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Unfolding the material: A proposal of a multi-sensory experience oriented material exhibition medium

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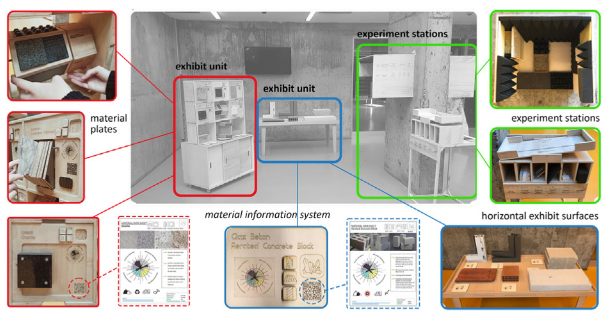
HIGHLIGHTS

- This study addresses the scientific gap in material exhibition design by providing a framework for developing the design considerations.
- Through its theoretical and experimental phases, this study proposes an exhibition model based on human-exhibit interaction and multi-sensory experience.
- The study was led with a participatory mindset. Both the process and the outcome contribute to hands-on learning.
- The students provided insights on audience opinion. It was evident that the students preferred experimental & comparative design language.

GRAPHICAL ABSTRACT



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ABSTRACT

Experience with a product or a space occurs via different interfaces and one of those, perhaps the most significant one, is the material. Sensory properties of materials along with technical ones are essential inputs during the material selection process in design. This leads to the necessity of material exhibition platforms specifically configured for design students and novice designers, where material properties can be observed through experiencing, and experimenting. Thus, a multimodal reasoning process can be generated which would enhance design thinking.

Through its theoretical and experimental phases, this study aims to develop the fundamental considerations and propose a model for a multi-sensory material exhibition medium where both tangible and intangible characteristics of materials can be observed, and interacted with, thus inducing hands-on learning. The study further aims to propose a material information system where quantitative and qualitative information are given in a visual representation layout. By adopting a participatory mindset, two workshops (15 + 10 days) were conducted with architecture faculty students, thus enabling audience opinion during the design of systems and transformation of material properties into scalar data and diagrams. The results and the merits of the proposed exhibition medium are presented and the educational implications are discussed.

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1. Introduction

'Material' is a substantial design component to convey a notion and an experience to the user as part of an architectural discourse. Embracement of a 'performance-based design approach' necessitates careful evaluation and optimization of material's quantifiable attributes, in order to achieve high-quality design output and to meet relevant regulations and standards. Performance-based design approach drew its strength from increasing concern for the environment, improved policies, and advancements in simulation technologies especially during the 20th century [1,2]. Hence the designer should account for the physical performances (e.g. thermal, water, moisture, acoustics, lighting, fire resistance) of the design output and their implications on environment and human health. From another perspective, materials do not only affect the technical performance of a building/product, but also their sensual features affect the quality of experience [3]. Materials outline the poetics of a design, evoke emotions, give form, and shape the way users interact with the design output. Meanwhile, as Zumthor [4] - a recognized architect for his emphasis on materiality in architecture - suggests "material is endless" and "there are a thousand different possibilities in one material alone" because one can reshape the material and achieve a different effect each time. Through this statement Zumthor gives the designer the role to not only select a material but also to interpret and reshape it in order to configure an atmosphere by generating an architectural articulation with respect to design processes conducted in different scales.

By all means, the selection of material is a complicated and time-consuming process that needs parallel processing of various material characteristics and multi-criteria decision-making [5]. Traditionally, these characteristics are derived from various resources such as textbooks, laboratory test results, brochures, which are scattered and sometimes even misleading for a novice designer. 'Ashby plots', with their comparative and visual representation of material information, have been widely used in design and engineering fields, for assessing the material characteristics and to induce the visual-thinking process [6,7]. These material characteristics are primarily the tangible ones such as mechanical, physical, thermal, electrical etc. On the other hand, the importance of sensory and other intangible characteristics of materials are lately recognized as fundamental elements that determine the emotional response of the user [5,8–15]. Karana et al. presented an overview of the most recent studies on the intangible characteristics of the materials and underlined the necessity for material selection resources that contain information on intangible characteristics. Their research with product designers implies that sensory (such as tactile, visual, auditory, olfactory, gustatory) properties of materials are essential data for the design process together with other intangible characteristics such as perceived values, associations, emotions, cultural meanings, and trends, which were also found to be associated with sensory properties [5]. In consecutive studies, material experience was defined over four experiential levels, *(1) sensorial (*i.e. *sensory properties of materials) (2) interpretive (*i.e. *associated values), (3) affective (*i.e. *evoked emotions) and (4) performative (*i.e. *actions)*, referring to the human interaction [12,13]. With a similar perspective, Veelaert et al. investigated the experiential characterization of materials in the materials and design domain, and highlighted the need for a multimodal approach in sensory material evaluation [14]. One of the identified research gaps was about the complementary methods for enhancing multimodal interaction and translating subjective experiences of materials into data. Apart from assisting material selection, these setups are also useful for the designer-led materials development process [15].

A vast amount of research and publications are available on decision support tools for material selection process, such as simulations and online material databases [11], yet material exhibition design is not addressed scientifically despite its potential for creating a platform where both tangible and intangible characteristics can be conveyed through hands-on experience. Several material exhibitions (permanent or temporary) and fairs are available to designers, where one can interact with the exhibited materials. Allowed interaction is mostly limited by the exhibition technique and not specifically tailored despite its potential to convey experiential qualities. Furthermore, the content of such platforms is mostly limited with commercialised and product-oriented information [16], thus can be misleading for less-experienced designers when inadvertently generalised. Finally, interpretation of the material properties necessitates technical knowledge and/or professional experience when the presented data comprises numerical results or when the indicators and units are inconsistent among material samples. Therefore, generating non-commercial, experience-based material exhibitions with comprehensible representation of material information is quite essential for unveiling tacit design-based knowledge that pioneers the usage of material as a design tool especially by novice designers.

Acknowledging the importance of materials' role in obtaining qualified design outputs, and the interactive potential of material exhibitions, this research bridges the multisensory perception in material selection process to exhibition design studies. The research aims to reconsider the material exhibition from an educational perspective and to propose a multi-sensory material exhibition system by improving the interactive attributes. The proposed exhibition system aims to support the designer in evaluating both tangible and intangible characteristics by enhancing human-exhibit interaction and providing a sensorial experience. The design students and novice designers ('designer' is used as an umbrella term for architecture, interior design, product design disciplines in this article), constitute the target audience of the proposed exhibition. Therefore, the primary concern is not only supporting material selection but also stimulating long-time memory and learning. By means of a multimodal experience-based exhibition, one can interact with the exhibition pieces, experiment with the material characteristics and develop a positive experience. From this perspective, the material exhibition holds a potential to be used as a learning tool in design education.

2. Materials and methods

The research consisted of three phases as (1) configuration of the theoretical framework, (2) design and prototyping of the exhibit unit and, (3) integration of the material information system. In the first phase a framework was developed to apply the exhibition design considerations to a material exhibition medium. The second phase was dedicated to generating the most adequate solution for high-level human-exhibit interaction and executing the physical prototyping process. The final phase was focused on organisation and representation of materials information upon constructing an informative representation system.

A participatory mindset was embraced in this research in order to receive feedback from the audience and to establish engagement. The authors conducted the first phase, while the final output of the research was obtained during the sequential workshops with students. Two workshops were organised as part of this research and as a contribution to the design practice internship course of the Faculty of Architecture at Istanbul Bilgi University in the 2019 summer term. During the workshops, students' approaches were observed and integrated into the proposed material exhibition. Fig. 1 illustrates the flow of the methodology.

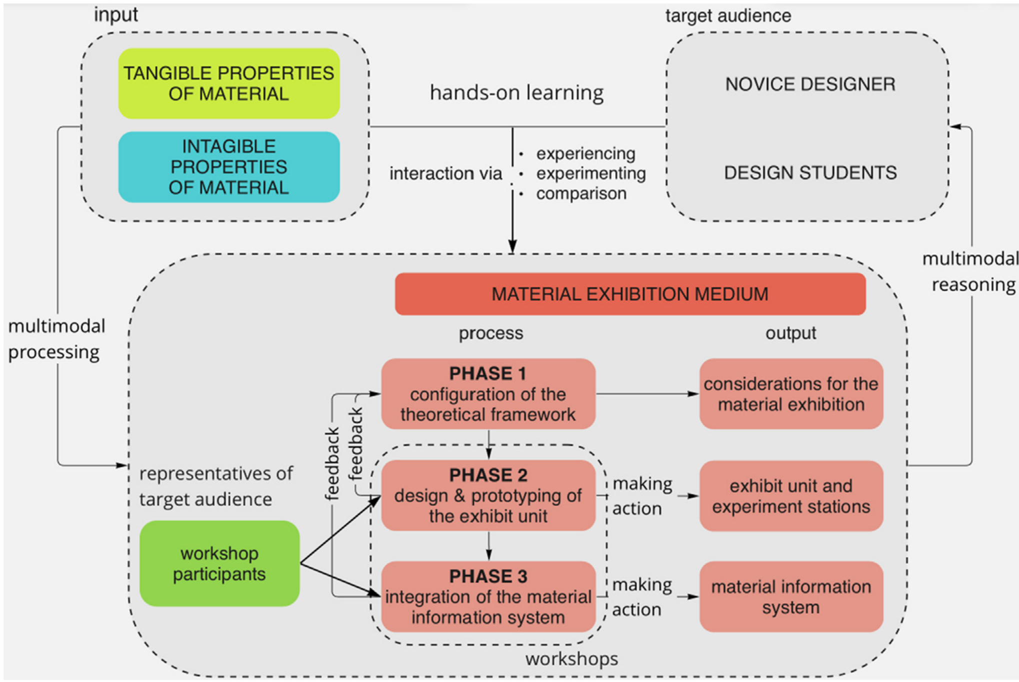

Fig. 1. Methodology flow chart.

