons were not permitted to communicate with each other, to discuss the test or exchange results, or to make utterances, a noise, or to gesticulate.

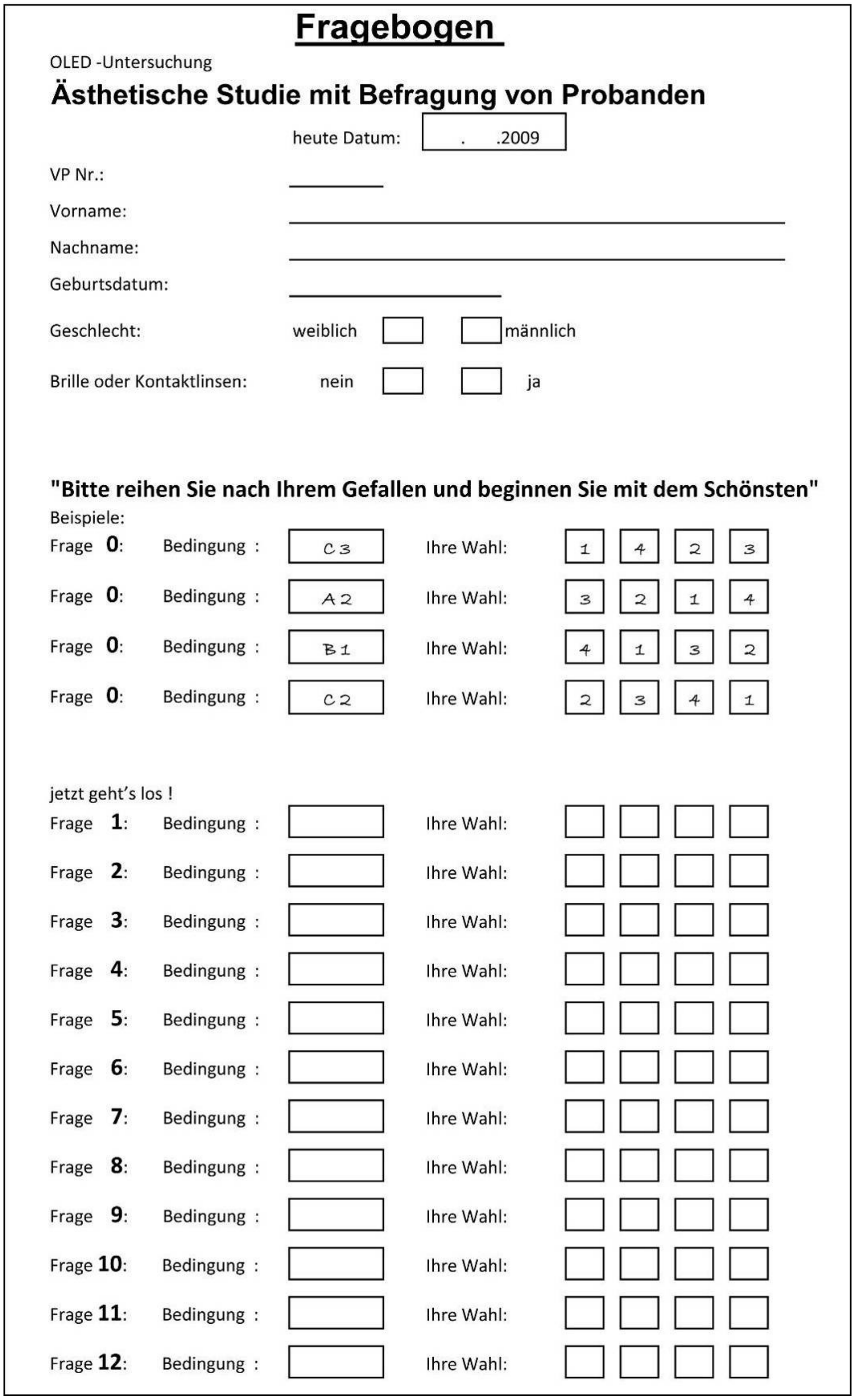
After the last questionnaire the subjects got paid EUR 40 for time and travel expenses. The study started 3 times a day at 10 am, at 1 pm and 4 pm and ran for 1.5 to 2 hours each.

Fig. 3.29: Model boxes 1 to 4 with test persons moving freely around and investigating the scenarios closely

Questionnaire

Each test person received the following questionnaire (figure 3.30) to complete the evaluation. The initial statement read as follows. „Please rank the scaled models starting from number 1, being the most preferred appearance.“

The test persons proceeded from question to question and made their choice. The number of the most preferred box was to be entered first and the number of the least preferred box to be entered last. At first, four examples were given for briefing purpose, before the real test started. This questionnaire was used for all questions and studies described also in the following chapters.


Fragebogen

OLED -Untersuchung

Ästhetische Studie mit Befragung von Probanden

heute Datum: . .2009

VP Nr.:

Vorname:

Nachname:

Geburtsdatum:

Geschlecht: weiblich ☐ ☐ männlich

Brille oder Kontaktlinsen: nein ☐ ☐ ja

"Bitte reihen Sie nach Ihrem Gefallen und beginnen Sie mit dem Schönsten"

Beispiele:

Frage **0**:	Bedingung : C3	Ihre Wahl:	1	4	2	3
Frage **0**:	Bedingung : A2	Ihre Wahl:	3	2	1	4
Frage **0**:	Bedingung : B1	Ihre Wahl:	4	1	3	2
Frage **0**:	Bedingung : C2	Ihre Wahl:	2	3	4	1

jetzt geht's los !

Frage **1**:	Bedingung :	Ihre Wahl:				
Frage **2**:	Bedingung :	Ihre Wahl:				
Frage **3**:	Bedingung :	Ihre Wahl:				
Frage **4**:	Bedingung :	Ihre Wahl:				
Frage **5**:	Bedingung :	Ihre Wahl:				
Frage **6**:	Bedingung :	Ihre Wahl:				
Frage **7**:	Bedingung :	Ihre Wahl:				
Frage **8**:	Bedingung :	Ihre Wahl:				
Frage **9**:	Bedingung :	Ihre Wahl:				
Frage **10**:	Bedingung :	Ihre Wahl:				
Frage **11**:	Bedingung :	Ihre Wahl:				
Frage **12**:	Bedingung :	Ihre Wahl:				

Fig. 3.30: Excerpt of the German questionnaire, the top area is asking for personal data including the use of watching aids like glasses or contact lenses. In bold letters follows the main question asking for the preference ranking ("Ihre Wahl"). At first, four examples are given. The subjects also had to fill in the lighting condition ("Bedingung") which was coded by the test supervisor. The order of scenarios was random. In total 32 evaluations were performed.

Tile Size Variation Series

All the scenarios were coded with letter code and summarised in series. In series A and E, three different square tile sizes were tested. In doing so, the first box had an OLED ceiling on which the tiles had a size of 60 cm x 60 cm, in the second box a size of 30 cm x 30 cm and in the third box a size of 15 cm x 15 cm. The same tile size was used in the fourth box, but exhibited the TLM lighting scenario. In all boxes, a color temperature of 4000 K prevailed.

In series A, the room type is office. The series E is equipped the same as the series A, but the room type is changed to residential. The non-lighting area between the OLED tile was designed in black colour (black square) in all cases. Figure 3.31 shows the variation for the case of series E (living room conditions) and table 3.4 gives a detailed overview on the variations.

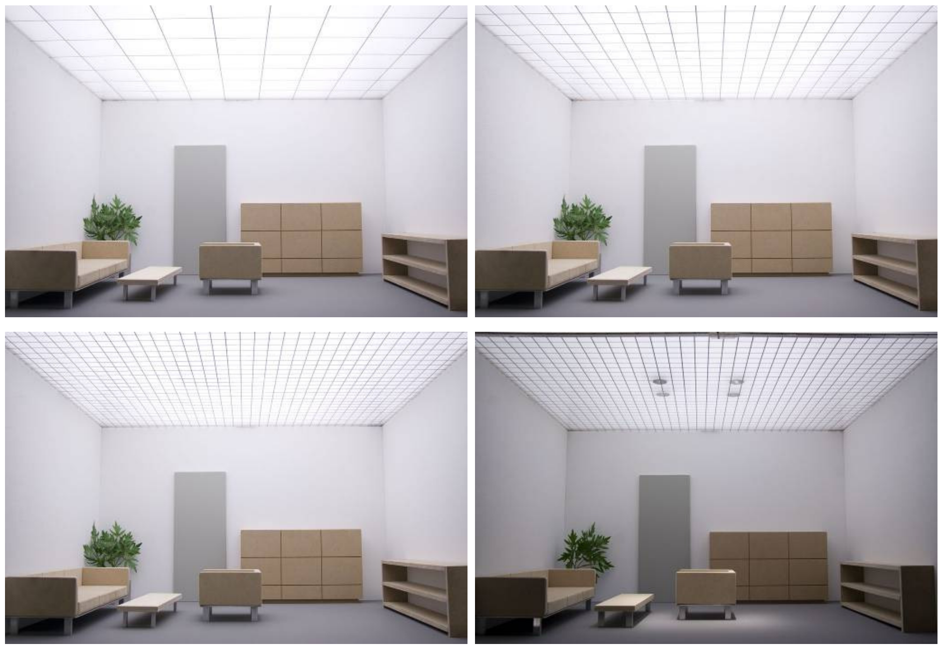


Fig. 3.31: Series E (living room) comparison; 60 x 60 cm² tiles (top left), 30 x 30 cm² tiles (top right), 15 x 15 cm² tiles (bottom left), 15 x 15 cm² tiles under TLM conditions (bottom right)

Table 3.4: Details of A and E test series with different tile sizes

A		Box 1	Box 2	Box 3	Box 4 / TLM
	Edge Length	60 cm	30 cm	15 cm	15 cm
	Tile Shape	Black Square	Black Square	Black Square	Black Square
	Color Temperature	4000 K	4000 K	4000 K	4000 K
	Room Type	Office	Office	Office	Office

E		Box 1	Box 2	Box 3	Box 4 / TLM
	Edge Length	60 cm	30 cm	15 cm	15 cm
	Tile Shape	Black Square	Black Square	Black Square	Black Square
	Color Temperature	4000 K	4000 K	4000 K	4000 K
	Room Type	Residential	Residential	Residential	Residential

Tile Shape Variation Series

In the series C and G, three different tile shapes were tested. In doing so, the first box had an OLED ceiling with squares. The second box had tiles with a hexagonal shape and the third box had tiles with an ornamental shape. The non-illuminating gap between the tiles is given in black in all three boxes. The fourth additional box was not equipped according to theoretical luminance model. In this case it was equipped with a square OLED ceiling having a white non-illuminating gap (white square). All tile shapes have an edge length of 15 cm and in all boxes a color temperature of 4000 K prevails.

In series C the room type is office. Series G is equipped the same as the series C, only the room type was changed to residential. Figure 3.32 shows the variation for the case of series C (office room conditions) and table 3.5 gives a detailed overview on the variations.

