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DIGITAL SUPPORT OF MATERIAL AND PRODUCT SELECTION IN THE ARCHITECTURAL DESIGN AND PLANNING PROCESS

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Abstract. *Finding the "optimal" material during the architectural planning process means playing with different and sometimes contradicting criteria. This selection process is supported only insufficiently by today's digital systems.*

If it would be possible to illustrate all the various parameters by numerical values, the method of multidimensional scaling will offer a solution for architects to find the best material on basis of his individual weighting of criteria. By displaying the result of the architect's multidimensional query in a spatial arrangement multidimensional scaling can support an interactive selection process with additional feedback over the applied search strategy.

1 INTRODUCTION

1.1 Material and Architecture

Architecture is predominantly perceived over the surfaces limiting the space. The used surface materials thereby can address all senses, even if the optical impression is the most important. The design intention can be supported purposefully by the choice of an adequate material.

Apart from these purely formative aspects the selected materials have to fulfil various technical and economical requirements.

If the architect wants to select the “right” or the “best” material he has to play with very different and sometimes contradicting criteria and must weight these individually for the special purpose.

1.2 The time of material selection

The way from early design to the realization of a building is characterized by an increasing concreteness of all parameters determining the design. Usually the process isn’t linear, but different solutions are tested in loops and alternatives.

The material selection process too goes from the first colour concepts via a more detailed specification of the desired material towards an exactly defined product of a special manufacturer.

Today the entire process of material and product selection is only insufficiently supported by digital systems [1].

1.3 Today’s systems

Today’s CAD systems allow to map arbitrary colours or textures onto surfaces in order to visualize and communicate colour and material concepts. Architecture oriented colour systems of various manufacturers can be merged without any problems. But the selection process itself isn’t supported at all.

The development of colour concepts based on admitted colour harmonies is supported by systems like “colored architecture” [2]. Surface colours can correlate with surface sizes and respect so peculiarities of the human perception. However, this pure colour based approach neglects that in architecture a lot of surfaces receive their colour only by the assigned material. Also material properties beyond the optical characteristics are not regarded.

A more comprehensive approach to materials even according to further criteria is possible by various web-based material databases. Differences can be constituted in the orientation of the databases (e.g. search for technical parameters of special materials or search for possible materials in principle), in the spectrum of the offered materials (e.g. search only for woods), and particularly in the arrangement and complexity of the retrieval queries. Further material databases allow searching for manufacturers. On the manufacturer’s websites finally the concrete products can be found.

All of these databases work without any reference to the CAD planning, they allow only searching by keywords, the results are listed linear and one-dimensional and they don’t provide a direct comparison between products of different manufacturers.

1.4 Necessary system

In order to support the complex material selection process a system would be useful which unites formative and technical criteria and bridge the gap between design of a building and its realization. The desired material characteristics (e.g. colour) and the required properties (e.g. resistance to humidity) should be compared with offered products of manufacturers in order to be able to make a safe decision afterwards.

2 SYSTEM DESCRIPTION IN PRINCIPLE

2.1 Possible ways in material selection

Ashby [3] describes four fundamental approaches how to support the decision for a certain material in product design. In principle they are transferable to architecture.

1. Analysis: Due to objective (technical) criteria, constraints, requirements the number of possible materials can be limited, until the suitable one remains
2. Synthesis: existing experiences and analogies to other examples are used, in order to segregate respectively select preferentially certain materials
3. Similarity: in similar situations already used materials are taken as example for the new search. Innovation so is naturally limited.
4. Inspiration: also unplanned search results and creative thinking can determine the material selection, particularly because in architecture the new and unexpected expression is often very important.

None of these mentioned ways will lead to the optimal solution. But a tool for supporting the material selection process should facilitate all of these approaches [4].

2.2 Concept

First it is assumed that for each material/product the relevant data is available (most products are described in detail by data sheets as well as by pixel images). Crucial for the material selection is as stated above a set of attributes (Fig. 1) which can be different nature (emotional/sensorial or technical/economical). If it would be possible to express these characteristics in numerical values (e.g. from 0 to100 percent), they can be adjusted with the respective values of the quested material. The smaller the difference between the values of two materials the smaller their dissimilarity (Fig. 2).

Fig. 1: possible attributes in material selection

attribute A attribute B attribute C

material selection

attribute D attribute E attribute F

Fig: 2: materials described by attributes

material M1: A=30, B=30 C=70, D=20 E=15, F=80

material M2: A=20, B=10 C=70, D=75 E=55, F=10

quested mat. M: A=50, B=30 C=70, D=90 E=75, F=90

material M4: A=50, B=30 C=10, D=90 E=15, F=90

material M3: A=80, B=90 C=50, D=20 E=55, F=70

However, which material will be the optimal for the special application? There is no objective criterion, because each designer will weight the attributes differently depending on the intended use.