2.1. Configuration of the theoretical framework

The first phase of the study included a theoretical research for determining fundamental considerations for a multi-sensory material exhibition. Since there are scarce amounts of specialised resources on a physical material exhibition design, the considerations were built on the literature of museum and exhibition design. Meanwhile, building materials literature was referred with regards to material classification systems.

Theoretical research continued with regards to the content of the exhibition. Within the scope of this research 115 most common design materials were determined excluding atypical materials such as hybrid and/or specialised products. These predetermined materials were analysed and classified according to the function, origin, prominent sensorial properties, and the most adequate exhibition techniques (classified as vertical hanging, freely standing on a horizontal plane, or mechanical fixation). 22 representatives were selected among 115 material samples and were included in the prototyping stage. The selected samples provided diversity in means of sensorial qualities, exhibit methods and interaction potentials.

At the end of this phase, the design considerations, potentials and educational implications of material exhibitions were established and a material chart was prepared for the following phases. This process was iterative, thus introduction of new ideas and approaches from students was possible. Chapter-3 of this paper propounds the considerations for the development of a multi-sensory material exhibition.

2.2. Design and prototyping of the exhibit unit

The second phase, namely exhibit unit design and prototyping process, occurred in a workshop environment with the participation of fourteen students. The workshop continued for fifteen days. The topic was introduced to the participants through theoretical explanations about materiality and exhibition design, site visits to several exhibitions of different scale items and recognition of tangible and intangible properties of materials over selected samples. The study continued with form-finding and system development processes to provide the visitor-exhibition interaction and to meet the technical requirements related with subtractive manufacturing techniques. During the process, the participants focused on implementing aforementioned exhibition criteria into the prototyping process of exhibition units and experiment stations (Fig. 2).

The final prototypes were manufactured by applying interlocking wood joineries and subtractive manufacturing techniques by using a computer numerical control (CNC) machine due to easiness and fast assembly of the production method. As a prior study for digital fabrication, a 1:100 scale prototype of the exhibition unit was produced with a laser cut machine to verify the accuracy of the joints and dimensional properties of the unit.

Digital drawings were prepared in RhinoCeros3D medium and shop drawings were implemented to the CAD plugin of the CNC machine in order to obtain qualified digital fabrication of the exhibition unit. After the CNC cutting process, the pieces were assembled, and the selected samples were attached to the exhibition unit. The exhibition unit and the experiment stations were developed and manufactured under the instructors' full supervision and guidance. A technical brief was provided to the students prior to the usage of CNC and other digital fabrication tools in order to ensure a safe production process. Representative material samples were gathered from the existing semi-organized material archive of Istanbul Bilgi University, Faculty of Architecture.

2.3. Integration of the material information system

The third phase of the study was dedicated to organising the material information and integrating it to the prototyped exhibit units. This phase occurred in a workshop environment, with the participation of sixteen students. The workshop continued for ten days, starting with theoretical explanations about material selection in the design process, performance approach and materials information (properties and characteristics). Further steps included determination of the material information to be repre-

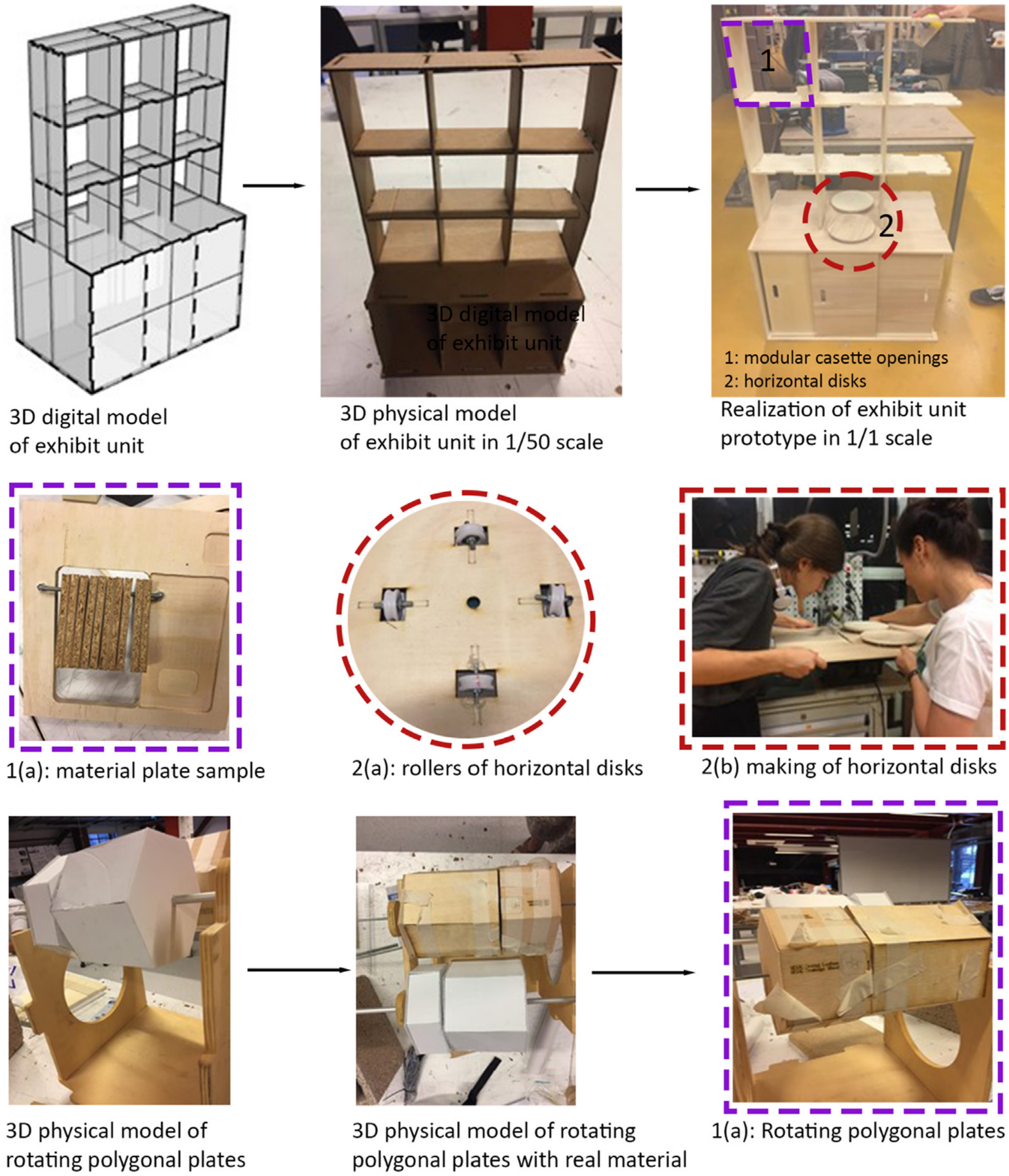

Fig. 2. Prototyping process of the exhibit unit.

sented in this type of an exhibition, and preparation of the iconography and the layout for the material dashboards.

In order to enhance a dialogue between the exhibition and the visitor, and to use a vocabulary to which the visitor can relate, the scope of the material information was determined by a combination of theoretical knowledge and students' opinions as articulated in brainstorming sessions. The first brainstorming session was conducted over the question: *"What are the factors affecting a designer's material selection?"*. Each student was asked to write at least 5 factors on the post-its. Later on, all students shared their ideas one-by-one and through a group discussion, the factors were clustered together (Fig. 3). While doing so, instructors aimed to understand the students' mindset, and to translate the existing vocabulary on the material properties, hence improving the comprehensibility of the information that is to be used during the material selection. Several online material databases [17–31] were referred to reveal the performances of the materials. The materials that were preselected for the prototyped exhibition unit were examined by using these databases and a list of material properties was used as the basis of the information system along with the outcomes of the brainstorming session.

In order to translate the qualitative sensorial properties of the materials into quantitative information, an interaction exercise was conducted over a second question: *"How would you classify different materials according to senses?"* Students were divided into groups of four and asked to organise the materials according to their contrasting features –inspired from Johannes Itten's approach at Bauhaus (as cited in [32])– with regards to one of the following senses; *visual, haptic, auditory, olfactory* (Fig. 4). A common vocabulary to represent sensorial properties of the materials emerged from each groups' proposition of keywords for definition of different experiential characteristics of the materials. Through group discussions and further examination of material properties driven from the first session, a framework to cover both sensorial and technical aspects of materials was generated. Applying a semantic differential method (similar to [15,33]), perceived experiential and performance qualities were scaled using antonymous keywords at the beginning and at the end.

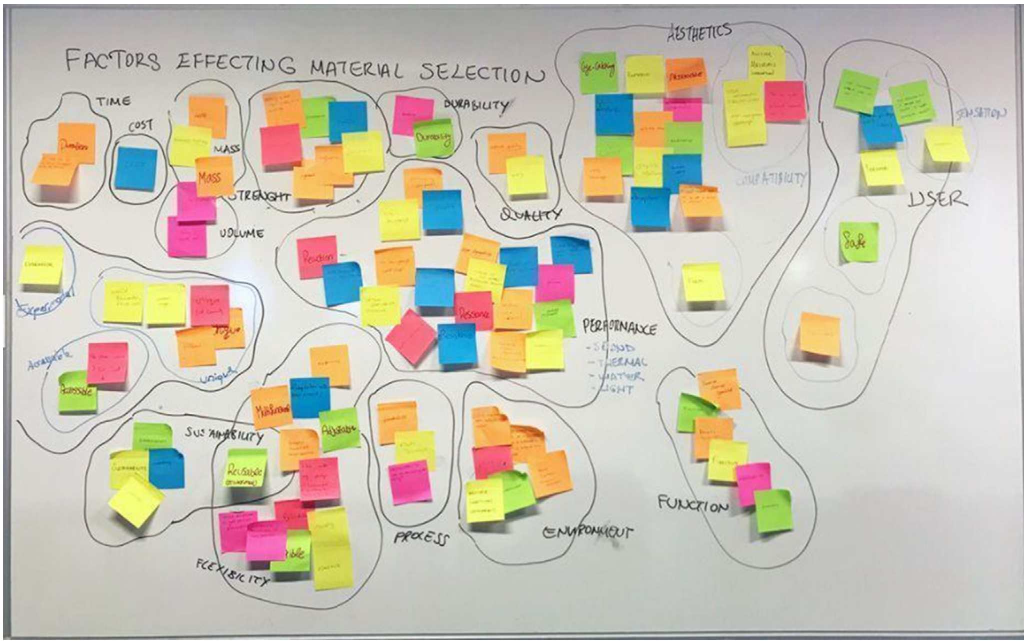

Fig. 3. Clustering exercise during the brainstorming session.