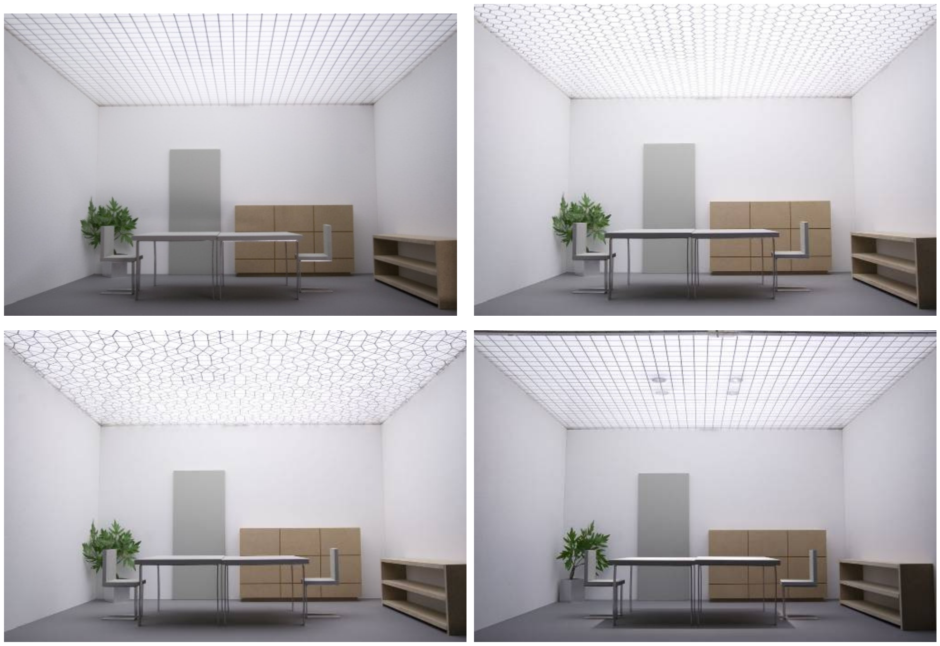


Fig. 3.32: Series C (office) comparison; square tiles (top left), hexagonal tiles (top right), ornamental tiles (bottom left), white gap square tiles (bottom right)

Table 3.5: Details of C and G test series with different tile sizes

C		Box 1	Box 2	Box 3	Box 4
	Edge Length	15 cm	15 cm	15 cm	15 cm
	Tile Shape	Black Square	Black Hexagon	Black Ornament	White Square
	Colour Temperature	4000 K	4000 K	4000 K	4000 K
	Room Type	Office	Office	Office	Office

G		Box 1	Box 2	Box 3	Box 4
	Tile Size	15 x 15 cm	15 x 15 cm	15 x 15 cm	15 x 15 cm
	Tile Shape	Black Square	Black Hexagon	Black Ornament	White Square
	Colour Temperature	4000 K	4000 K	4000 K	4000 K
	Room Type	Residential	Residential	Residential	Residential

3.2.3 Results

3.2.3.1 Description of Sample and Analysis Methods

Socio-demographic Data

All in all 61 test persons participated in the study. The average age of the test persons was 30 years (min: 19 years; max: 55 years).

The subjects originated from a ratified random selection. In doing so, special attention was paid to the fact that an equal number of women as men were included. Attention was also paid to the fact that different age groups were included in the random sample. Therefore, test persons were to be between the ages of 18 and 65 years old. Finally, with regard to professional background, two groups were to be represented in the test person collective, (people with professional knowledge of light, illumination and lighting design, and people without this professional background knowledge).

It must be mentioned, that all 61 test persons originated from the metropolitan area of Innsbruck (Austria) and all had German mother tongue.

The sample size was determined in such a manner, that all characteristics of interest sufficiently frequently occurred for subsequent statistical analyses (multiple group comparison and groups- of- two comparisons).

Due to the fact that several models were ranked in accordance with their aesthetic appearance, it is assumed that with an equal distribution of the ratings per model, the following calculations of the sample size can be carried out. If every model is potentially ranked at least ten times on the first, second, third etc. position, then, the comparison of 3, 4 or 5 models requires 3*10, 4*10 or 5 * 10 test persons (note: usually, non-parametric statistical tests are applied in investigations with a sample size of at least 10 test persons, although in exceptional cases – e.g. effect research of medicinal products – could be performed with fewer test persons). Overall, the sample size should be at least 50 test persons.

Description for Coding of Test Conditions

All test conditions were coded by means of letter-figure combinations. Within the tiling architecture study 1 the letters A and C were used when the scaled room models were equipped with office furniture, whereas conditions with residential furniture were signified with the letters E and G.

All of the above described conditions were varied in three luminance levels and coded from 1 to 3: “1” signifies 100 cd/m², “2” signifies 300 cd/m² and “3” signifies 1000 cd/m².

Data Analysis

Data analysis can be divided into the following parts:

a) Comparison of ratings within one series, subject to luminance levels and room setups

b) Comparisons of ratings with regard to gender, age and professional background

Data Analysis Methods

After the detection of significant differences in aesthetical preferences within a certain test series (derived by applying a Friedman-Test), the Bonferroni-corrected significance levels were calculated according to the number of models which were compared within these series [FRI1, FRI2, BON1].

Afterwards, some post-hoc analysis by applying Wilcoxon-Tests was done to find out, which pairs of models were significantly different in their rankings. Additionally, Mann-Whitney-U-tests were applied to determine gender-, age- and profession-specific differences within the rankings of each model in each series [WIL1, MAN1].

The significance level was fixed to 5%.

The flow-chart in figure 3.33 summarises all steps within the data analysis procedure.

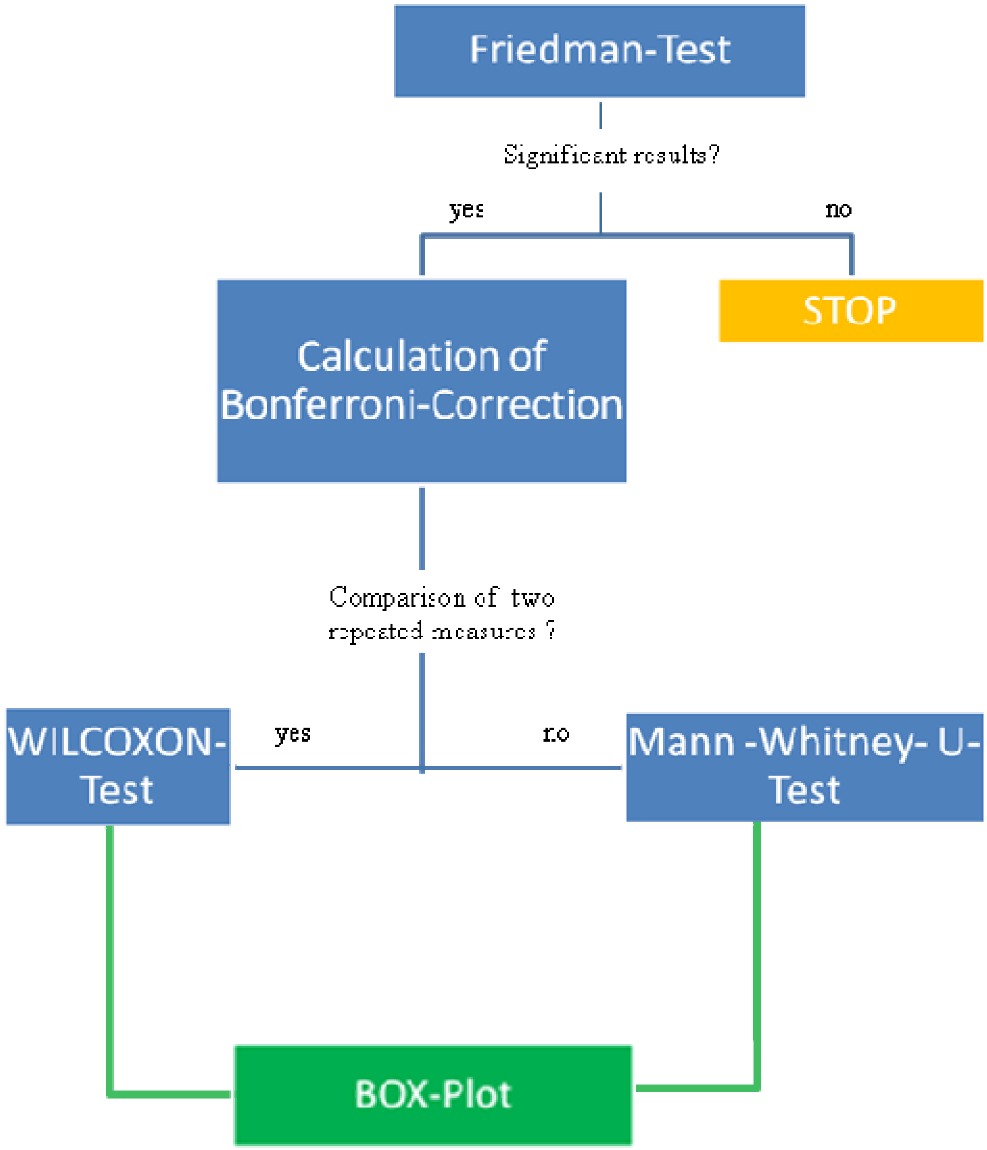


Fig. 3.33: Data analysis procedure

Below each of these tests or calculations are described in more detail.

a) The Friedman test [FRI1] is a non-parametric test for analysing randomised complete block designs. It is an extension of the sign test when there may be more than two treatments. The Friedman test assumes that there are *k* experimental treatments ($k \geq 2$). The observations are arranged in *b* blocks, that is

	Treatment			
Block	**1**	**2**	**...**	***k***
1	X_{11}	X_{12}	...	X_{1k}
2	X_{21}	X_{22}	...	X_{2k}
3	X_{31}	X_{32}	...	X_{3k}
...	...	...	...	...
b	X_{b1}	X_{b2}	...	X_{bk}

Let $R(X_{ij})$ be the rank assigned to X_{ij} within block i (i.e., ranks within a given row). Average ranks are used in the case of ties. The ranks are summed to obtain

$$R_j = \sum_{i-1}^{b} R(X_{ji})$$

Then the Friedman test is

H_0: The treatment effects have identical effects

H_a: At least one treatment is different from at least one other treatment

In the following T_1 is a well defined test statistic that indicates a significance or not [FRI2].

Test Statistic:

$$T_1 = \frac{12}{bk(k+1)} \sum_{i=1}^{k} (R_i - b(k+1)/2)^2$$

If there are ties, then

$$T_1 = \frac{(k-1) \sum_{i=1}^{k} (R_i - b(k+1)/2)^2}{A_1 - C_1}$$

where

$$A_1 = \sum_{i=1}^{b} \sum_{j=1}^{k} (R(X_{ij}))^2$$

and

$$C_1 = \frac{bk(k+1)^2}{4}$$

Note that Conover recommends a modified test statistic T_2

$$T_2 = \frac{(b-1)T_1}{b(k-1) - T_1}$$

since it has a more accurate approximate distribution [FRI2]. The T_2 statistic is the two-way analysis of variance statistic computed on the ranks $R(X_{ij})$.

The significance level α is fixed to 0.05 or 5 %.

Critical Region: $T_2 > F_{(\alpha,\ k-1,(b-1)(k-1))}$

where F is the percent point which can be found in the F distribution table

Conclusion: Reject the null hypothesis if the test statistic is in the critical region.

b) In statistics, the Bonferroni correction [BON1] states that if an experimenter is testing n dependent or independent hypotheses on a set of data, then one way of maintaining the familywise error rate is to test each individual hypothesis at a statistical significance level of 1/n times what it would be if only one hypothesis were tested. So if you want the significance level for the whole family of tests to be (at most) α, then the Bonferroni correction would be to test each of the individual tests at a significance level of (α/n). Statistically significant simply means that a given result is unlikely to have occurred by chance assuming your hypothesis is correct.

The Bonferroni correction is derived by observing Boole's inequality. If you perform n tests, each of them significant with probability β, then the probability that at least one of them comes out significant is (by Boole's inequality) ≤ n.β. Now we want this probability to equal α, the significance level for the entire series of tests. By solving for β, we get β = α/n. This result does not require that the tests be independent.

Due to our study, we can derive the following Bonferroni-corrected significance levels for higher numbers of comparisons:

Significance level	Number of Comparisons
$\alpha = 0,0167$	3
$\alpha = 0,0125$	4
$\alpha = 0,01$	5

c) The Wilcoxon signed-rank test [WIL1] is a non-parametric statistical hypothesis test for the case of two related samples or repeated measurements on a single sample. It can be used as an alternative to the paired Student's t-test when the population cannot be assumed to be normally distributed. The test is named for Frank Wilcoxon (1892–1965) who proposed both t- and the rank-sum test for two independent samples. The Wilcoxon test does not require assumptions about the form of the distribution of the measurements. It should therefore be used whenever the distributional assumptions that underlie the t-test cannot be satisfied.

d) In statistics, the Mann–Whitney U test [MAN1] (also called the Mann–Whitney–Wilcoxon (MWW), Wilcoxon rank-sum test, or Wilcoxon–Mann–Whitney test) is a non-parametric test for assessing whether two independent samples of observations come from the same distribution. It is one of the best-known non-parametric significance tests. It was proposed initially by Frank Wilcoxon in 1945, for equal sample sizes, and extended to arbitrary sample sizes and in other ways by H. B. Mann and Whitney (1947). MWW is virtually identical to performing an ordinary parametric two-sample t-test on the data after ranking over the combined samples. The Mann-Whitney U test assumes, that the two samples under investigation in the test are independent of each other and that the observations within each sample are independent and that the observations are comparable, i.e., for any 2 observations, one can assess whether they are equal or which one is greater.

e) Statistical significant results are depicted with box-plots as shown in figure 3.34.