This possibility of an individual weighting can be implemented by multiplying all values of all materials with a weighting factor from 0 to 100 percent (Fig. 3 and 4).

Fig. 3: weighting of attributes by importance

attribute A wf_A=100%	attribute B wf_B=50%	attribute C wf_C=50%
	material selection	
attribute D wf_D=0%	attribute E wf_E=20%	attribute F wf_F=20%

Fig. 4: weighted materials

weighted M1: A=30, B=15 C=35, D=0 E=3, F=16		weighted M2: A=20, B=5 C=35, D=0 E=11, F=2
	weighted M: A=50, B=15 C=35, D=0 E=15, F=18	
weighted M4: A=50, B=15 C=5, D=0 E=3, F=18		weighted M3: A=80, B=45 C=25, D=0 E=11, F=14

How dissimilar a material is to the quested one can be determined afterwards e.g. by the total Euclidean distance (square root of the sum of all squares of the dissimilarities of all partial aspects). This value can be normalized to a range from 0 to 100 percent by dividing the sum of squares by the sum of all weighting factors.

$$D = SQRT\ (\ (\Delta A^2 + \Delta B^2 + \Delta C^2 + \Delta D^2 + \Delta E^2 + \Delta F^2) \,/\, (wf_A + wf_B + wf_C + wf_D + wf_E + wf_F)\ )$$
$$\text{with } \Delta A = A(M_i) - A(M_j) \ldots$$

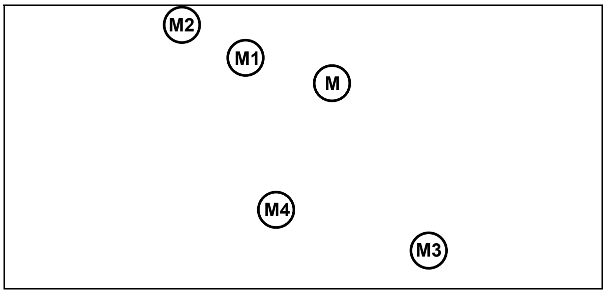
After the comparison of all individually weighted materials also among themselves, a dissimilarity matrix can be set up, filled out by the differences between all materials (Fig. 5). This matrix can be displayed in a n-dimensional space by multidimensional scaling, a technique used in statistics [5]. The so generated spatial distances between the points correspond to the dissimilarity of the materials among themselves. Existing deviations of the illustration from the origin matrix can be computed by different methods as so called “stress”. This deviation here is less relevant, because multidimensional scaling is only used to illustrate a principle spatial distribution. Nevertheless, the value can assist to evaluate the spatial conversion.

For the representation on a screen a 2D or 3D order is suitable (Fig. 6).

Fig. 5: dissimilarity matrix

	M	M1	M2	M3	M4
M	0	15,11	23,02	28,37	20,86
M1	15,11	0	13,84	38,56	23,31
M2	23,02	13,84	0	47,63	30,41
M3	28,37	38,56	47,63	0	30,82
M4	20,86	23,31	30,41	30,82	0

Fig. 6: spatial arrangement of materials in 2D

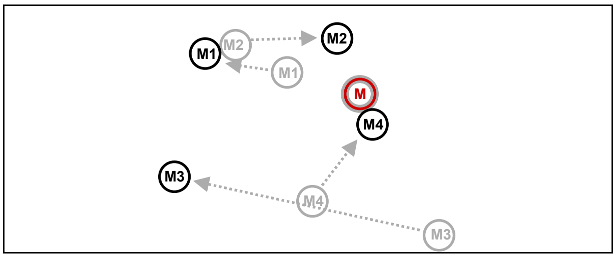


When the result is spatially arranged, it is easy to browse from the quested but fictive material M to the close lying offered materials in order to examine them further. A typical result by using multidimensional scaling is that elements which are similar in many attributes will arrange in clusters or neighbourhoods. So the user can explore purposefully one material group or change consciously to another group.

The addition and conjunction of very different parameters can also lead to unexpected results and can serve as source of inspiration.

Of course it is possible to change the individual weighting of the attributes at any time. Thus the spatial arrangement of the elements changes. Some materials will react sensitively to the change and depart from the proximity to the quested material, others will move into the focus and come to a closer selection (Fig. 7). This immediate rearrangement of the elements will help the user to improve his own searching strategy.