Fig. 4. Materials examined (left) and grouped (right) during the interaction session.

The iconography and the layout of the material dashboards were developed with the considerations of enhancing the human-exhibit interaction and visual thinking process. This step included preparation of (1) the icons indicating materials' origin and function, (2) the material property diagrams, (3) the online material dashboards and (4) Quick Response (QR) codes to link the online medium. The icons and the material property diagrams were prepared with RhinoCeros3D and Adobe Illustrator software. The icon drawings were engraved on wooden plates using laser cut machines and attached on the exhibit unit. Online material dashboards were created with Microsoft Office PowerPoint software and converted to a portable document format (pdf) before uploading on the web. The hyperlinks were embedded in QR Codes. Lastly, QR codes and material property diagrams were printed on transparent self-adhesive acetate papers and placed on the exhibit unit. The motivation behind the hybrid use of physical exhibition and online database, was to cascade the information and engage the visitors through allowing control over their experience.

3. Considerations for the material exhibition

3.1. Configuring the material exhibition in design education

Design education paradigms were mainly configured as studio practice and workshops in history, in order to provide students with holistic design approaches. This approach is also stated in Bauhaus Manifest via defining the relationship between applied science and applied art in the design process with three components: craft, drawing and painting, science and theory [34]. Furthermore, Fraylin describes design education as a series of reflective design actions that includes conceptual recognition of the problems and their reflections (solutions) with tangible things [35]. In that aspect, material exhibition is a medium that can integrate materials as tangible things into the design process as both part of applied science and instruments of crafting by exploring intangible characteristics of material. Following Schön's description, material should be considered as a responsive design component that enriches the reflective design process [36]. Thus, the material exhibition should accentuate the multimodal experience of materials to unveil tacit design knowledge and to improve creativity in the design process. To construct a didactic framework for the material exhibition, main components of an adequate learning medium were determined. Effective learning processes and learning environments were defined to apply experimental and reflective educational approaches via material exhibition.

Learning process: Kolb defines the learning process as a medium for knowledge creation via transformation of experience [37]. He indicates four phases of the learning process as (1) sensory perceptions about concrete objects, (2) thinking and mental experimenting, (3) translating experiences in general notions, conceptualising, and construction relationships, (4) active experimenting via physical modelling and prototyping. Experiential Learning Theory also supports Kolb's statements with the concept of 'learning by doing' [38]. Resnick and Rosenbaum further emphasises the substantial role of making action and experimentation without too definite instructions, namely 'tinkering', in the effective learning process [39]. Following these notions, the main learning approach for the study was determined as an experience based reflective design process. Thus, the material-based experimentation of the students via making action and obtaining experiences was encouraged to induce hands-on learning.

Learning environment: According to Zhou, Ragnoli & Ayala-Garcia [40], flexible learning environments such as workshops combined with classroom didactics is quite efficacious for establishing a design medium that helps to transforming traditional material didactics into participatory activities by using digital manufacturing tools (CNC machine, 3D printer, laser cutting, etc.). In this study, the design process of the material exhibition was configured as a workshop environment including brief theoretical lectures to provide students with necessary background to perform experimental design research via materials. Flipped Learning Network (FLIP) [41] was also used during the workshops to create student-centred learning environments. FLIP aims to establish an interactive learning environment where the tutors guide students for both group work and individual studies at different levels. Besides the workshop environment, the material exhibition is also regarded as an informal and flexible learning medium for the visitors. The concept of 'learning by doing' was embraced for the configuration of this medium through elaborated interactive attributes. In that aspect, material exhibition was designed not only to perceive the sensory properties of materials but also to produce adequate representations of material properties; which can also be observed in various layouts at conventional and mostly commercialised material databases. Consequently, the proposed model for the material exhibition is configured as an experiment-oriented learning medium where design students can relate to the material in a reflective design education environment.

3.2. Engaging the audience

Engaging the audience is one of the main considerations in any exhibition design and it can be defined with a set of parameters such as appealing to one's senses, stimulating and attracting attention of the target audience, creating positive and long-lasting impressions and conveying information and new insights [42,43]. A common misconception is overemphasised 'learning objects' while most people in fact visit exhibitions to have a "good time" [44]. This statement is considered as relevant in the case of a material exhibition design. Attributes that qualify the definition of the 'good time' from the audience perspective have been long discussed in literature. An exhibition can attract the audience through meeting their expectations and primary necessities. These necessities are listed as *comfort, orientation, belonging, respect, challenge, learning, doing something worthwhile, communication, active participation, control, social interaction, enjoyment, and revitalization* [42,44–47].

Among these parameters, *comfort*, *orientation* and *belonging* are closely related to the design of the exhibition environment: whether or not the designed environment meets the visitors' requirements, allowing them to orient in the space easily and creating a sense of belonging and welcoming through eased exhibition codes ("do not touch" signs can be referred as the most well-known example of codes). *Respect*, *challenge*, *learning* and *doing something worthwhile* can be achieved through a carefully selected language and mediums for the transfer of knowledge upon investigating the visitor profile, understanding their knowledge level, creating the sense of affirmation and challenging them in new knowledge or experiences. *Communication*, *active participation* and *control* demands interaction between the visitor and the exhibition by means of communicative and participatory assets and the amount of control or choice provided. Finally, *enjoyment*, *social interaction*, *revitalization* and *learning* are rewarded upon the interaction.

While providing a general idea on how to engage the audience, this approach still lacks the specificity in expectations of the selected audience profile and requires consolidation through information gathering from the specific audience [46]. Suggested methods for gathering audience opinion are demographic research, interviews and focus groups. With this perspective, a representative group, i.e. workshop students, was included in the decision-making process of this research and interaction methods were designed accordingly.

3.3. Human-exhibition interaction (HEI)

A systematic review and a framework for human-exhibition interaction (HEI) design can be found in [48]. This framework considers the exhibition space as a communication medium that transfers a message from the sender –*corresponds to* '*client*'– to the receiver –*corresponds to* '*audience*'– through the transmitter –*corresponds to* '*designer*' –. Within this framework, our approach was to consider the design faculty students as *receiver*, the university and the instructors as *sender* and material properties as emitted *messages* (Fig. 5). Meanwhile workshops with instructors allowed the participants to take roles as both *transmitter* and *receiver* bringing additional emphasis on *experience*. As argued above, engaging the audience was the first design parameter. The inclusion of participants as both the transmitter and the receiver enabled communication and feedback. Thus, the audience were involved in decisions on formation of the interaction.

In HEI design, the language for the intended communication is determined by exhibition-design factors such as exhibit components, technology, and atmosphere whereas design decisions are made based on audience experience factors [48]. In a material exhibition intended for design faculty students and novice designers, *curiosity*, *interest*, *fun*, *stimulating long-time memory*, *learning* and *triggering creativity* can be regarded as experience factors. A written medium is the most direct forward effort to convey a message. However, its mental processing needs the most effort compared to sensations and visual stimuli [35]. Thereby, following exhibition design factors were used for the exhibit unit:

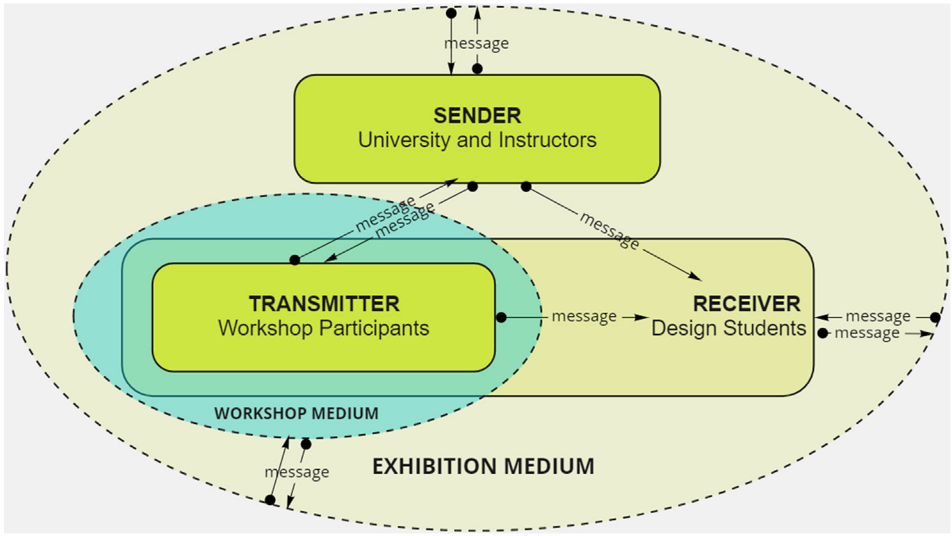

Fig. 5. Communication process as adapted from HEI framework (image by authors themselves based on the approach in [48]).