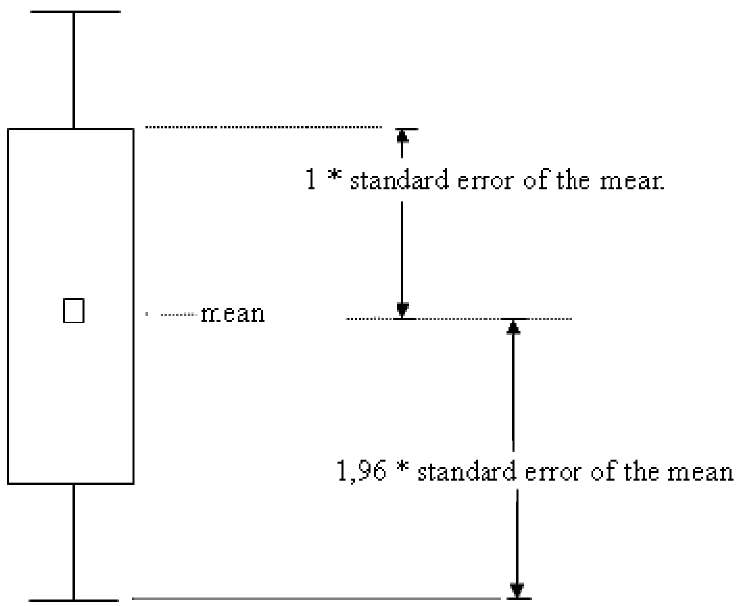


Fig. 3.34: Box plot

The standard error [WIK1] of a method of measurement or estimation is the standard deviation of the sampling distribution associated with the estimation method. The term may also be used to refer to an estimate of that standard deviation, derived from a particular sample used to compute the estimate.

For example, the sample mean is the usual estimator of a population mean. However, different samples drawn from that same population would in general have different values of the sample mean. The standard error of the mean (i.e., of using the sample mean as a method of estimating the population mean) is the standard deviation of those sample means over all possible samples (of a given size) drawn from the population. Secondarily, the standard error of the mean can refer to an estimate of that standard deviation, computed from the sample of data being analysed at the time.

The standard error of the mean (SEM) is the standard deviation of the sample mean estimate of a population mean. (It can also be viewed as the standard deviation of the error in the sample mean relative to the true mean, since the sample mean is an unbiased estimator.) SEM is usually estimated by the sample estimate of the population standard deviation (sample standard deviation) divided by the square root of the sample size (assuming statistical independence of the values in the sample):

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

where

s is the sample standard deviation (i.e., the sample based estimate of the standard deviation of the population), and

n is the size (number of observations) of the sample.

If the data are assumed to be normally distributed, quantiles of the normal distribution and the sample mean and standard error can be used to calculate approximate confidence intervals for the mean. The following expressions can be used to calculate the upper and lower 95% confidence limits, where $\bar{x}$ is equal to the sample mean, S_E is equal to the standard error for the sample mean, and 1.96 is the .975 quantile of the normal distribution:

Upper 95% Limit = $\bar{x} + (S_E \cdot 1.96)$,

Lower 95% Limit = $\bar{x} - (S_E \cdot 1.96)$.

For a better understanding, two graphs should explain this in detail exemplarily.

Figure 3.35 shows the mean ranks and their variations of the four models within condition A1 (office area with a mean ceiling luminance of 100 cd/m², 4000 K colour temperature of the light source and quadratic tile shape) by the aid of four boxes, which are outlined on the x-axis.

As a consequence of comparing four models, a ranking of the models stresses the usage of four integers, starting from 1, which represents the most preferred, and ending with 4, which represents the least preferred model. The mean rank of each model is shown on the y-axis.

Additionally, all significant differences between these models are shown, which can be interpreted in the following way: Box 1 and Box 2 are significantly more preferred than Box 3. Compared to the other models, Box 3 is the least favoured. Significant differences are indicated by the use of brackets.

Basically, the box-plots in figure 3.35 were derived from the frequency distributions of the four models' ranks as shown in figure 3.36.

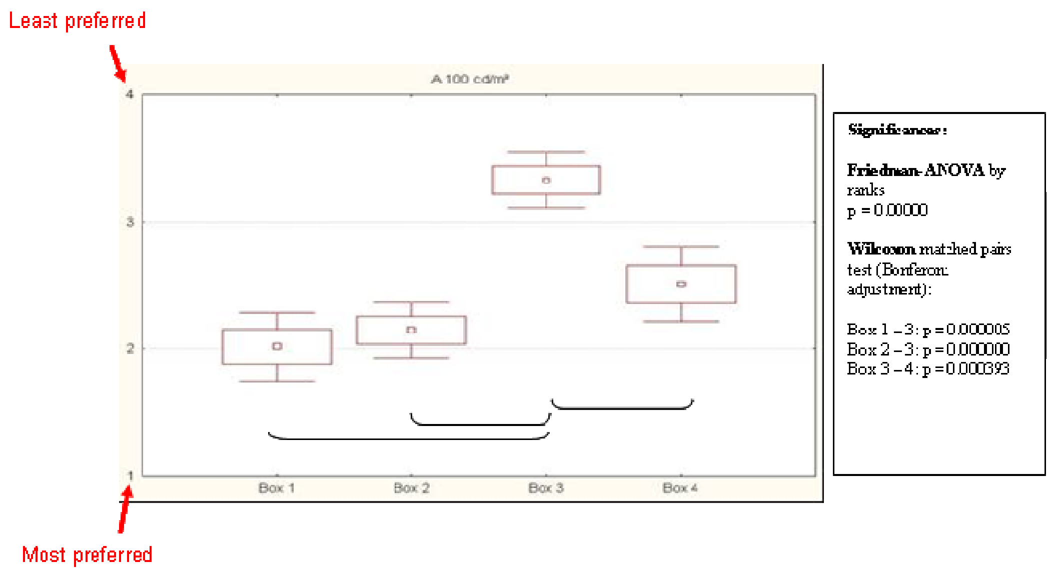


Fig. 3.35: Box plots of the four models ranked in condition A1, significant differences are indicated by the brackets, i.e. Model 3 is significantly ranked lower than Models 1, 2 and 4. Between Model 1, 2 and 4 there is no significant difference.

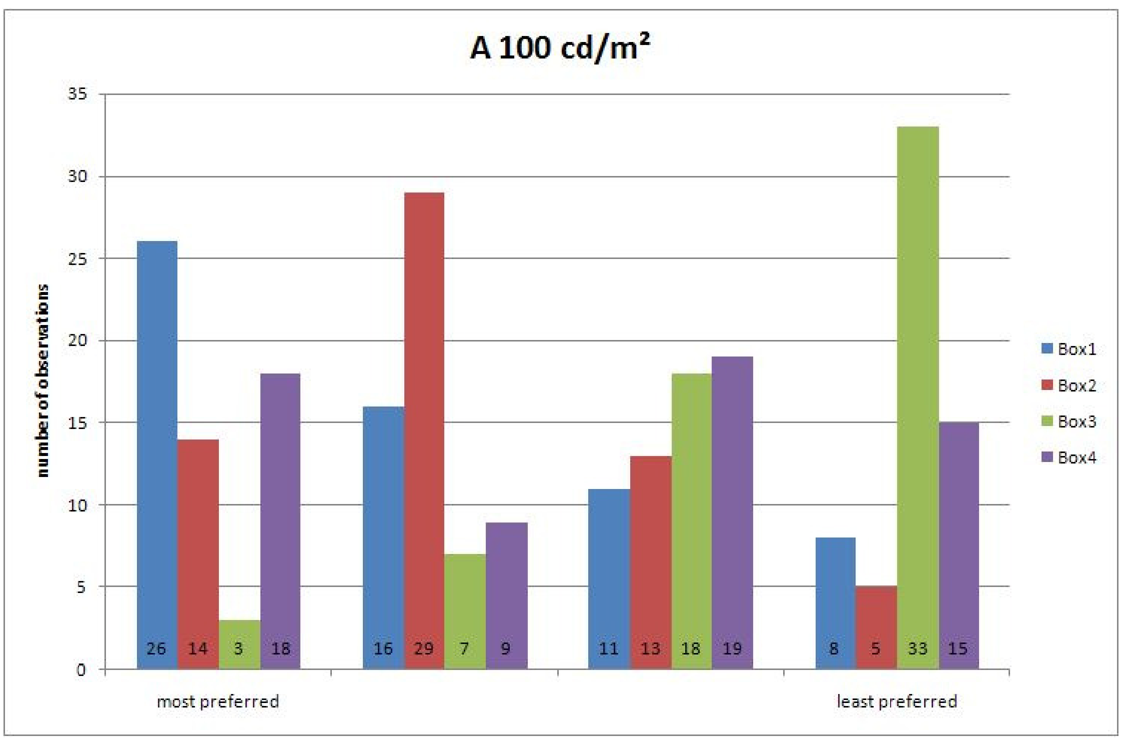


Fig. 3.36: Frequency distributions or single ranks occurred under scenario A1

3.2.3.2 Results Tile Sizes

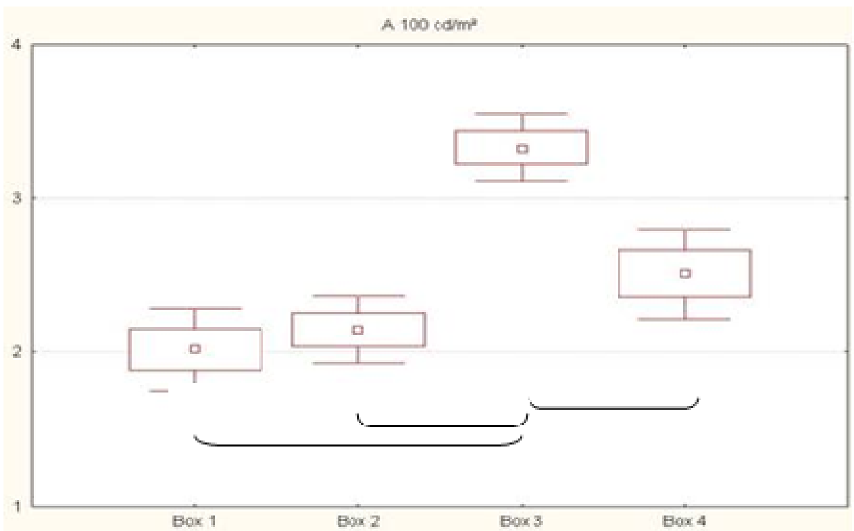
Series A

Within series A the following application context was evaluated:

- office area
- colour temperature of the lighting system: 4000 K
- tile shape: square
- three different tile sizes.

It could be shown, that the most preferred tile size for working areas was 30 cm x 30 cm and 60 cm x 60 cm independent of the ceiling luminance level. Small-scale tiling receives a negative evaluation even if the luminance distribution is balanced (by means of TLM).

Figures 3.37 to 3.39 represent the results of the statistical analysis.