Fig. 7: rearrangement of elements



It can occur that the deviation between materials is very strong only in one attribute, otherwise however they are very similar. Each attribute contributes only a small part to the total result, hence it is possible that this material is indicated still as very similar. A solution for this problem can be to increase the dissimilarity not linearly but e.g. by the square to the differences. Thus strongly deviating values will influence the final result stronger. Also the individual weightings needn't applied only linearly, so that a value of e.g. "100% importance" can have a particularly stronger influence.

3 IMPLEMENTATION

3.1 Conditions

The suggested proceeding is based on the assumption that in principle it is possible to translate all search criteria into numerical values. Moreover they should mirror the human perception, so that differences in material properties correspond to the differences in the values. Different ranges of values can be normalized (e.g. into values between 0 and 100 percent), in order to permit a comparability between the attributes.

Thus it is necessary to examine the criteria of selection, whether and how these can be illustrated numerically most meaningful, how them can be processed internally and which is the best form for input.

In principle the input should correlate to the human perception and the human concepts of language. The necessary accuracy of the demanded inputs must be determined. Especially emotional criteria are described e.g. rather by indistinct terms, thus a certain range in the interpretation is quite desired. The computational processing follows naturally via deposited numerical values.

Further must be considered, which kind of data is available from the manufacturers today and perhaps more generally in future. Certain specific material indices cannot be compared with those of other materials groups (e.g. brinell-hardness of woods). Other criteria (e.g. colour) are not supplied at all, but can derived from associated pixel images.

3.2 Desired criteria for the selection

Two kinds of criteria can differentiated categorically: characteristics captured by human senses (optic, touch, acoustic, smell, taste) and technical/economical properties (behaviour in case of fire, electrostatic loading, durability, cleaning, price, origin...).

It is relatively plausible that technical/economical criteria can be stored in numerical values. Hence they are not further examined here, although the questions of terms in human languages, the necessary graduation in the partitioning and the access or comparability of the data are still to be clarified.

The further text will examine only the characteristics captured by human senses.

3.3 Characteristics derived from pixel images

Some optical characteristics of the material can be derived in principle from the pixel image supplied by the manufacturer and can be compared with the quested values. For an effective search it makes sense to compute these values only at the first time and to store them as a fixed data.

Many characteristics of the surfaces depend strongly upon the distance of view. The pattern how the raw material is arranged also has a large influence how the material is perceived. Therefore all pixel images should illustrate a representative cut-out of the surface in the same size (e.g. $1m^2$ pattern of tiles) The resolution can be relatively small as basis for an evaluation (e.g. 512x512 pixel at $1m^2$ show still details of 2mm).

3.4 Colour

The translation of colour into numerical values seems to be relatively simple. In that manner e.g. special colour systems from diverse manufacturers can be transformed into RGB space.

The problem of a colour safe representation of materials can be neglected here, because exactly the same applies on other today’s systems too, no matter if digital or analogue. It can be minimized by appropriate calibrating systems.

The input of the query in HSV colour space corresponds in principle to the human way of thinking by partitioning in basic colour, brightness and saturation. The organization of the retrieval query should permit to define also second or third colours, because many materials are mixed from several basic colours in different portions (e.g. terrazzo, natural stones). The three colours can be logically linked with AND or OR, depending upon the goal. Also a hierarchical gradation in first, second and third colour can describe a useful search criterion.

If the colours are not imported from an existing CAD file, it suffices to be able to give the input only in relatively large steps which corresponds to human terms illustrated in the “color naming system” [6]. So Hue can be limited e.g. on 15° or 30° steps, saturation and brightness e.g. on 20-25% steps.

The search routine can be organized similar to algorithms, which are developed for image based searches in image databases [7].

Many natural materials include colour fluctuations or little grain, which are hardly noticed in the overall view. Thus it is meaningful to interpolate deviating or very small colour areas first.

For a rough image description the pixel image can be summarized under relatively large colour gradations. An indexing on maximally 20 colours (with partitions of at least 5% of the total area) applies as sufficient to picture comparisons. Searching only for three basic colours, as suggested above, means that it will be possible to reduce the number of indexed colours without substantial quality losses in the result.

The computer-internal processing best works in L*a*b colour space, because here Euclidean distances correspond linearly to the differences in colour perceived by humans. For every indicated colour the distances to the quested three colours are determined (a search for only one colour means that all three values are identical). If the colours are linked by OR, the shortest colour distance in each case is rated as "the most similar" and is used further. Linked by AND means that each colour must be selected at least once as the shortest distance. The hierarchy arrangement of the three colours has to be solved by well described optimization algorithms.