- Design language that allows multi-sensory experience of the material samples
- Ergonomics to allow interaction and hands-on learning: comfortable interaction height (Recommended interval is 1.0 m – 2.2 m [46])
- Use of both text and graphic contents to transmit information and development of a visual language
- Cascading the retrieved information through technology integration via mobile phones and QR codes

Informative visual aspects are one of the essential parts of an exhibition for better human interaction [49]. A well-developed dashboard can significantly enhance the comprehension of the most critical information; provide practicality and easiness in communication and support decision-making while occupying the least possible space –possibly not exceeding a single page/screen– so that the data can be monitored at a glance [50,51]. As set of rules, Few settles the following criteria for a successful dashboard design [51]:

- Graphical representation should be preferred instead of textual data. The chart type, colours and key performance indicators should be selected based on the context.
- Perceiving the data at a glance enables the user to identify the interrelations, similarities and differences. Therefore, layout design must be brief and legible.
- The inclusion of users is essential to provide usability.

These criteria provided essentials for developing a material dashboard layout as presented in Section 6. The proposed material dashboard included 20 tangible and intangible characteristics. Material performances were expressed with gradual scales instead of numeric results and a radar chart format was adopted for visualisation. Despite the drawbacks due to cognitive load and lack of precision, the interpretation and comparison of these charts were found easy due to people's higher-ability of distinguishing differences between shapes and compact representation of multiple criteria.

3.4. Self-supporting exhibit units

In general, exhibition design needs to be considered together with the potentials and limitations of an exhibition space and the existing technical infrastructure. This includes vertical surfaces for hanging or plinths for placing the objects, necessary constructive interventions such as partitions between different sections, seating area, lighting, access to power points, outlets, electrical wires, safety and health concerns [43].

In the case of a material exhibition mobility is of concern. This is firstly because in an exhibition where exhibit items are *materials*, a continuous expansion and reformation should be estimated due to the immensity of the material world and growth potential of the field thanks to the material science and developing technologies. But also, flexibility is necessary in order to host various activities such as workshops, installations and other exhibitions, in the common areas of a design faculty. Lastly, such material exhibitions are usually temporary interventions that are assembled during the fairs. Although this study was primarily intended for non-commercial applications, the potential of a mobile and self-sufficient material exhibition was acknowledged for easy assembly at temporary events such as festivals and fairs and for resource allocation between different universities. Furthermore, mobility and standardisation are also required in material research, in order to allow research partnerships and communication across cultures and geographical distances [15].

3.5. Sustainable exhibition strategy

Sustainability is among primary concerns in an exhibition design. Exhibitions can cause high carbon footprint due to production of exhibit items, furniture, transport cases, transport, temporary constructions at the exhibition venue, and energy consumption during the event [43]. In this study some strategies were developed to provide sustainability of the material exhibition medium:

- Material use: Recyclable materials with low environmental footprint should be used such as certificated wood.
- Automation and digital manufacturing: Through use of digital manufacturing techniques high precision can be obtained. The model and placement of pieces on a board should be optimised to reduce waste material.
- Transport: Although transportation is not one of the requirements in this study, digital manufacturing opens new possibilities for developing a systematic for open design. Open design is a movement that argues the necessity of putting the digital files

in circulation rather than the physical object [52]. Disseminating the digital model of the exhibit unit can minimise the transportation.

- Easy and fast assembly: For budget, time and resource management the material exhibition design should allow fast and commonly known joinery systems such as traditional interlocking joinery, which is also selected for this study.
- Allowing future expansions: Considering the future needs for including more items, the exhibition should bring flexibility for expansion, re-organisation and re-classification. Modularity should be a key parameter in meeting this concern.
- Maintenance: Human-exhibition interaction will shorten the ageing period of exhibit items. Allowing replacement of material samples and storage of spare samples should be of concern.

3.6. Systematic organisation of exhibition content

Considering the audience of the proposed exhibit system, materials and the required information for the material selection process are to be organised in a systematic and informative, yet practical and easily comprehensible way.

Systematic organisation of the building materials in an exhibition requires adoption of a classification system mainly according to the origin and the function. Many studies agree on usage of a common classification system according to the *origin* of the building materials [53–58]: According to the *function*, mainly for the field of architecture and construction, there are several proposals for a unified classification system such as; CI/SfB, UNICLASS, CAWS and ISO 12006–2 [59–62]. However, each material database follows its own system tailored to the needs of the organisation, their users, and the material range that they present. The classification methods of various material databases (including but not limited to [17–31], and structures of books about building construction and materials [63–66] were analysed for this study and also in authors' previous studies [16,67]. Ramalhete et al. also presented a comprehensive analysis of 87 digital tools for material selection [68].

Based on the most repeated titles, this study embraces the following classes for origin: stone, bitumen, wood, mineral based, soil based, plant/animal based, glass, metal, polymer, and composite. In the context of their area of use in a building, materials are classified under four main groups: *structural systems, service systems, building elements system, furniture and accessories.* Under these main system groups, each element and its related components are also categorised with respect to the hierarchy in between. With that respect, the building elements system group is divided into 5 sub-categories as; *roof, wall, wall opening, floor* and *stair*. Among these groups, for instance for the external building elements, the classification system branches further with the function as; *outdoor finishing, insulation, sub-construction, core and indoor finishing.*

4. Multi-sensory interaction analysis for material samples

In addition to the aforementioned theoretical classification models (i.e. origin and function), 115 pre-determined material samples were also classified according to their distinguishing sensory property and material sample's exhibit method. Exhibit

Table 1
Selected samples and classification according to the origin, function, distinguishing sensory property and exhibit method.

Origin	Function[1]	Selected material samples	Distinguishing sensory property	Exhibit method[2]
Natural stone	OF / IF	Travertine, granite	Visual, haptic	VH + MF / HP
	C	Pumice (Bims) block	Visual, haptic	HP
Mineral - based	OF / IF / SC	Fibre cement board, perforated plasterboard, acoustic plaster	Visual	VH + MF / VH
	I	Rockwool	Visual, auditory	VH
	C	Concrete block, AAC (Autoclaved aerated concrete) block	Visual, haptic	HP
Clay - based	OF	Clay roof tile	Visual, haptic	HP
	C / OF /IF	Brick	Visual, haptic	HP
Glass	WO / C	Float glass, laminated glass	Visual	VH
	O / C	Glass block	Visual	HP
	I	Glass wool, foam glass	Visual, auditory	VH
Metal	OF	Zinc plate, perforated aluminium plate, aluminium diamond plate, steel diamond plate	Warmth of touch, hardness,	VH
	C	Aluminium SHS (square hollow section)	Visual, haptic	VH / HP
	C	Steel C section, steel I profile	Visual, haptic	HP
	WO	Aluminium window frame	Visual	HP
Wood - based	OF / IF / SC	Wood (oak), impregnated wood, thermally modified wood, laminated chipboard	Visual, haptic, auditory, olfactory	VH + MF / VH
	I / IF	Wood wool	Visual, auditory, haptic	VH + MF / VH
Natural	IF / I	Cork, rubber, sprayed cellulose	Impact dampening	VH
Bituminous	I	Bituminous membrane	Visual, haptic	VH
Polymer	IF / OF / I	PUR (open & closed cell foam & sprayed), PE (open & closed cell), PES (foam & felt), EPP, Mel foam, EPDM geomembrane, PVC geomembrane, HDPE Drainage plate	Visual, haptic, auditory	VH
	WO	PVC window frame	Visual	HP
Composite	IF	Composite floor covering	Visual	VH + MF / VH
	C	Concrete block with EPS infill	Visual, haptic	HP

Notes:
[1] OF: outdoor finishing, IF: indoor finishing, I: insulation C: core, SC: sub-construction, WO: wall opening.
[2] VH: vertical hanging, HP: freely standing on a horizontal plane, MF: mechanical fixation.

Table 2
Required operation to observe the specified material properties.

Sense	Required operation	Material property	Material samples
Visual	Look	Texture, colour, thickness	All
	Look through	Transparency	Glass
	Look from side	Anisotropy, composite structure, joints	Wood, composite floor covering, laminated glass, laminated chipboard
	Rotate [1]	*Form*	*I beam, C section, brick, glass block*
	Move around	Form (oversized elements)	Window frame, oversized building blocks (pumice, autoclaved aerated concrete), clay tile
	Visual comparison of alternatives [1]	*Texture, colour, thickness*	*Laminated chipboard samples, water insulation membranes (bituminous membrane, pvc membrane, epdm ...)*
Haptic	Touch	Texture, warmth of touch, hardness	All (Integrating a warning of skin irritation is necessary for glasswool and rockwool)
	Push / Pull	Elasticity, stiffness	All, especially membranes
	Lift	Weight	Aluminium profile, steel profile
	Weight comparison of alternatives [1]	*Weight*	*Float glass vs. glass foam, concrete block with EPS infill vs. concrete block, aluminium plate vs. steel plate*
Auditory	*Listen (auditory comparison of alternatives)* [1]	*Sound absorptivity*	*Absorptive materials (rock wool, sprayed cellulose, wood wool, acoustic plaster, glass wool, melamine, polyethylene foam, polyester foam) vs. Reflective materials (wood etc.)*
	Hit and listen (auditory comparison of alternatives) [1]	*Impact dampening*	*Impact mats (Cork, rubber, neoprene, polyethylene, polyurethane, expanded polypropylene)*
Olfactory	*Smell (olfactory comparison of alternatives)* [1]	*Smell*	*Wood (oak), Modified woods (thermally modified wood, impregnated wood)*

Notes:
[1] The participants' proposals of operations.

method classification was based on the sample size and weight assumption. Materials that had one dimension significantly smaller than other two dimensions were considered as 2-dimensional samples and fit to vertical hanging. For board type samples, mechanical fixation was optional but preferred in order to extend the service life. For stone samples, either mechanical fixation or exhibiting on a horizontal plane was necessary due to the weight. Other 2-dimensional samples were seen fit to adhesives. 3-Dimensional samples were grouped according to their weight. High-weight materials (e.g., building blocks) needed a horizontal surface while lightweight materials (e.g., aluminium profile) were fit for both methods. For the prototype of the exhibit unit, several representatives were selected to represent each of these predefined classes (Table 1).