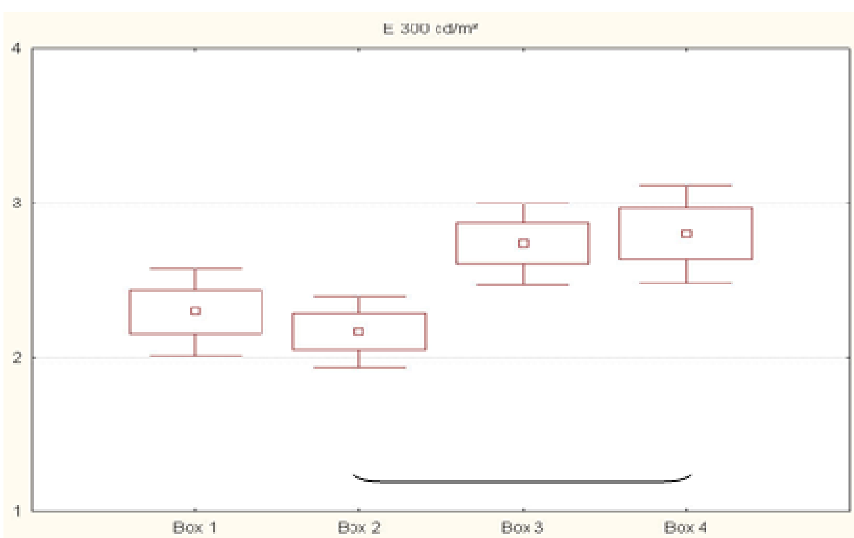
Significances:

Friedman-ANOVA by ranks
$p = 0.00000$

Wilcoxon matched pairs test (Bonferoni adjustment):

Box 1 – 3: $p = 0.000005$
Box 2 – 3: $p = 0.000000$
Box 3 – 4: $p = 0.000693$

Fig. 3.37: Results of tile size study, condition A1 (100 cd/m²); Box 1 denotes large tiles, Box 2 denotes medium tiles, Box 3 denotes small tiles, Box 4 denotes small tiles under TLM condition



Significances:

Friedman-ANOVA by ranks
$p = 0.00299$

Wilcoxon matched pairs test (Bonferoni adjustment):

Box 2 – 4: $p = 0.000649$

Fig. 3.38: Results of tile size study, condition A2 (200 cd/m²); Box 1 denotes large tiles, Box 2 denotes medium tiles, Box 3 denotes small tiles, Box 4 denotes small tiles under TLM condition

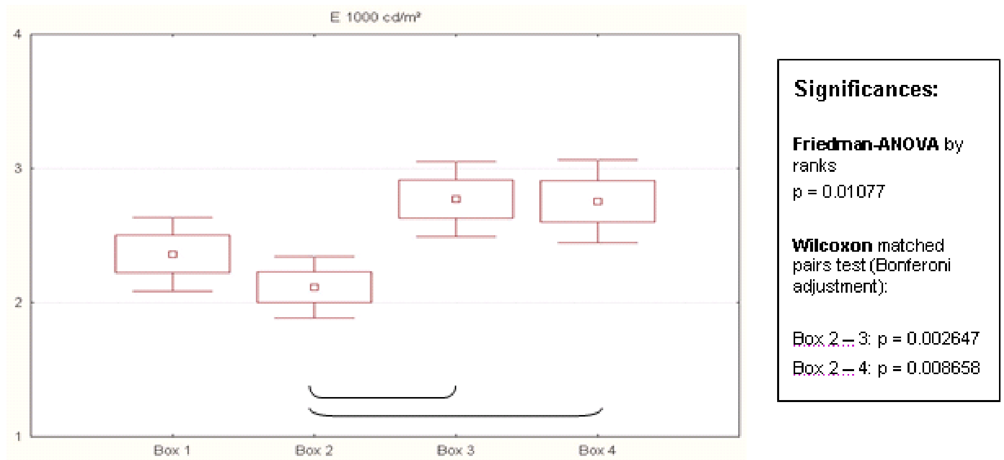


Fig. 3.39: Results of tile size study, condition A3 (1000 cd/m²); Box 1 denotes large tiles, Box 2 denotes medium tiles, Box 3 denotes small tiles, Box 4 denotes small tiles under TLM condition

Series E

Within series E the following application context was evaluated:

- residential area
- colour temperature of the lighting system: 4000 K
- tile shape: square
- three different tile sizes.

Statistical tests revealed no significant differences in aesthetical preferences of tile sizes with a ceiling luminance level of 100 cd/m². Higher ceiling luminance levels (300 cd/m² and 1000 cd/m²) implied a clear preference of 30 cm x 30 cm tile sizes within residential areas.

Figures 3.40 to 3.42 represent the results of the statistical analysis.

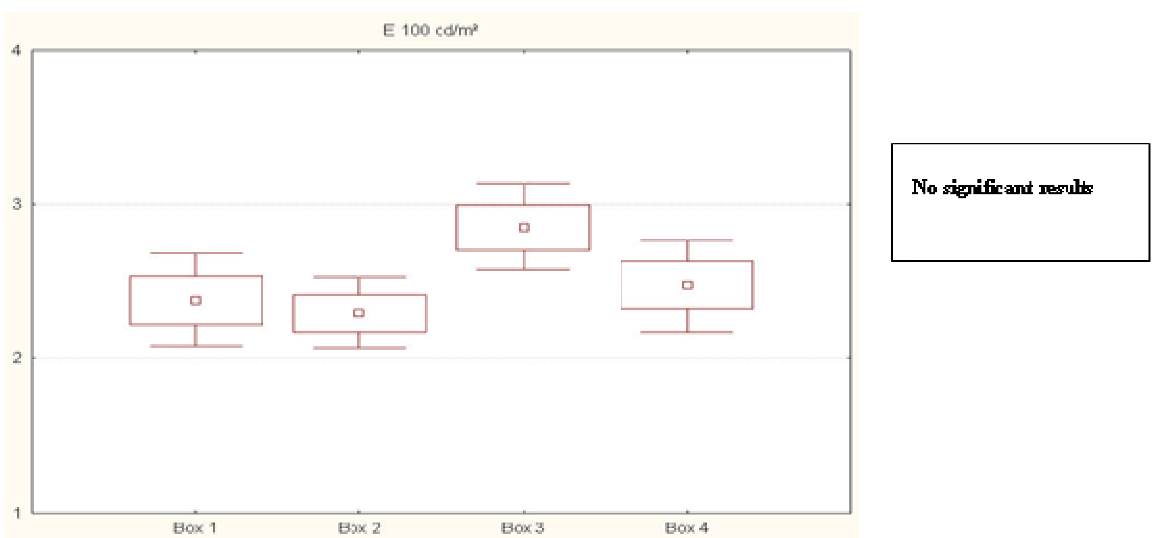


Fig. 3.40: Results of tile size study, condition E1 (100 cd/m²); Box 1 denotes large tiles, Box 2 denotes medium tiles, Box 3 denotes small tiles, Box 4 denotes small tiles under TLM condition

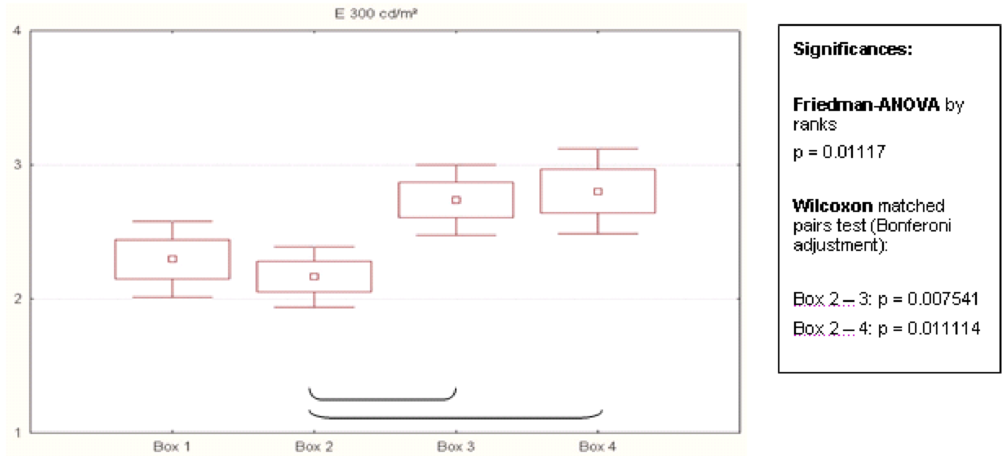


Fig. 3.41: Results of tile size study, condition E2 (300 cd/m²); Box 1 denotes large tiles, Box 2 denotes medium tiles, Box 3 denotes small tiles, Box 4 denotes small tiles under TLM condition

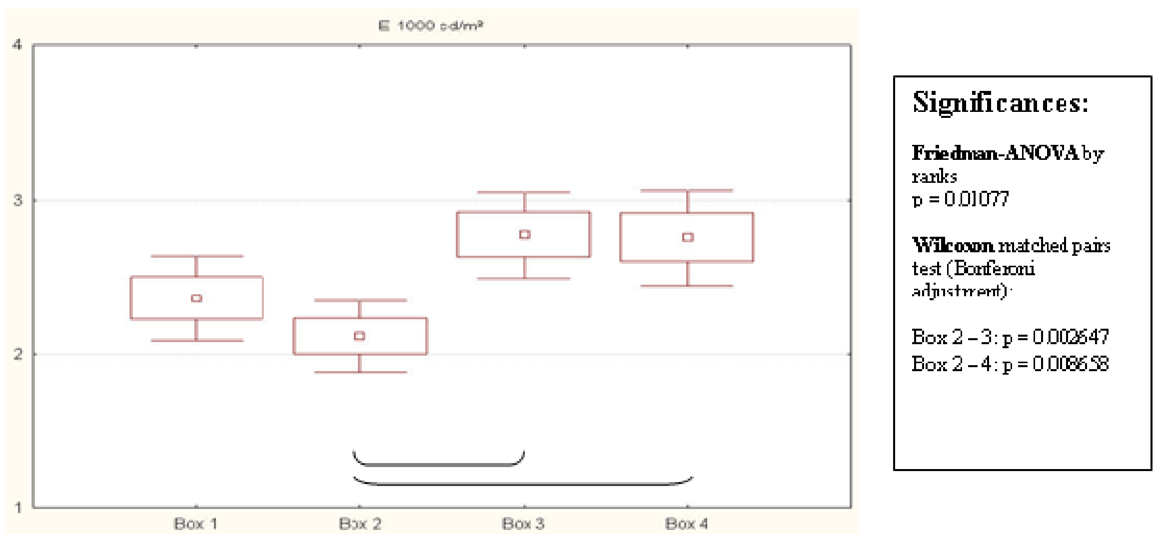


Fig. 3.42: Results of tile size study, condition E3 (1000 cd/m²); Box 1 denotes large tiles, Box 2 denotes medium tiles, Box 3 denotes small tiles, Box 4 denotes small tiles under TLM condition

3.2.3.3 Results Tile Shapes

Series C:

Within series C the following application context was evaluated:

- office area
- colour temperature of the lighting system: 4000 K
- edge length of tiles: 15 cm
- three different tile shapes, one of them with white non-lighting gap

Lower luminance level (100 cd/m²) of the ceiling caused an aesthetical preference of squared tile shapes. Hexagonal and ornamental tile shapes were clearly refused.

On the contrary, higher luminance levels wiped out these differences. Thus it can be assumed, that at higher luminance levels differences in the aesthetical preferences of different tile shapes disappear. Potentially, at such high luminances brightness was more integrated in aesthetic evaluation rather than the tiling shape.

Figures 3.43 to 3.45 represent the results of the statistical analysis.