The total colour distance between pixel image and retrieval query corresponds to the Euclidean distance if the distances to the indicated colours are weighted with their proportional values. It is represented only by one numerical value.

3.5 Brightness

In addition to colour it can be meaningful to be able to search purposefully for bright or dark materials. A similarity in the total brightness can be determined similarly to colour. The luminance values of each indicated colour (which are important for human perception) are weighted by the proportional values of the areas. In contrast to the colour the distance already lies within the range of 0 to 100 as L is coded in L*a*b space.

3.6 Texture

Many surfaces used in architecture particularly take effect because of their pattern or their texture. The terms used by humans are not clearly fixed, therefore it is not simple to define to a purposeful query.

Ware and Knight [8] as well as Rao and Lohse [9] found some fundamental parameters about texture perception by empirical studies. Crucial for human description of textures seem to be orientation, size and contrast respectively repetitiveness, directionality, coarseness and complexity. Some of these parameters correspond, so that it suffices to regard only some of them.

A connection to the colour of a sample was not determined [10]. Hence computing based on achromatic bitmaps suffices. If these bitmaps are derived from coloured images that the grey level codes the order of the colour portions instead of brightness only, the influence of colour disappears completely, the structure becomes more recognizable.

In order to get comparable results in the proposed system, it is again necessary that the pixel images illustrate a representative cut-out of the surface in the same size. The geometrical pattern of a tiled surface will substantially be more expressive than the grain of an individual tile.

Researchers in computer vision and in the field of image based database retrieval tried to determine explicit values for a comparison of textures by statistic image analysis procedures, picture decomposition and wavelet transformations [11, 12].

These procedures show that it is possible to classify texture images automatically according to criteria mentioned. These values generated in the publications mostly refer to natural textures and depend on the selected procedure. In addition there is not always a linear connections between a value and human perception. Thus the values have to be interpreted or converted. Perhaps this corresponds to the fuzziness of human terms respectively the impossibility to classify a texture e.g. accurately as "50% directional" [13].

In architecture where surfaces are perceived in a normal distance clear clusters are to be expected e.g. due to typical patterns of arrangement. It appears meaningful for the proposed system to work with only quite rough gradations and to enable an input by offered examples of textures. Depending upon selected algorithm the computed values must be assigned to these ranges.

According to the proceeding by colour description it is aimed determining only a few parameters for each texture first and store them with the data set for an effective query.

3.7 Glossiness, transparency

Attributes such as gloss or transparency can be derived automatically in principle from series of pixel images under different view and lighting directions. Examining natural surfaces the value can change depending on viewing and lighting angle. However, such image series usually are not available. Thus manufacturer data are necessary.

The values can indicated mathematically as an angle depending set of numbers in the range from 0-100% or however in rougher terms as shining, silk matte, matte respectively transparent, transluzent, opaque, which can be translated afterwards into mean values.

3.8 Touch

The topic “touch” is often used as argument that material cannot be obtained at the computer. The question arises, how far the tactile sense is inserted actively while perceiving surfaces in architecture. Because of the remote perception of building surfaces perhaps many tactile impressions e.g. roughness are perceived more via the eye in connection with existing experiences over materials. Touch is mostly a so called synaesthetic procedure, visual stimulus can overlay the tactile sense.

Nevertheless, technical values of materials correspond to the tactile characteristics and can be expressed by them. The felt warmth of a surface is determined by the heat conductivity of the material. The roughness of the surface is described by three numerical values [14]. Weight, absorption and rigidities are usual material properties, too.

The designing architect who is searching for a certain material will express himself rather in indistinct terms than in concrete numerical values. But these terms can be translated in principle into numerical values and mark up similarities between materials.

3.9 Smell / Taste

It is hard to find data concerning olfactoric peculiarities of materials. Depending upon material group terms can be defined as e.g. "smells as leather" or "smells artificially".

However, for an indexation of all materials a solution could be to divide all elements only into "smells" and "does not smell"

3.10 Acoustics

One can differentiate the acoustic characteristics of a material into the sound of the material itself when hit (e.g. sharp, dull, muffled) and the characteristic affecting the room acoustics. Both properties can be described by technical parameters and will be available in principle.

4 SUMMARY

The decision for a concrete material in architecture always means weighting total different criteria, which the surface should and has to fulfil. Today's systems support this decision-making process only insufficiently. The proposed system shows a principle way of evaluating surface materials by an individually changeable weighting of the criteria. The further search can be concentrated purposefully on certain materials groups by a spatial arrangement of the results by multidimensional scaling. An immediate reaction to changes in the individual weighting by the rearrangement of the results will give additional feedback over the applied search strategy.

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