Upon selection of materials, their distinguishing sensory properties were analysed in detail and the required operations to observe the material property were listed. This analysis provided the foundations for the second phase of the study, in which the interaction methods and systems were developed through discussions with the workshop participants. The participants' feedback and experiments with the exhibition systems were later integrated in the analysis. Table 2 presents required operations, both the ones that instructors had initially planned and the ones that the participants' proposed. The proposed operations clearly demonstrate the students' need for comparative mediums in order to learn and internalise the material properties.

5. Proposed exhibit system

In the second phase of this study, a fifteen-day workshop was conducted to develop an exhibit system that will assist the material selection in design and encourage active learning by enabling interaction with the materials.

Two different exhibit strategies emerged in the brainstorming sessions with the participants. The first one consisted of a modular exhibit system. This strategy required development of a modular 'material plate' which would allow the pre-designated interactions and an exhibit display unit that would contain the material plates. The modular exhibit units primarily allowed visual and haptic interaction with the materials.

Each unit consisted of four parts:

1. Modular cassette openings (25x25 cm): This part created the main vertical exhibit surface for lightweight material samples that were exhibited in hanging position. 25x25 modularly designed material plates fitted in these openings and allowed continuous relocation and reorganisation of samples for future needs.
2. Horizontal surfaces and disks: This part was designed to accommodate heavy materials that require solid ground. Some of these surfaces were designed with rotating disks to easily observe the 3-dimensional form of the materials and to allow visitor interaction.
3. Storage unit: A storage unit was planned at the lower parts of the unit where it wasn't ergonomic to observe the material samples. The frequency of maintenance was one of the concerns due to the interactional attributes of the exhibition. The storage unit kept the spare material samples, creating a self-sufficient exhibit unit.
4. Material plates: Material plates were the modularly designed 25x25 cm wooden boards that held the material sample, relevant tags and information. These plates varied according to designated operation for interaction.

The second strategy was to develop experiment stations. This strategy was developed particularly to encourage comparison among different material samples and to answer the needs of some

Table 3
Explanation of system proposals to enable pre-assigned operations.

Sense	Operation	Manufacturing method
Visual	Look	Material plates: a) For heavy materials plates included screw fixation and a 2 mm nest where samples can be snapped. b) For lightweight materials plates introduced adhesive fixation without a nest.
	Look through	Material plates with voids: These were produced with a void at centre to exhibit transparency properties of relevant materials.
	Look from side	Material plates with additional slot:Some materials' cut sections (e.g. composites) provided essential information about inter-layers, inner structure or junctions. An additional slot was designed on the material plates to emphasise the side-view.
	Rotate	Rotating disks: Rotating disks were composed of a round wooden plate, which pivoted on ball bearings. These served to examine the 3D shape of heavyweight materials, which were otherwise harder to interact with.
	Move around	Static horizontal surfaces: Materials that did not fit on the rotating disk due to their large size were exhibited on a separate horizontal surface. Instead of rotating the sample, the audience moved around the sample.
	Visual comparison	Rotating polygonal plates:To emphasise functional categorization of materials with similar performance (e.g. water permeability) a polygonal plate was designed that allowed exhibiting multiple samples at the same cassette opening. The polygonal plates included a horizontal mil in the centre, allowing fixation to the exhibit unit and the pivot movement.
	Visual comparison	Material plates with colour chart: To assist selection among colour alternatives of finishing materials, these material plates were designed with a void at centre and a mil to hang numerous material samples side-by-side, in an axis perpendicular to the exhibition plane.
Haptic	Touch	Exhibit unit dimensions: The dimensions of the exhibit unit were designed with ergonomic considerations. Maximum height was defined as 140 cm and minimum height as 60 cm.
	Lift	Material plates with void: These plates were designed with a void at centre and two vertical mils on which materials moved vertically. This design allowed weighing the material.
	Weight comparison	Experiment station 1 – haptic comparison:This station was designed as a seesaw for materials to compare weight. Material samples of the same origin but different internal structure were selected for the station to emphasise how porosity, density and composite structure changed their weight. Designated comparisons were: (1) Float glass *vs.* glass foam, (2) aluminium plate *vs.* steel plate, (3) composite concrete block with EPS *vs.* concrete block
Auditory	Listen (Auditory comparison)	Experiment station 2 – Auditory comparison of airborne sounds: This station introduced two 40x40 cm cubic enclosures. The reflective cube was built only with uncovered wood while the absorptive cube was covered with various types of sound absorptive materials inside. Visitors walked inside the cubes and experienced the changes in the sonic environment.
	Hit and listen (Auditory comparison)	Experiment station 3 – Auditory comparison of impact-borne sounds: This station introduced a small hammer for hitting – therefore creating an impact sound on a) wood surface and b) on various impact dampening elastomeric materials applied on wood surface.
Olfactory	Smell (Olfactory comparison)	Experiment station 4 – Olfactory & visual comparison:This station was designated to emphasise how modification of wood changes its sensory properties (i.e. smell and colour) . Unlike the other samples these samples were connected to the unit with an elastic band, which allowed the visitor to approach the material to their nose.

sensory interactions (such as auditory interaction), which would not be possible otherwise. Contrary to the modular exhibit units, experiment stations did not require a systematic order to display the materials, rather a creative collection of samples. They also met the necessity of a fun-element to engage the audience and to transfer the knowledge.

Following an experimental phase, the manufacturing methods were defined to enable designated operations (Table 3). The exhibit elements were manufactured with CNC-cut plates and interlocking joints. Figs. 6 and 7 shows the prototypes of the exhibit system.

The proposed exhibit system goes beyond the state-of-the-art of the conventional exhibition approaches, through implementation of current material design notions and its increased interactive attributes. Thereby, an interactive material selection process is configured. For the exhibit unit, while modular cassette openings provide rapid application of all selected material plates properly; the design of the material plates transforms the material samples to interactive exhibit pieces. Thus, the material plates become attractive learning tools for novice designers and design students. Additionally, implementing various predefined operations -such as rotate, lift, and visual comparison- allows the material samples to be analysed in various aspects, conveys their performative experience and boosts the human-exhibition interaction. All in all, the exhibit system aims to generate novel experiments and experience media for the audience in order to enhance multimodal reasoning processes.

6. Material information system

In the third phase of this study, a ten-day workshop was conducted to develop an information system to be integrated with the prototyped exhibit unit. It aimed to visually represent the material information required for an *informed* material selection process during design and/or provide an educational background on the general aspects of the materials. Developed information system was intended for design students and novice designers, therefore it was aimed to be practical yet informative to stimulate multimodal reasoning processes and to enhance the design thinking.

Firstly, the main organisation of the material information was shaped around the classification of materials according to origin and function. Iconography was used as the visual representation method, which is a common practice in the areas of developing human–computer interaction and user interface design [51]. The resultant icons are presented in Fig. 8. Icons for the material origin were inspired from the raw materials and they were created considering their generic, recognizable and sensorial aspects. For

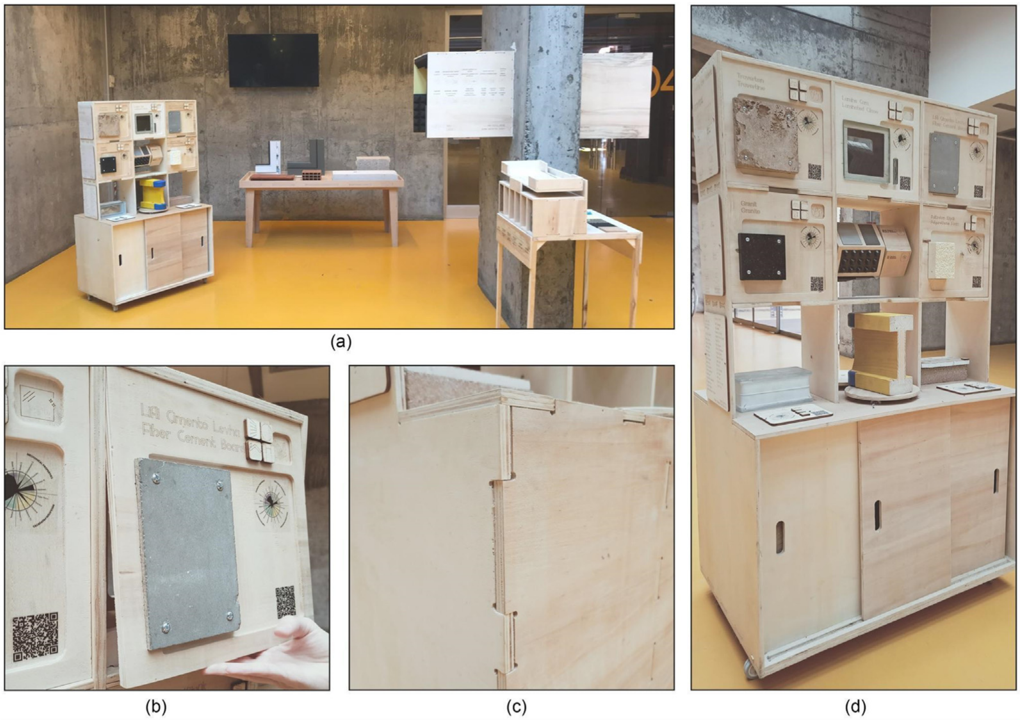

Fig. 6. Overview of the exhibit system; (a) prototypes, (b) modular cassette openings and material plates, (c) interlock system, (d) modular exhibit unit.

instance, stone icon refers to the fragmental shape of a rock, bitumen icon refers to the fluidity of the origin, polymer icon refers to its inner material structural and composite icon refers to the layered formation of the material.