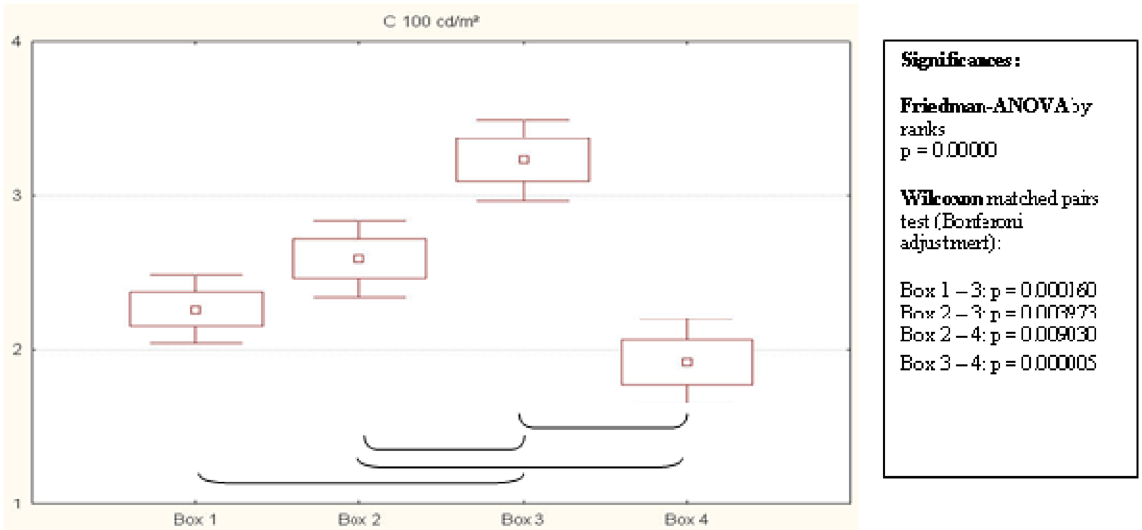


Fig. 3.43: Results of tile shape study, condition C1 (100 cd/m²); Box 1 denotes square tiles, Box 2 denotes hexagon tiles, Box 3 denotes ornamental tiles, Box 4 denotes square tiles with white non-lighting gaps

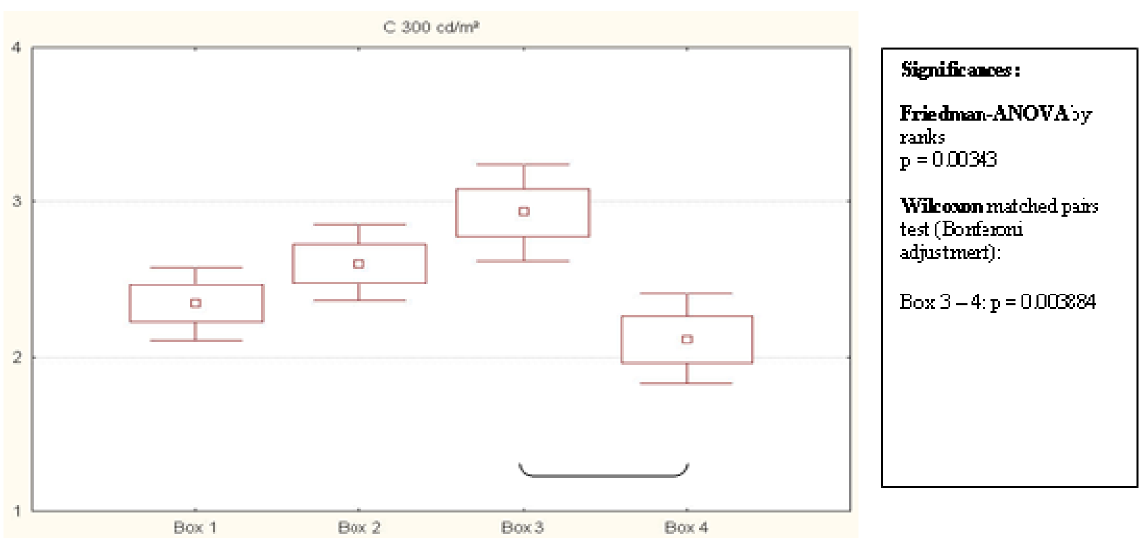
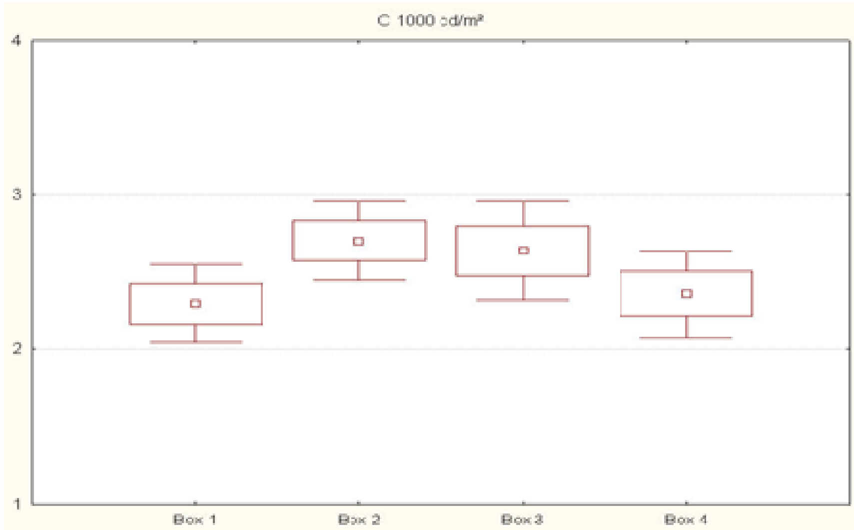


Fig. 3.44: Results of tile shape study, condition C2 (300 cd/m²); Box 1 denotes square tiles, Box 2 denotes hexagon tiles, Box 3 denotes ornamental tiles, Box 4 denotes square tiles with white non-lighting gaps



No significant results

Fig. 3.45: Results of tile shape study, condition C3 (1000 cd/m²); Box 1 denotes square tiles, Box 2 denotes hexagon tiles, Box 3 denotes ornamental tiles, Box 4 denotes square tiles with white non-lighting gaps

Series G:

Within series G the following application context was evaluated:

- residential area
- colour temperature of the lighting system: 4000 K
- edge length of tiles: 15 cm
- three different tile shapes, one of them with white non-lighting gap

Surprisingly, in residential areas no significant differences in aesthetical preferences could be revealed due to different tile shapes. This statement is valid for all three luminance levels (100 cd/m², 300 cd/m³ and 1000 cd/m²).

Probably within this application area the room periphery is considered as decorative element and may attract attention. Like wallpapers, clearly visible ornamentation is well accepted.

Figures 3.46 to 3.48 represent the results of the statistical analysis.

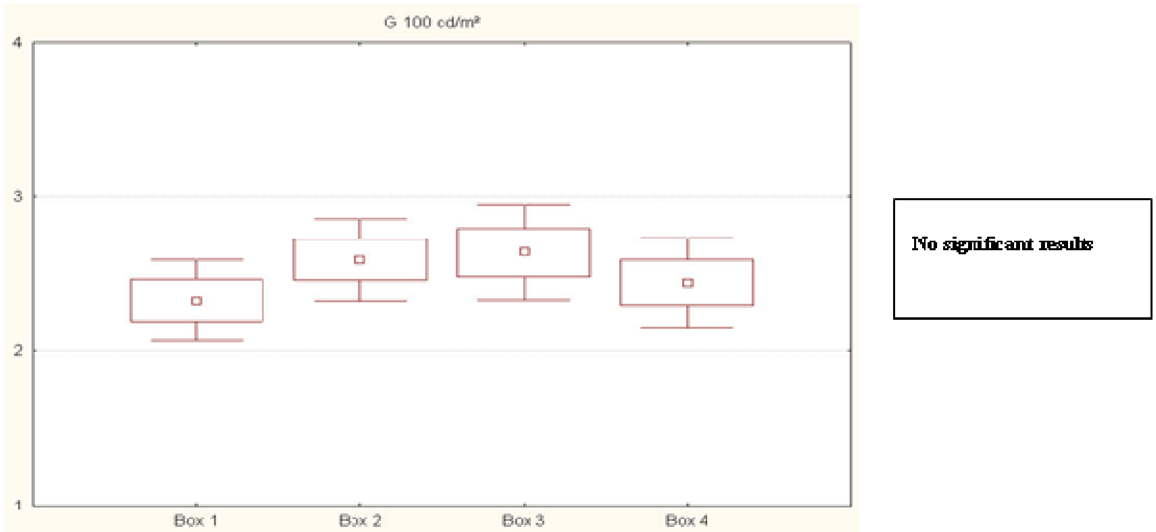


Fig. 3.46: Results of tile shape study, condition G1 (100 cd/m²); Box 1 denotes square tiles, Box 2 denotes hexagon tiles, Box 3 denotes ornamental tiles, Box 4 denotes square tiles with white non-lighting gaps

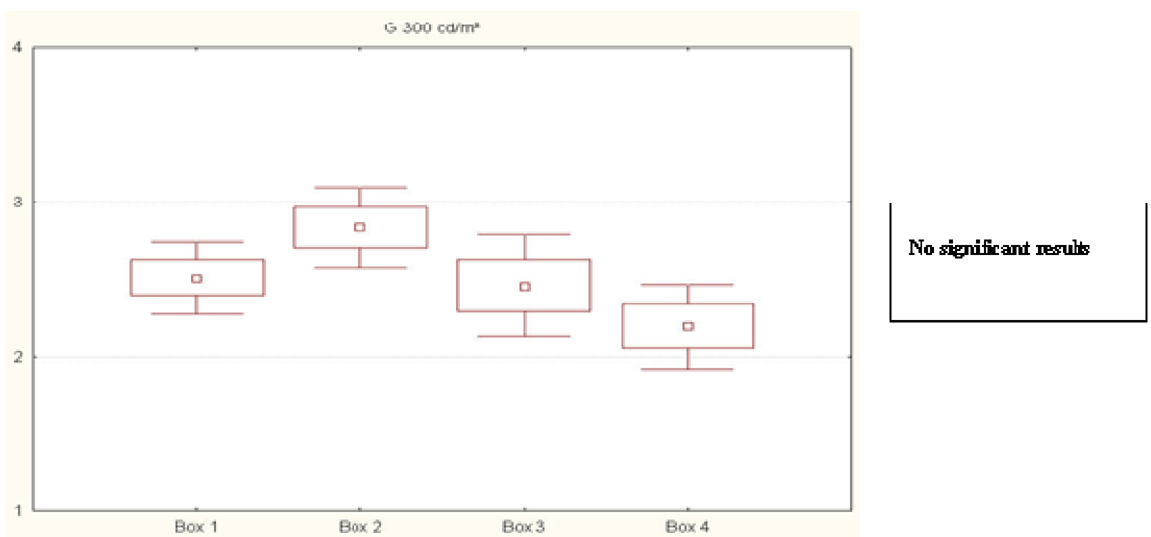
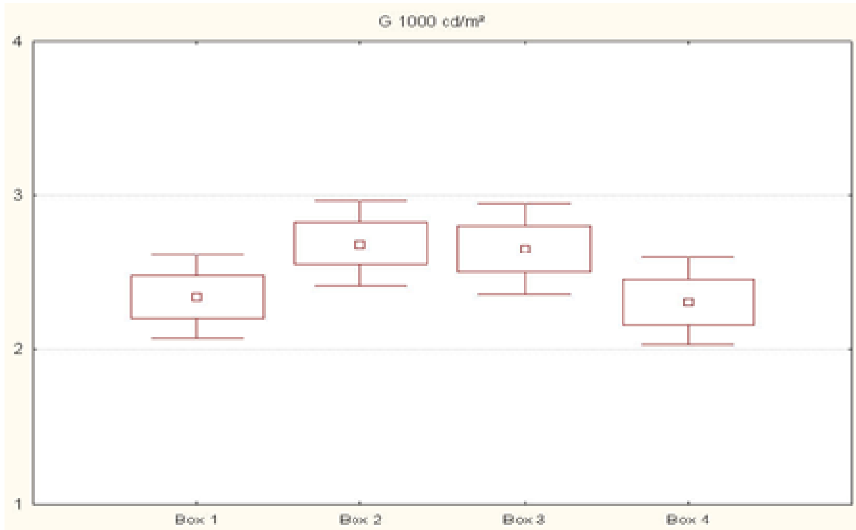


Fig. 3.47: Results of tile shape study, condition G2 (300 cd/m²); Box 1 denotes square tiles, Box 2 denotes hexagon tiles, Box 3 denotes ornamental tiles, Box 4 denotes square tiles with white non-lighting gaps



No significant results

Fig. 3.48: Results of tile shape study, condition G3 (1000 cd/m²); Box 1 denotes square tiles, Box 2 denotes hexagon tiles, Box 3 denotes ornamental tiles, Box 4 denotes square tiles with white non-lighting gaps

4 Off-State

4.1 Introduction

When the OLED is implemented in rooms with additional light sources or with daylight, the OLED can also be seen in a switched-off situation. In this case (off-state mode) the formal design of the OLED plays an important role.

The OLED can be constructed with a mirror or a milky white surface. To achieve higher luminous efficacy, external light outcoupling structures may be applied to the OLED, resulting in a diffuse white surface.. Even other off-state appearances can be realised, but the two above mentioned ones represent the highest technical relevance.

For an OLED in a luminous on-state, both surfaces do not differentiate very much from an aesthetical point of view. But in the off-state mode the appearance of the OLED differs a lot in both cases.

4.2 Aesthetical Perception Case Study

4.2.1 General Description

Due to the visual difference between a diffuse and mirror surface of the switched-off OLED, the off-state mode was evaluated in an aesthetical perception case study.

The test set-up with its procedure and scale models was exactly the same, analogue to the first aesthetical perception case study, which is described under chapter 3.2.

It was attempted to simulate diffuse and mirrored surfaces appearances of the OLED. A simulation of the diffuse OLED surface turned out to be difficult. Since the study should be combined with the other perception case studies in a time effective manner, a quick exchange of various scenarios was a boundary condition. Thus the transparent plexiglass panel carrying the OLED tile imprints had to be the surface which still needed to be exposed to the room. The mirror state was achieved by an accordingly reflecting sheet which was placed between the plexiglass panel and the light box. The diffuse white off-state was realised by just using the light box surface. The bottom plexiglass panel exhibited a glossy surface which made the diffuse white appearance not a fully realistic simulation, especially when viewing the ceiling under extreme angles. In case of the mirror reflecting sheet the non-lighting gap imprints were double reflected because zero distance between the print and the mirror surface could not be realised. This effect is also strongest under extreme viewing angles. The subjects were instructed to “enter” the model rooms and to perform their examination under perpendicular viewing. However, during execution of the tests it could not be determined whether all subjects really followed the instructions.

Thus, the study was performed somehow under imperfect conditions, and the results have to be judged carefully. At least, a first tendency should be obtained.

4.2.2 Set-up

4.2.2.1 Procedure

The off-state study was simultaneously carried out with the first aesthetical perception case study, which is described in chapter 3 and has the same set-up and procedure. The conditions are described exactly in the following points. Of course, no dependency on illuminance or luminance levels was investigated, since this study was an off-state study. The difference between office and residential environment was still subject of investigation.

4.2.2.2 Off-State Comparison Scenarios

In addition to the available model situations, the simulation of the off-state mode of the OLED ceiling, a mirror reflecting sheet was slid between the transparent OLED mounting plates and the diffuse light box. The light box itself served as simulation basis for the diffuse white off-state.

Two of the four boxes represented the diffuse OLED off-state. The light boxes are switched off in all models. In order to have sufficient diffuse light input for the evaluation of the non-illuminated ceiling situation a dim indirect test room light illuminated the boxes.

Two series of experiments, D and H, were performed. D was the office series, H was the residential series.

In the first box a square tile with the size of 60 cm x 60 cm was presented in diffuse state. The boxes 2 and 3 had square tiles with the size of 15 cm x 15 cm. In box 2, diffuse off-state modus was implemented while in box 3 a mirror off-state was realised. In box 4, mirrored OLED in off-state modus are presented as well. In contrast to all other boxes the non-illuminated gaps are white (white square). All other boxes had black grids (black square). Figure 4.1 clarifies the reflecting effect of the plexiglass panel. It has to be mentioned, that the test person could see a visual difference between the first (without mirror reflecting sheet) and the last two boxes (with mirror reflecting sheet). This effect could not be depicted in our photo documentation.

The detailed conditions are listed in table 4.1.

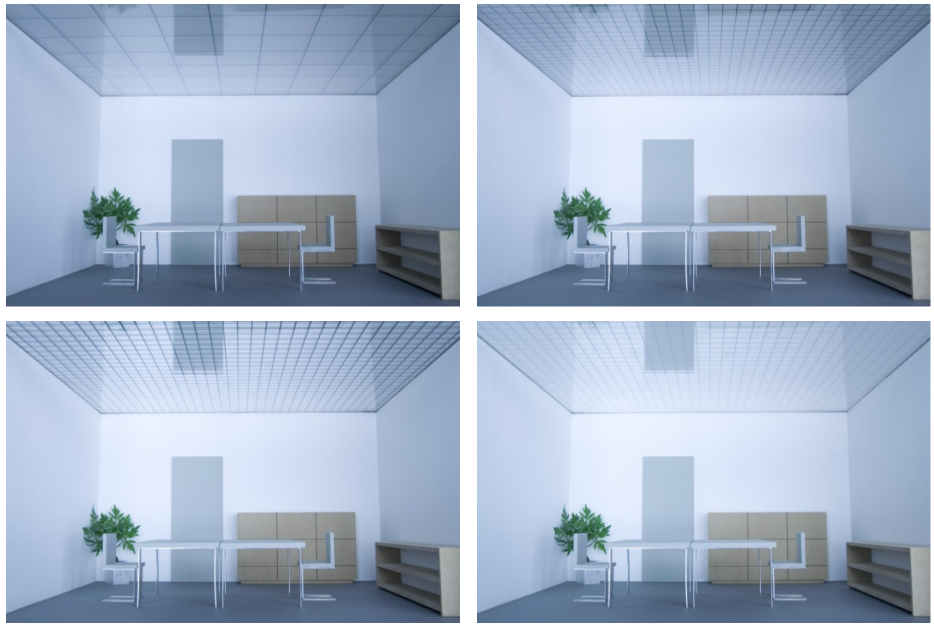


Fig. 4.1: Series D (office) comparison; large tiles with diffuse white off-state (top left), small tiles tiles with diffuse white off-state (top right), small tiles tiles with mirror off-state (bottom left), white gap small tiles tiles with mirror off-state (bottom right); due to the glossy surface of the plexiglass the photographs cannot express the real difference between diffuse and mirror

Table 4.1: Details of D and H test series with different tile sizes and off-states

D		**Box 1 / Diffuse**	**Box 2 / Diffuse**	**Box 3 / Mirror**	**Box 4 / Mirror**
	Edge Length	60 cm	15 cm	15 cm	15 cm
	Tile Shape	Black Square	Black Square	Black Square	White Square
	Colour Temperature	n.a.	n.a.	n.a.	n.a.
	Room Type	Office	Office	Office	Office

H		**Box 1 / Diffuse**	**Box 2 / Diffuse**	**Box 3 / Mirror**	**Box 4 / Mirror**
	Edge Length	60 cm	15 cm	15 cm	15 cm
	Tile Shape	Black Square	Black Square	Black Square	White Square
	Colour Temperature	n.a.	n.a.	n.a.	n.a.
	Room Type	Residential	Residential	Residential	Residential

4.2.3 Results

4.2.3.1 Description of Sample and Analysis Methods

The data analysis was performed in the same way as for Series A, C, E and G. A detailed description is given in chapter 3.

4.2.3.2 Results Off-State

Within series D and H the following application context was evaluated:

- working area (D) or residential area (H)
- tile shape: square
- box 1 and 2: diffuse tiling; box 3 and 4: mirrored tiling
- frame: black in box 1-3; white in box 4

In both conditions (D working area, H residential area) box 3 was equipped with reflecting small-scale tiles in the size of 15 cm x 15 cm. It is evident from box-plots in figures 4.2 and 4.3 that this box is clearly rejected within both areas. That means that reflecting small-scale tilings with black frame are not accepted. The same tilings with white grid are definitely favoured against the black grids.

On the other hand, both figures indicate that large-scale diffuse OLEDs with black frame are preferred in off-state mode, regardless of the room type.

However, it has to be pointed out that the simulation of the diffuse tilings was rather challenging as the different OLED foil designs were embedded in plexiglass panels. These plexiglass panels themselves are reflecting to a certain extent, therefore in our simulation the tilings were not realised properly. Furthermore, in case of reflecting OLED the plexiglass surface caused a clearly visible double image of the black tiling structure. Thus, the low acceptance of box 3 might (mirror with black frames) might be an artefact especially caused by the setup. Thus, the results must be handled with care.

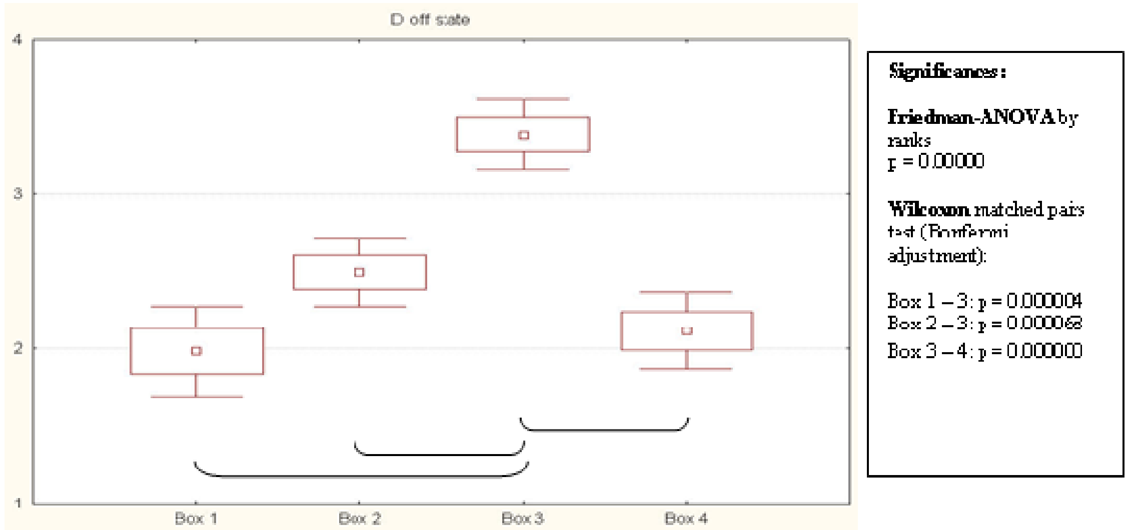


Fig. 4.2: Results of off-state study, condition D; Box 1 denotes large tiles with diffuse off-state, Box 2 denotes small tiles with diffuse off-state, Box 3 denotes small tiles with mirror off-state, Box 4 denotes small tiles with mirror off-state and white non-lighting gaps

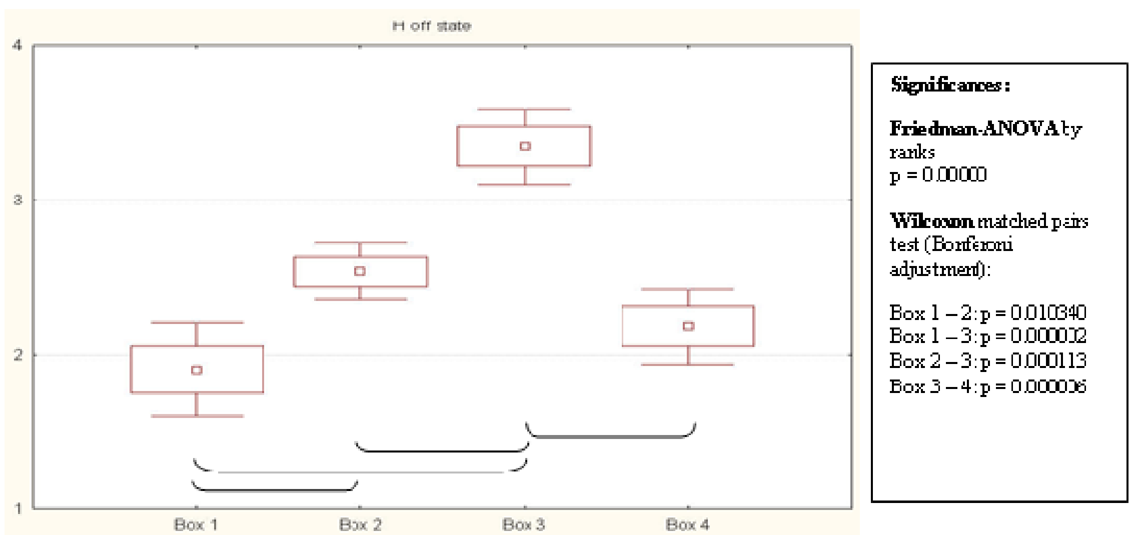


Fig. 4.3: Results of off-state study, condition H; Box 1 denotes large tiles with diffuse off-state, Box 2 denotes small tiles with diffuse off-state, Box 3 denotes small tiles with mirror off-state, Box 4 denotes small tiles with mirror off-state and white non-lighting gaps

5 Colour Temperature

5.1 Introduction

In common illumination technology, different colour temperatures of the light sources are used depending on the field of application. The colour temperature can have an impact on human performance abilities, well-being and comfort [DEG1, MUK1].