In order to have a holistic context in the scale of a building and to cover different areas of use, a systems approach was embraced for the classification according to function. In the scope of this part of the study, this classification was constructed based on architectural and interior design applications. Icons for the function were created with reference to the construction type and method of the related system and how it becomes a part of the building. For example, icons developed for the *structural system* refer to the construction process; icons of the *service system* and the *window opening* groups refer to the common elements of the related function group. Furthermore, for the roof, wall, floor and stair groups, icons were created to represent the generic layers of the related building element. Hence, the classification of materials aims to be informative and guiding during the material selection.

Secondly, an informative representation layout that transfers both technical and sensorial properties of the materials emerged through brainstorming sessions and interaction exercises with the sixteen participants of the conducted workshop (Fig. 9). The main principle behind the development of such representation was to transfer materials information without any need of complicated written information or incomparable technical data. With that perspective, material properties were represented in a five-point rating scale –the ratings were determined with respect to one another- and radar charts were prepared for the visualisation of the data.

After exploring the information systems of different material databases and selection tools and based on the outcomes of the brainstorming and interaction exercises, the scope of the presented material properties was grouped under four titles; *physical, mechanical, insulation, surface*. Each title consisted of five parameters, where a common vocabulary was generated to represent both tangible and intangible characteristics of materials, in terms of their performances related with their function. Later on, the workshop participants investigated the material properties. Minimum / maximum values for each title were determined, and each material was rated with group discussions over the collected materials' information.

The novelty of the developed material property diagrams is that it covers not just the technical information but also the sensorial ones. Thus, it adds on to the experience and learning medium provided by the exhibit units, compliments to the processing of the material information gained by means of sensory interactions.

The radar charts were directly applied as stickers on the exhibit unit to enable simultaneous learning and interaction. Along with these stickers, icons showing the origin and function classifications were placed next to each exhibited material. Lastly, material dashboards were created and integrated with the exhibit unit via attached QR codes (Fig. 10). The dashboards provided digital access to the material properties, origin and function classifications, as well as to more-detailed information on the other aspects such as weight, size, construction type, construction method, and recyclability. An iconographic representation technique was again used for visualisation of information. Additionally, photos, written information, brands and resources used for the preparation of the material dashboards were also provided.

All in all, the developed material information system is comprehensive to cover the needs of the novice designers and design students and to guide them during the material selection process, in addition to offering a learning medium. The material information system includes (1) technical properties with respect to building elements functional requirements, (2) sensory properties in relation with the multimodal reasoning in the design process, and (3) properties related to materials environmental impacts regarding the sustainability of the design. During the material selection,

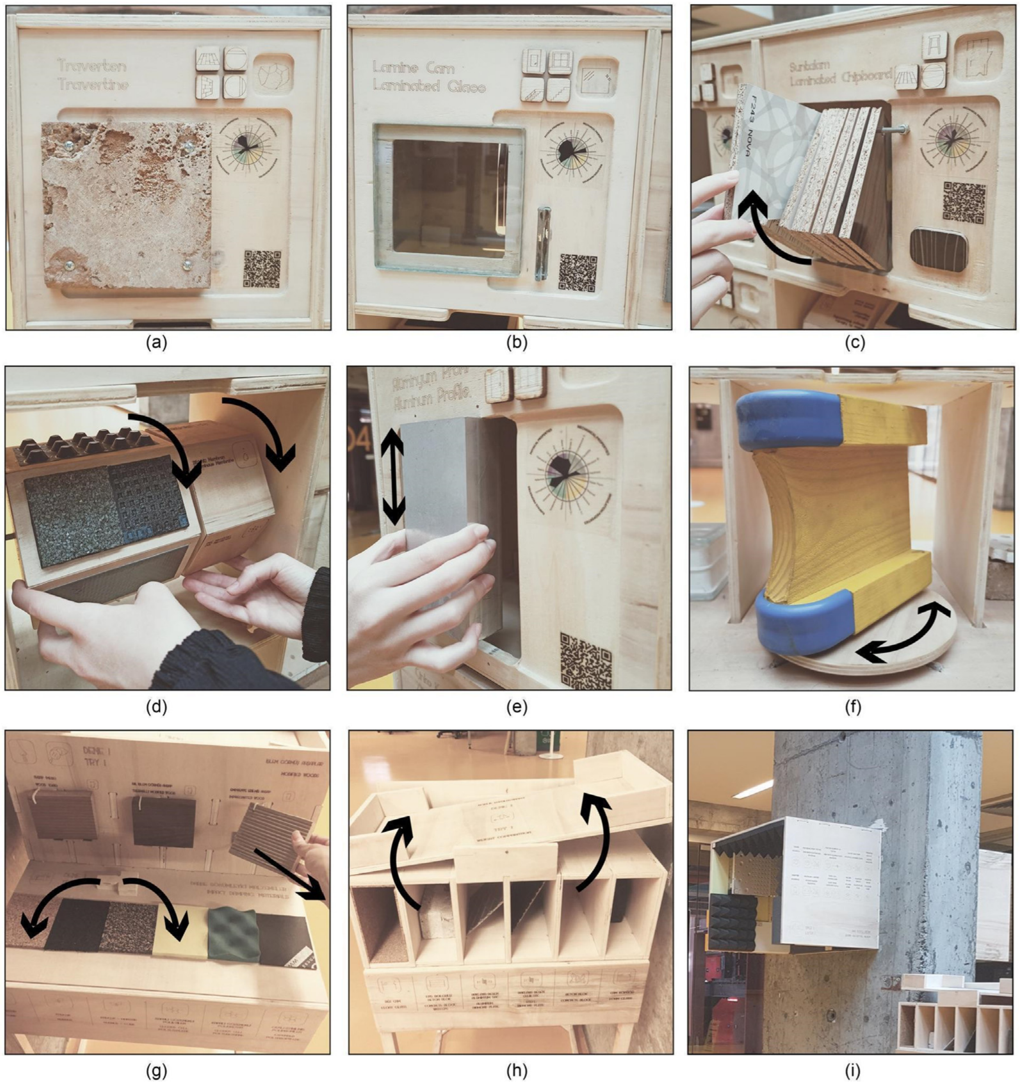

Fig. 7. Different types of operations; (a) look + touch, (b) look through + look from side, (c,d) visual comparison among alternatives, (e) lift, (f) rotate, (g) olfactory comparison + hit and listen (auditory comparison), (h) weight comparison, (i) auditory comparison.

considering the requirements and the identity of the design, possible material options could be compared easily by means of interacting with the exhibit unit both physically and visually.

7. Discussion

By acknowledging the importance of multisensory perception in designers' material selection process, this study suggests improvement of the physical material-exhibition mediums by considering their multi-sensory interactional attributes and their potentials for hands-on learning in material education. It reconsiders information delivery methods about material properties and qualities through implementing audience engagement and human-exhibit interaction approaches. The proposed system encapsulates the design considerations for a non-commercial and refined material exhibition for educational purposes.

On the other hand, this study also presents an approach on how to design and curate material exhibitions with a participatory mindset where a representative group from the audience is included in the design phase. This leads to integration of a feedback mechanism in the design phase to address the audience's necessities and also learning by 'making' action. With this approach, it is possible to tailor exhibition methods for each sample considering their multi-sensory perception. This approach can further lead to a 'do it yourself' model for exhibits where given information can be connected to a single open-repository.

7.1. Potentials of a multi-sensory material exhibition

The multi-sensory properties of materials were acknowledged as essential characteristics that have an impact on material selection during the design stage, therefore creating a medium to experience such properties was one of the main concerns. The proposed exhibit system allowed interaction with these properties upon a systematic analysis of materials and through assigned operations.

Apart from referring to sensorial properties as a selection parameter, one also needs to address the togetherness of these senses in a multi-sensorial experience and how they interact with each other in the cognitive process. As Dean indicates: "Although humans are primarily visual creatures, the other senses reinforce what is gained by sight. For example (...) the touching reinforces, confirms, and adds to the information gained through the eyes." [47]. In real-life, how people perceive their surroundings rarely depends on solely one sense. Multiplicity of sensory clues

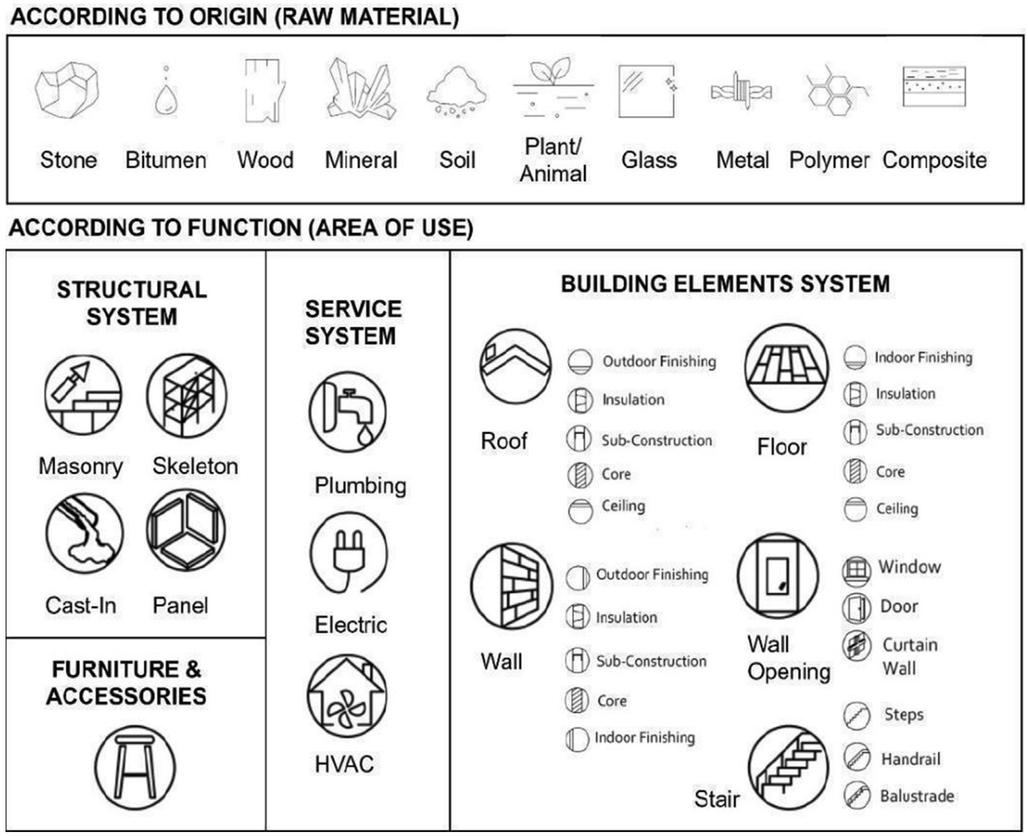

Fig. 8. Icons for the classification of materials.