The current technology status of OLEDs indicates that they are delivering their best performance at lower colour temperatures – contrary to inorganic LEDs. One reason is the lack of stable blue phosphorescent emitters. Since an investigation on the acceptance of various colour temperatures could be easily integrated into the existing concept of tiling and off-state study, it was decided to involve this aspect into the testing though it was not part of the DoW.

The following test series should lead to a recommendation, which colour temperature is mostly preferred in working and residential areas. Furthermore, it is interesting to see whether the most preferred colour would match with the capabilities of OLED technology.

5.2 Additional Aesthetical Perception Case Study

5.2.1 General Description

Primarily, we are interested in investigating the most preferred colour temperature according to the room utilisation. Therefore, the scaled models were illuminated with the following three colour temperatures: 3000 K, 4000 K and 6500 K. The boxes were shown simultaneously to the subjects as in previously described tests and the luminance levels were also altered in the well-known manner as well as the room types.

5.2.1.1 Procedure

This additional study was carried out simultaneously with the other parts of the study, which are described in chapters 3 and 4.

5.2.1.2 Three Colour Temperatures

Different colour temperatures can be achieved with the usage of additional fluorescent lamps with higher or lower color temperature within two of the existing scaled models (box 1 and box 3).

Box 2 and box 4 remained unchanged with regard to other tests. The colour temperature was 4000 K. They only differed in the luminance distribution, meaning that TLM was applied in box 4. Additional light systems are used and the luminance distribution was adjusted in accordance to the recommendations described in the TLM (theoretical luminance model).

Box 1 was illuminated with 3000 K and box 3 was illuminated with 6500 K.

All four models had square OLED shapes with a tile size of 15 x 15 cm and black edges. A picture of the complete test setup presented to the subjects is already shown in figure 3.28.

The test series were now coded with letters B and F. In series B and F, three different color temperatures were evaluated. In series B the office environment was presented and in series F the models showed a residential area. Figure 5.1 shows exemplary the residential scenarios and an overview is given in table 5.1.

Fig. 5.1: Series F (residential) comparison; 3000 K (top left), 4000 K (top right), 6500 K (bottom left), 4000 K with TLM (bottom right

Table 5.1: Details of B and F test series with different colour temperatures

B		**Box 1**	**Box 2**	**Box 3**	**Box 4 / TLM**
	Edge Length	15 cm	15 cm	15 cm	15 cm
	Tile Shape	Black Square	Black Square	Black Square	Black Square
	Colour Temperature	3000 K	4000 K	6500 K	4000 K
	Room Type	Office	Office	Office	Office

F		**Box 1**	**Box 2**	**Box 3**	**Box 4 / TLM**
	Edge Length	15 cm	15 cm	15 cm	15 cm
	Tile Shape	Black Square	Black Square	Black Square	Black Square
	Color Temperature	3000 K	4000 K	6500 K	4000 K
	Room Type	Residential	Residential	Residential	Residential

5.2.2 Results

5.2.2.1 Description of Sample and Analysis Methods

The data analysis was performed in the same way as for Series A, C, D, E, G and H. A detailed description is given in chapter 3.

5.2.2.2 Result Colour Temperature

Series B

Within series B the following application context was evaluated:

- office area
- tile size: 15 x 15
- tile shape: square
- three different colour temperatures.

For small-scale squared tiling (15 cm x 15 cm) well-defined preferences for colour temperatures were derived. At luminance levels up to 300 cd/m² colour temperatures of 4000 K and 3000 K receive high acceptance. Additionally, at 1000 cd/m² 4000 K is definitely favoured to 4000 K with TLM on the one hand, but also in reference to 3000 K. In all cases 6500 K is evaluated the worst, regardless of the luminance level. Figures 5.2 to 5.4 show the detailed results. Again, the brackets in these figures are used to highlight significant differences in the subjects' rankings.

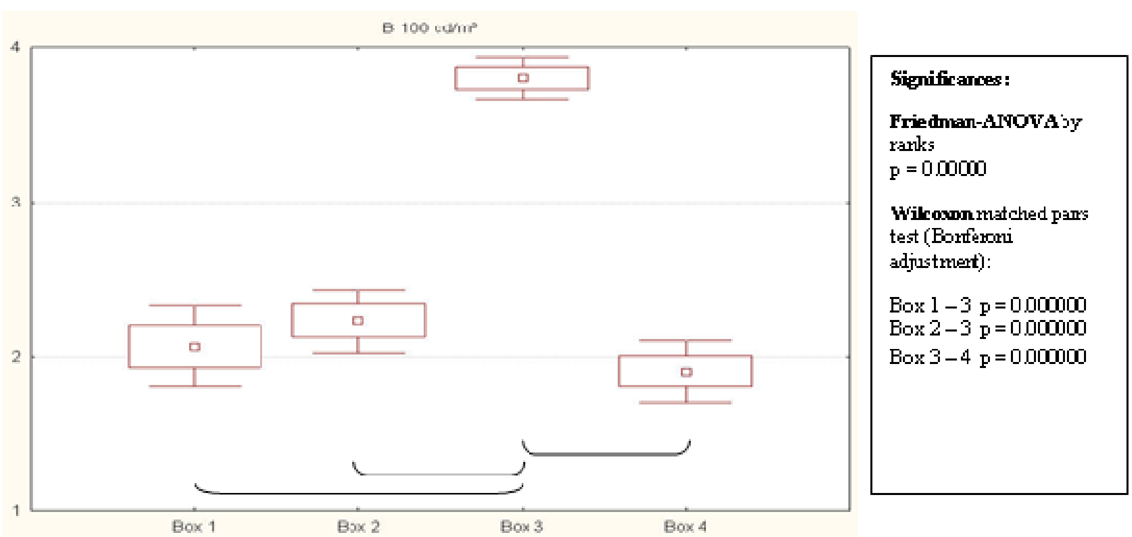


Fig. 5.2: Results of colour temperature study, condition B1 (100 cd/m²); Box 1 denotes 3000 K, Box 2 denotes 4000 K, Box 3 denotes 6500 K, Box 4 denotes 4000 K with TLM

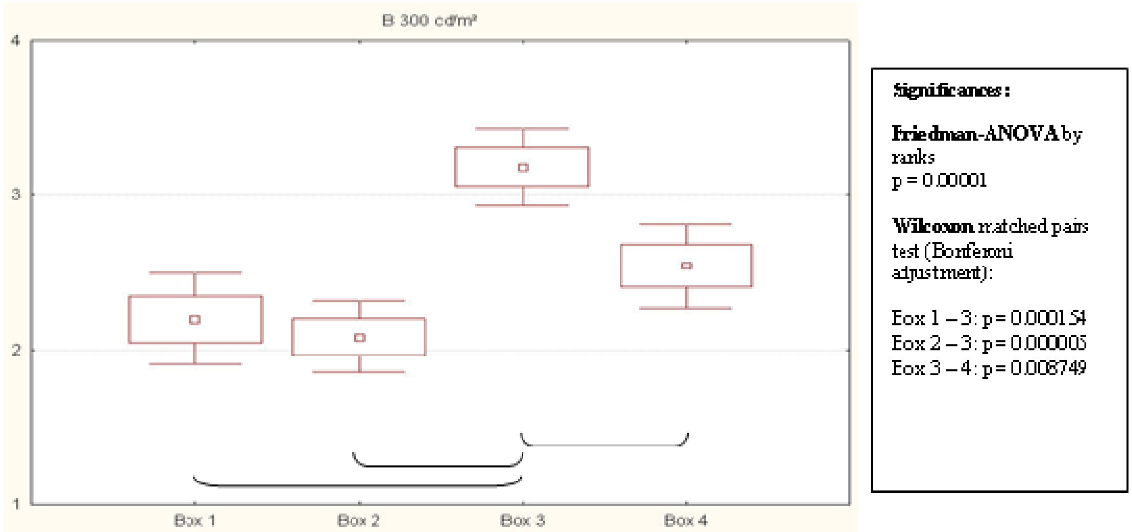


Fig. 5.3: Results of colour temperature study, condition B2 (300 cd/m²); Box 1 denotes 3000 K, Box 2 denotes 4000 K, Box 3 denotes 6500 K, Box 4 denotes 4000 K with TLM

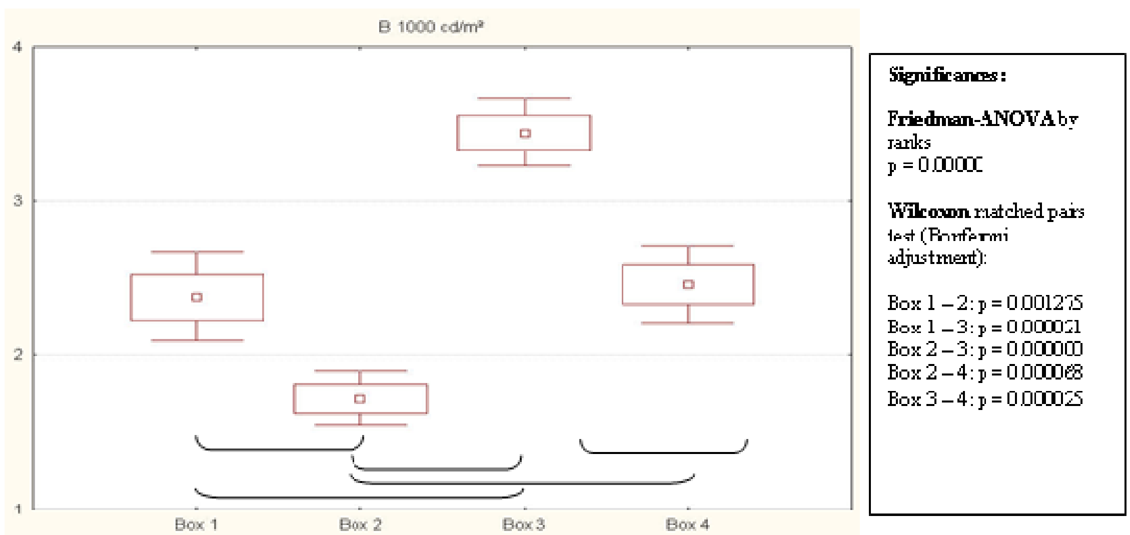


Fig. 5.4: Results of colour temperature study, condition B3 (1000 cd/m²); Box 1 denotes 3000 K, Box 2 denotes 4000 K, Box 3 denotes 6500 K, Box 4 denotes 4000 K with TLM

Series F

Within series F the following application context was evaluated:

- residential area
- tile size: 15 cm x 15 cm
- tile shape: square
- three different colour temperatures.

Regardless of the luminance level, 6500 K is clearly rejected in residential area. In contrast, colour temperatures of 3000 K and 4000 K are well accepted. Therefore, compared to working areas, the range of preferred colour temperatures is expanded from neutral to neutral and warm white The detailed results are shown in figures 5.5 to 5.7.

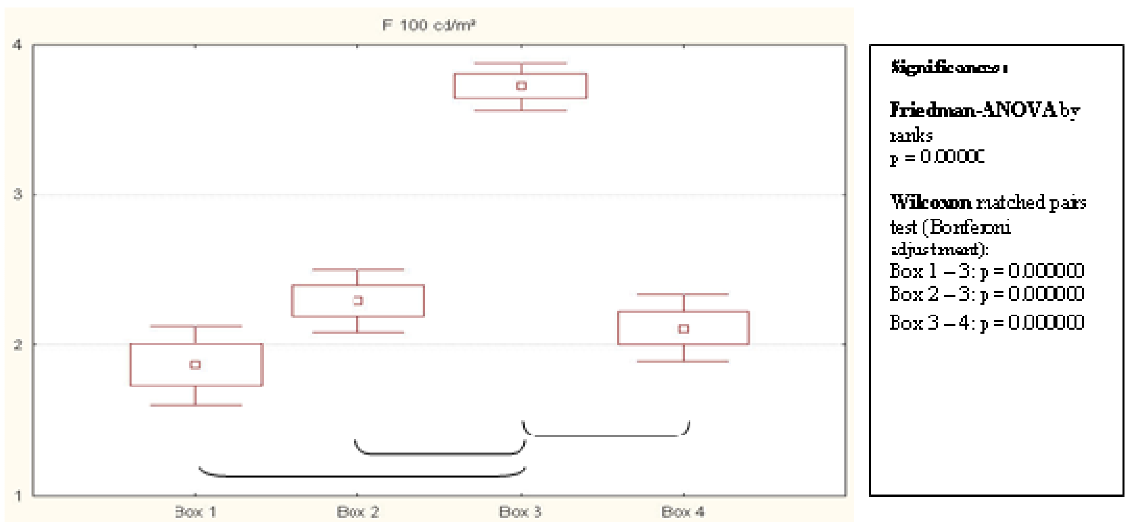


Fig. 5.5: Results of colour temperature study, condition F1 (100 cd/m²); Box 1 denotes 3000 K, Box 2 denotes 4000 K, Box 3 denotes 6500 K, Box 4 denotes 4000 K with TLM

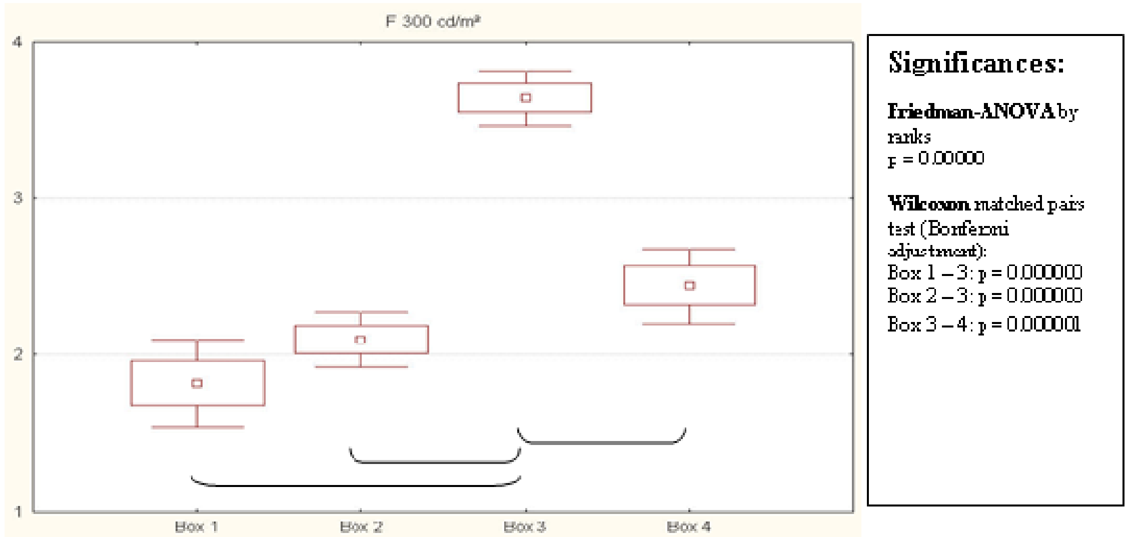


Fig. 5.6: Results of colour temperature study, condition F2 (300 cd/m²); Box 1 denotes 3000 K, Box 2 denotes 4000 K, Box 3 denotes 6500 K, Box 4 denotes 4000 K with TLM

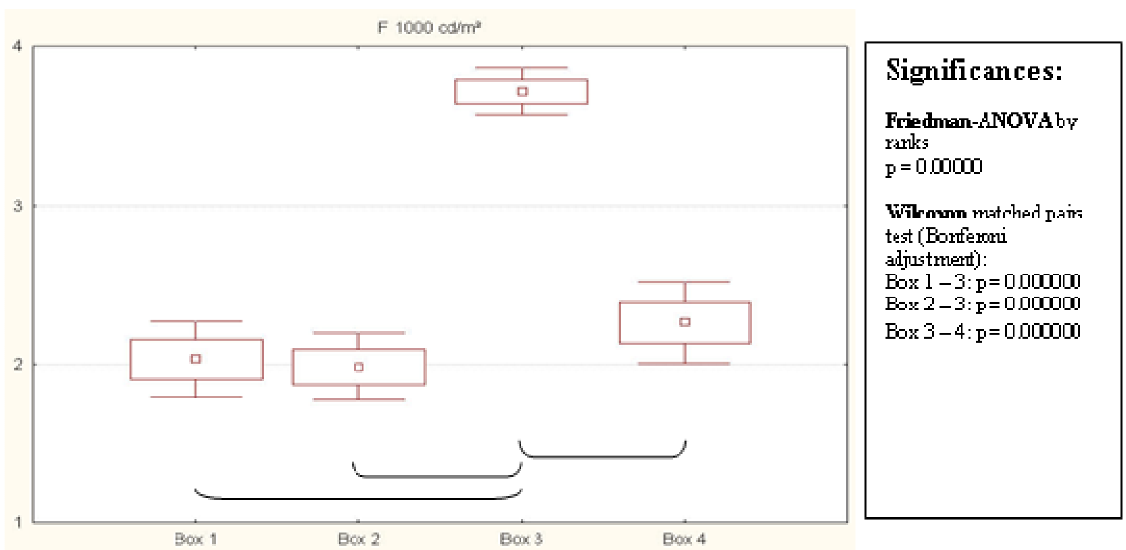


Fig. 5.7: Results of colour temperature study, condition F3 (1000 cd/m²); Box 1 denotes 3000 K, Box 2 denotes 4000 K, Box 3 denotes 6500 K, Box 4 denotes 4000 K with TLM

6 Age, Gender and Profession Specific Analysis

6.1 Gender-Specific Evaluation

Our sample contained 31 female and 30 male subjects. A detailed gender-specific analysis of all study runs could not reveal any significant differences between female and male test persons in their aesthetical preferences.

6.2 Age-Specific Evaluation

We divided the test person collective into two similar age groups. One group consisted of 29 test persons of the ages between 18 and 27 years old, and the second group consisted of 32 test persons who were between the ages of 27 and 55 years old.

Overall, a statistical analysis for both of these age groups surprisingly failed to identify a significant difference in the aesthetic rankings. Therefore, it can be assumed that persons between the ages of 18 and 55 have the same aesthetic preferences with regard to the form of the OLED tiles.

6.3 Profession-Specific Evaluation

As 19 of a total of 61 subjects are employees of Bartenbach LichtLabor it was considered to conduct a profession specific analysis of aesthetical preferences between two groups, namely “professional” versus “layman”. The latter group was thought to be “photometrically less versed” than employees of Bartenbach LichtLabor.

In the course of the whole studies, a few scattered differences could be detected in the residential room situations. However, these outcomes do not demonstrate any clear evidence.

7 Conclusion

7.1 Tiling Architecture - Literature Research and Architectural Suggestions

This report intended to come up with some design recommendations for initial OLED products on the lighting market.

As a basis for the dimensional determination, normative regulations which make standardisation of the components possible, serve to optimise their fusion from a practical and economic point of view.

Harmonic standards of proportion are currently only of historical significance. Due to the industrialisation of construction engineering, additional standards of proportion have forced their way through which are recorded in the standards DIN 4172 “Standards of Dimension in Structural Engineering” and in the DIN 18000 “Module Dimensions in Civil Engineering”. DIN 4172 is based on an octametric system (basic module 12.5 cm) and originated in brickwork construction. Important preferred dimensions are 62.5 cm and 125 cm. These are primarily used in German speaking countries. For international use 60 cm is a preferred dimension..

DIN 18000 is based on the decimal system and its basic module, M, is defined as 10 cm. Preferred dimensions are multiples of the basic module such as 3M, 6M and 12M. The purpose of this standard is an international standardisation, and is primarily used outside the German speaking countries. Upon observation of the most commonly available components, the use of the mentioned standard proportions is documented. An exemplary overview of utilised flat components, which are especially used for finishings (building panels, tiles, glass) and systems (ceiling systems), is documented and substantiated by a market analysis.

On this basis, a square basic module is defined, which forms the axial proportion of 1.5M, then following – 3M, 6M, 12M. The aim of the dimensional determination should be simple application and compatibility with existing systems. Exact construction dimensions depend on the selected support construction, the joint dimensions which arise as a result of this selection, together with technical general conditions for the OLED-surface (electricity supply).

As an example, the integration into a ceiling raster system was indicated. There are uncountable further combination possibilities, but the choices for this research work have been restricted to a reasonable selection. The integration into ceiling raster systems is reasonable from a practical and an economic point of view, as it deals with standardised systems which are sold in great numbers and also, application of the OLED is relatively simple. The design requirements in architecture are diverse and are not always resolvable with purely orthogonal systems. Therefore, in a further step, it was attempted to develop further module forms which can all be combined with each other. The basis is the use of the basic module dimension as edge lengths. As a result, various shapes are possible which, from an aesthetic point of view, are interesting and could open up new areas of application. Some of these shapes and arrangement options have been transferred into perception case studies in order to evaluate end user’s acceptance regardless of easy integration or standardisation.

Due to its flat surface expanse, the OLED makes an impression on the overall appearance of a room, as no other light source. It is an illuminant and building material all in one. In the off-state the OLED can exhibit several visual appearances which were also evaluated in perception case studies.

This report serves as a basis for stimulation and discussion. In further steps, a comparison with the technical requirements (possible shapes, sizes) should take place, in order to make a step closer to development of the real product.

7.2 Aesthetical Perception Case Studies Conclusion

In the course of the aesthetical perception studies scaled models of office and residential rooms were utilised. Additionally, OLED tiles with different busbar architectures were simulated in a very realistic manner.

Altogether we simulated future OLEDs with backlit transparent plexiglass with the aid of fluorescent lamps.

All relevant results of the aesthetical studies are summed up in the following four tables 7.1 to 7.3.

Table 7.1: Tiling Architecture

	Office area	**Residential area**
Tile size	Squared tiles with edge length of 30 cm and 60 cm were preferred independent of the luminance level	30 cm x 30 cm tile size was preferred independent of the luminance level
Tile shape	Significant differences at 100 cd/m² occurred No significant preferences at higher luminance levels	No significant preferences

Table 7.2: Off-state (careful interpretation, because realistic simulation turned out to be challenging)

Office area	**Residential area**
15 cm x 15 cm tile size with mirror-reflection clearly refused	15 cm x 15 cm tile size with mirror-reflection clearly refused

Table 7.3: Colour temperature

Office area	**Residential area**
6500 K refused independent of the luminance level 3000 K and 4000 K preferred with 100 cd/m² and 300 cd/m² 4000 K preferred with 1000 cd/m²	6500 K refused independent of the luminance level 3000 K and 4000 K preferred independent of the luminance level

It has to be mentioned that we could not reveal any profound gender, age and profession specific differences in aesthetical preferences in our studies.

With the aid of these four aesthetical perception studies we can draw the following conclusions:

- Decorative elements in form of specially designed tiling architectures are more accepted in residential areas, whereas working areas seem to be more critical in the selection of tile sizes and tile shapes.
- Squared tile sizes with a side length of 15 cm were preferred the least though they seem the first approach from standardisation and component integration point of view.
- Aesthetical preferences in e.g. tile shape, colour temperature, etc., were partially influenced by luminance levels. Generally spoken, higher luminance levels had a stronger effect on aesthetical preferences than tile shapes.
- Within both working and residential areas OLEDs should hardly be noticed in off-state mode. A neutral white appearance is recommended though the problems in creating a realistic simulation should be taken into account. The results of this particular study are the least reliable ones.
- We could find a clear preference for lower colour temperatures (3000 K and 4000K) of future OLED light sources. Generally speaking, the colour temperature 6500 K was clearly refused.

At the end design recommendations for future OLED tiles, OFF-state mode and colour temperature could be derived.

8 References

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