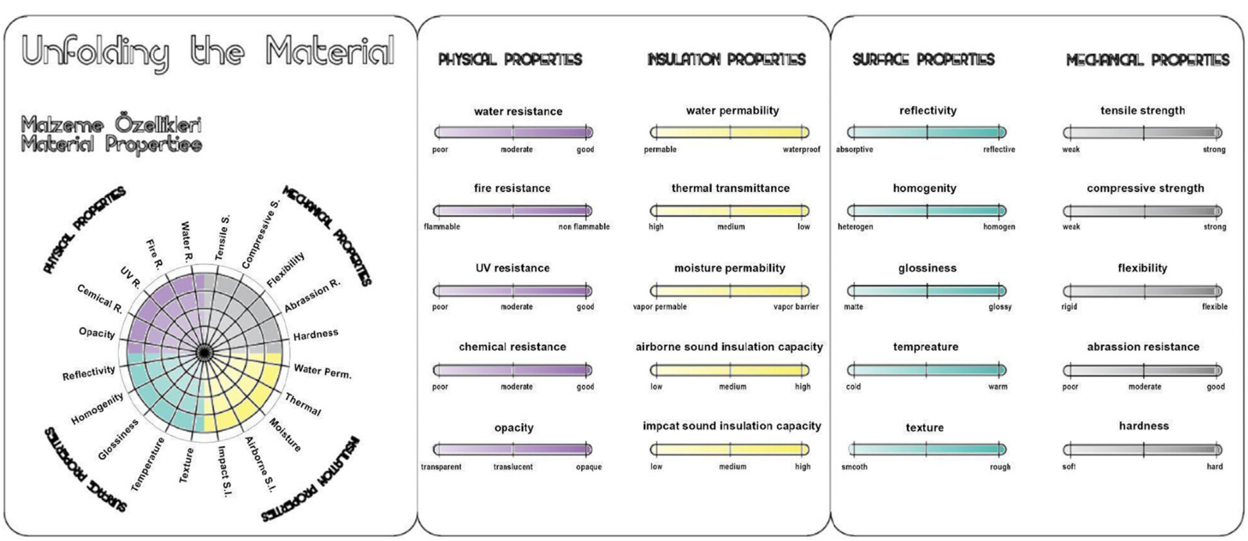

Fig. 9. Legend for the material property diagrams.

contributes to building a mental imagery for the surrounding or in this case for 'the material'. According to the scientists, this imagery does not need to be conscious; and once built, a multimodal mental imagery allows the perceptual processing to get triggered or modified by other senses [69]. A simple example is a thermally processed wood sample which can trigger the olfactory-mental imagery of a caramelised smell for those who spent a hot evening on a wooden deck. Some of these links are weaved unconsciously through the experiences when one does not pay attention. Yet, some others can be purposefully built-in young designers' minds via specific mediums designed to induce multi-sensory experiences.

Veelaert et al. highlighted the need for multimodal interaction environments and emphasised a research gap on conveying material experience not only at the sensorial level but also at the performative level [14]. In this context, the developed exhibition medium offers a divergent interaction at different levels of material experience. While developed modular exhibit units allow predefined actions related with selective senses, experiment stations offer a 'dynamic touch', thus enabling exploration of materials experien-

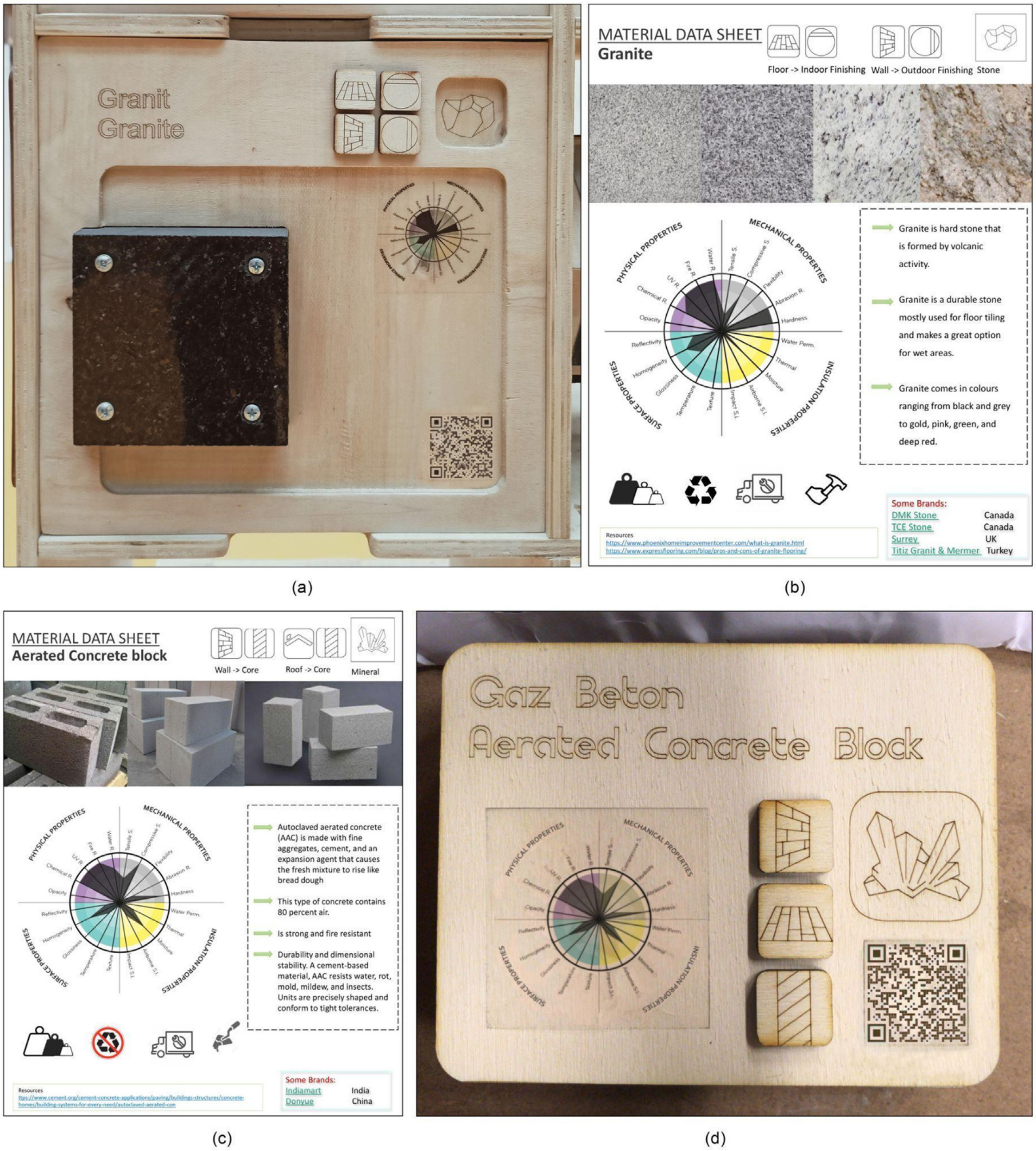

Fig. 10. Examples of integrated information systems; (a) icons, material property diagram and QR code integrated on the material plate, (b-c) online material dashboards (accessed via QR code), (d) icons, material property diagram and QR code integrated on the horizontal surface of the module for heavy materials.

tial qualities and acquisition of tacit knowledge through making comparisons.

Besides the aforementioned aspects, the study also outlined design considerations for multi-sensory material exhibitions. Among them, sustainable exhibition strategies and an open-design manufacturing process should be noted in order to decrease travel costs and environmental burden of such exhibitions. Build-it-yourself exhibition models already exist for science exhibitions where the collection is distributed digitally and printed at the exhibition site (e.g. [70]). For a travelling material exhibit system (for events such as fairs etc.) build-it-yourself options can be provided through digital fabrication. In this study, the exhibit unit and the material plates were designed as modular, thus decreasing the travel burden.

Mixed reality (MR), Augmented Reality (AR) and Virtual Reality (VR) studies are conducted in the design education and exhibition design fields in order to enhance conceptual thinking, transferring the knowledge between physical and virtual media, and providing alternative exhibit interaction in a virtually simulated physical world. To do so, virtual multimodal environments need to inhold fundamentals of the multi-modal experiencing parameters, which can only be obtained from user experiences in the physical world. To establish powerful learning domains in virtual environments that cannot be achieved in the physical environment, as Barker [71] said, the potentials of physical and virtual environments should be examined elaborately and effective communication between them is to be constructed. One of the recent studies focused on the effectiveness of virtual environments in the product design education by comparing it to the design process in a physical environment [72]. According to this research, while both environments equally enhanced students' design experience and knowledge domain, divergent research for ideation and advanced suggestions for further design steps were more successful in the physical environment than AR/VR. Additionally, for the exhibit systems, virtual environments were studied with a three-step exhibit scenario experiment, one of which also included a physical exhibition setup [73]. From this perspective, the proposed approach and findings of the current study applies also to this research field for improving multi-sensorial effectiveness of AR/VR applications intended for design students and novice designers.

7.2. Designing for hands-on education

Today the merits of hands-on approach in education are largely recognized and applied. The reasons come from the distinction between different learning types, which physiologically require the information to be processed in different domains of the brain. Bloom's taxonomy of learning is a widely recognized classification system that distinguishes three different learning types: cognitive learning which explains the mental process, connections to senses, experiences, and long-term memory; affective learning which explains the internalisation of learning through emotional and attitudinal responses; and psycho-motor learning which includes the physical encoding of information with movement and activities [74,75]. One might argue that by providing informal learning environments, interactive exhibitions address three domains of learning. They offer the possibility to explore, experiment, induce long-term memory, stimulate emotional responses, require physical and tactile activity, and incorporate kinaesthetic intelligence [75]. Nevertheless, current curriculums in most technical schools include material-based courses that are constructed as theoretical lectures and mostly provide technical properties of materials rather than sensorial ones [76]. Therefore, transferring the obtained technical knowledge to the design process without comprehending the material via multimodal reasoning phases is quite challenging for most of the design students. With that aspect, the material exhibition succeeds in creating an effective learning medium.

The study provided some insights on how to design these types of exhibitions. One of the strengths of this study was the participatory mindset. In design research, participatory mindset is defined as the attempt to involve the audience in the process as co-creators [77,78]. Through sequential workshops, this research included a group of students as active participants in the decision-making process and collected their inputs and opinions for the development of the interaction mediums. In this manner the exhibition planners were bridged to the audience's opinion. Some of the students' approach was rather experiential. They performed a large amount of experiments to retrieve the knowledge inherent in the materials' nature. Some of their experiences could be transferred to the experiment stations, while some others including fire, water, breakage experiments could not due to safety concerns (To avoid misleading the readers, it is worth clarifying that all the experiments were performed under strict supervision and safety precautions).

An important observation during the experiments was the students' need for making comparisons among different samples as a learning strategy. The material properties that were expressed verbally or in numbers were too obscure for young designers to fully comprehend the meaning. Experiments and comparisons seemingly helped them to internalise the material characteristics. Therefore, several comparison elements were introduced in the proposed exhibit system. Selected material properties were expressed in a gradual scale and a visual language to allow easy comprehension. Therefore, the information via the exhibit unit was transferred to the audience with a scalar data (five-point rating scale), which means, any precise numeric material properties or test results were not represented. With the ambiguity of the obtained information by the audience, novel material-based knowledge would emerge more effectively via the creative design thinking process of novice designers and design students.

Designing the experiment stations required a creative collection of items around a selected theme. From this point of view, the designers' responsibilities are similar to those of a museum curator: to create an interesting story, make research, design how the items will be observed and shape the experience of the visitor. The designer should be equipped with sufficient technical knowledge and background on the subject to develop meaningful collections that are fit to the purpose. For example, in the prototyping phase the idea of pair-wise weight comparison emerged from aluminium and steel plate samples in order to demonstrate the effect of density among different types of metals. Further comparisons were created between float glass and glass foam samples to introduce the role of materials' inner structure; and between a concrete block and a composite concrete block sample to introduce the decrease of weight through EPS infill. The idea led to the design of an experiment station in the form of a seesaw - a form most of the people are familiar with, thus engaging the audience.

7.3. Analysis of the exhibit system with audience engagement parameters

Several audience experience factors were outlined at the beginning of this article to engage the visitors to the exhibition. *Comfort, orientation, belonging, respect, challenge, learning, doing something worthwhile, communication, active participation, control, social interaction, enjoyment and revitalization* were mentioned as visitor engagement parameters for museums [42,44–47]. Although the scope and the scale are different from a museum's, these experience parameters are considered as relevant to this study. In order to succeed in its aim, a material exhibition should also lure and engage its visitors.

It was argued that *comfort*, *orientation* and *belonging* were mainly related with the design of the exhibit environment whereas in this study only prototypes were developed. However, regarding *comfort* it is safe to claim that removing the restrictions on "not touching", which is found highly controversial to human nature [46,75], and encouraging the interaction contributes to an increase in perceived comfort.

The study associated *respect*, *challeng*e, *learning* and *doing something worthwhile* with the transfer of knowledge. *Respect* was shown to the students by recognizing their level of the knowledge, selection of a terminology, to which they can relate and also by including two groups of students in brainstorming, decision-making and prototyping phases. The students' proposals led to the experiment stations, which encouraged young designers to learn by comparison and at the same time to *challenge* them in new experiences. Expectations on *learning* and *doing something worthwhile* were also met through creating different learning platforms. The knowledge was cascaded through integration of technology. Only limited information was provided in the physical exhibition, while more information was achievable at the online dashboard linked with the printed QR codes.

Other parameters; *communication*, *active participation*, and *control*, were achieved through the interaction. A great number of infographics and visualisations were prepared in order to *communicate* with the visitor and to facilitate the interpretations. The dashboard design principles were applied to assist comprehension. *Active participation* was encouraged through interaction with the material plates, interaction with the experiment station, interaction with the infographics and QR codes. The cascaded knowledge provided the visitors *control* over how much information they will be exposed to and how much time they will spend on the exhibition.

Finally, *social interaction*, *enjoyment* and *revitalisation* were rewarded at the end of the interaction. The sensory stimuli increase the audience's curiosity and attention towards an exhibition [46]. And the hands-on approach of the exhibition also adds to the fun-factor. Studies showed that the interactive exhibitions were found to be more enjoyable than the static exhibitions [75].

7.4. Limitations

Even though the proposed framework for the material exhibition system involves three design disciplines, i.e. architecture, interior design, product design, the manufactured prototypes and the integrated information system refers mainly to the architectural design practices by means of functional classification, certain titles in the material property diagrams and dimensional properties of some of the samples (e.g. building blocks). While architecture and interior design disciplines have similarities in interpreting the materials and associated performances from a building construction perspective, product designers have a larger spectrum of interpretations for a material. This brought the necessity of narrowing the scope during the prototyping phase. Nevertheless, the scope of the exhibition medium in practice can be extended to the other design disciplines through redefining the interactions with the materials' sensory properties with a more holistic approach and adjusting the information system accordingly.

One shortcoming of the proposed exhibit unit is the lighting. Each unit was originally designed together with two portable light sources of different temperatures: warm white around 2700 Kelvin and cool white around 5000 Kelvin. These portable light sources were designed to enable perception of colour and texture properties of materials under different light temperatures or beam angles, while also contributing to self-sufficiency of exhibit units. In the prototyping phase the light sources were eliminated for simplification.

In this study, the workshop participants prepared the content of the material dashboards and the material property diagrams within a limited duration. Even though it was supervised and guided by the instructors along the process, authors acknowledge the importance of expert involvement to the selection of the information and visualisation of the obtained data. Especially, an expanded research and an objective evaluation procedure should be followed in the process of transferring the information into scalar data.

8. Conclusion

This research proposes an integrated learning tool, which was configured as an interactive material exhibition that actuates design students and novice designers to improve their design skills by means of imposed multimodal sensorial properties of material into an experimental design environment. The exhibition medium was proposed to enable essential knowledge of material selection for novice designers and design students by not only focusing on commercialised technical information about material properties but also sensorial characteristics of materials. In this way, novice designers can construct adequate interrelationships between materiality and architectural design.

The study also fills a scientific gap by developing a framework to address design considerations for material exhibitions and recognizes the multidisciplinary applications. The research was developed considering design education pedagogy, museum/exhibition design, informative representation approaches together with the material selection process and material design research. Through theoretical and experimental phases of the research, a medium for providing human-exhibition interaction was developed. Materials were analysed and classified according to their distinguishing sensory properties, exhibit method, and the user operation required to observe the sensory property. Although the study addressed primarily non-commercial material exhibitions such as those at universities as an educational tool, the principles can also be applied to the commercial ones (e.g. material fairs), which can extend the scope to professional design practitioners.

A prototype was developed and manufactured in a fifteen-day workshop, together with fourteen students. The material information system was later integrated into the prototype unit, in a second ten-day workshop with sixteen students. Throughout the process, the participants were considered as transmitters between the sender (the university and the instructors) and the receiver (the faculty students). This approach enabled inclusion of the audience in the decision-making process and introduced their point-of-view to the instructors. It was evident that young designers' approach to design was hands-on learning mediums by experimenting with the materials, therefore the proposed exhibit system consisted of two different approaches: (1) modular exhibit units, and (2) experiment stations. The modular exhibit units required a systematic ordering of samples while the experiment stations required building up different collections like a curator. This suggests that the exhibit designer needs to be equipped with sufficient technological knowledge and background and to be willing to research, reinterpret and design for human-exhibition interaction. It was also observed that students preferred comparative evaluation of materials' properties rather than verbal or numeric data. This highlighted the importance of adopting comparative and experiential learning techniques supported by scalar graphics and informatics to transfer the knowledge. The proposed material information system accomplished this task by organising the material properties visually and comparatively. The informative representation translated the obtained experiences in general notions that enabled design students and novice designers to comprehend the role of material in design. Thus, the material exhibition is redefined as a medium for effective learning and experiencing in order to provide an efficient roadmap for material selection.

The benefits of a multi-sensory exhibition are twofold. In addition to assisting material selection in the design stage, the sensory stimuli also increase the audience's attention to the exhibition, contributing to audience engagement. Furthermore, it was proposed in the study that audience engagement can be provided in a material exhibition through (1) design of exhibition environment / medium, (2) developing interaction, (3) reward mechanism in response to interaction. Although supporting knowledge-transfer through stimulation of long-time memory was one of the reasons for conducting this study, there isn't enough evidence on learning implications of such exhibits in design education. Further research is necessary on material exhibit systems mainly to understand subjective responses of the visitors to such exhibitions and to evaluate the learning outcomes. In order to enhance the processing of sensorial and epistemological information about materiality as an integrated design-thinking phase, more academic and pedagogical approaches should be implemented into the design education via focusing on generating experience-based learning platforms.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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