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Emerging Material Research Trends: Fostering Critical Material Research in Design Students

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Abstract

Sustainable production transition requires new paradigms and strategies, as well as alternative materials. Recently, an increasing number of innovative materials were developed. Such novelties greatly affected the design practice, widening the materic possibilities for designed products. However, traditional material classification does not apply well for these new materials trend. In this paper, the authors cooperated with design students to identify an iterative tracing activity of the new material trends for design, finalised to embed in the same work new tendencies that may rise in future.

Keywords: emerging material trends, materials classification, design education, case study, sustainable design

1. Introduction

New materials often represent the starting point for product design innovation (Ashby and Johnson, 2003): by practicing and interacting with prime matter, designers are able to envision new product possibilities and trigger the design creative process (Karana *et al.*, 2014; Papile *et al.*, 2019).
Traditionally, materials research has been driven by military and aerospace industry. Afterwards, the motivation to discover new materials slightly shifted to accomplish the consumer needs, in terms, e.g., of hedonic appreciation (Ashby and Johnson, 2014). In this frame, the role of the designer was mainly identified as a material "manipulator" (De Giorgi *et al.*, 2020), who sees and appreciates the material potentialities, and creatively deploys matter into new products and shapes. Nowadays, materials evolution, alongside processes technological development, disrupted the design culture (Antonelli, 1995; Antonelli and Burckhardt, 2020) – think of e.g. composite materials, additive manufacturing materials, functional and smart materials – enabling totally new products shapes and aesthetics (Bergström *et al.*, 2010; Santi *et al.*, 2020; Vallgarda and Redström, 2007).
The contemporary incessant research for new materials is trying to respond, as efficiently as possible, to Sustainable Development: United Nations, as well as Europe, National regulations and people, are demanding for products that are Environmentally, Socially and Economically friendly (United Nations, 2021). Therefore, an increasing number of new materials is emerging in the material panorama, trying to address specific and/or systemic sustainable objectives.
These "new materials" often show peculiar characteristics and properties, most of the time they "behave" or change directly through environment interaction, sometimes they are re-discovered in their purity or with new established aesthetics. Therefore, new materials hardly match with traditional material classification.

At the same time, also the "relationships" between designers and materials are changing, shifting to new paradigms like the "materials designer" (Clèries and Rognoli, 2021), who both creates new designs from materials and designs new materials, is an emerging trend.
According to Dal Palù (De Giorgi *et al.*, 2020):

> *"The boundaries of the material designer's skills today are ephemeral and blurred. Thanks to practical research carried out in workshops and interdisciplinary laboratories, material designers play the role of emerging figures, characterised by a hybrid approach to research, and a mixture of knowledge borrowed from other professions. The experimentation ground coincides increasingly with learning-by-doing activities, in which new skills are proposed and "metabolised", eventually becoming recurrent approaches in the development of new materials".*

The material-designer, similarly to an alchemist, works at the edge of design and agriculture, of design and biology, of design and waste management and so on, diversifying and widening the design possibilities to be applied in projects. Such tendency directly reflects on the wide panorama of materials for design that nowadays is more than ever interesting and diversified. New materials emerging from these practices slowly detach from traditional material families and classes, shifting towards new possible material clusters and creating a crucial gap for design practitioners.
The exercise of finding a new way to define emergent material classes is not a novel attempt in design literature: previous authors (Brownell, 2017; Genovesi and Pellizzari, 2017, 2021; De Giorgi et al., 2020; Peters, 2011) tried with their work to narrate this difficulty to remain into traditional material classes with different approaches. Therefore, it becomes fundamental for designers to find some guidelines to navigate in this new material panorama.
In this work, the authors highlighted the emerging trends from a systematic literature analysis and material repositories scouting. Building on such identified trends, this work presents a repeatable and adaptable *modus operandi* to be used both in didactic and research scouting activities to monitor case study materials. The objective was to set up the bases for a repeatable activity, to track the new possible material classes offered to the designers and possibly embed new trends and tendencies that may rise in future.

2. Methodology

To monitor the new materials panorama and provide a useful picture of materials research and production trends, in this work the researchers - together with design students - carried on an extensive case study analysis.
In this work, an alternation of back-office tasks conducted by the research group and students' didactic activities led to the identification of material research trends that are useful for the designer's activities (Figure 1).

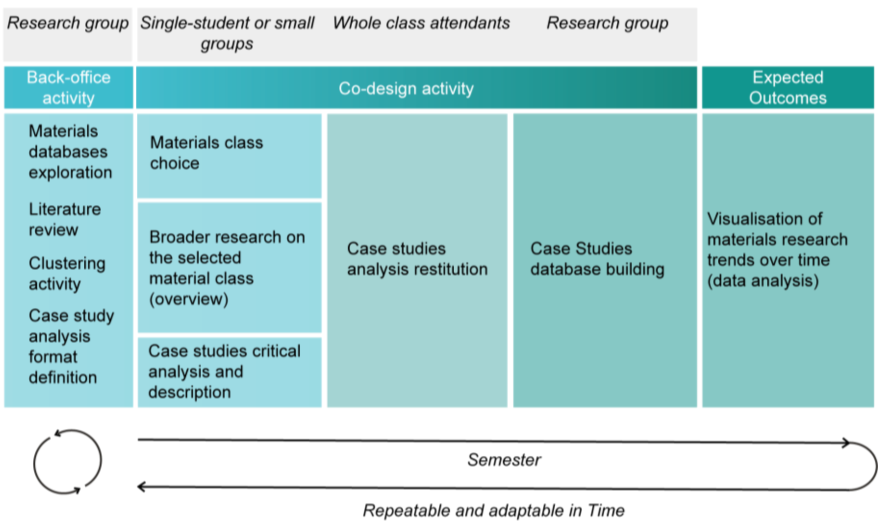

Figure 1. Research activity methodological path

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2.1. Back-office activity

Merriam-Webster dictionary defines a trend both as *"a general direction of change: a way of behaving, proceeding, etc., that is developing and becoming more common"* and *"something that is currently popular or fashionable"*. According to this dual definition of trend, the research team scouted the most recent and popular material proposals through material online repositories and databases (Papile and Del Curto, 2021) in order to define the main material research trends. Research through online databases, books and literature proved to be essential to understand how materials research in design is shifting towards new material alternatives, not matching with classical materials classifications. Research upon most common "novelties" found on online material databases and books allowed the researchers to identify some clusters that could contain those material novelties. Consequently, six different material trends were identified and defined by the authors, as represented in Figure 2 and described hereafter.

Figure 2. Material research trends

2.1.1. Functionals

Functional materials (smart materials) can respond to external stimuli. This peculiar category of materials shows a "non-intuitive" behaviour when exposed to the action of a certain chemical-physical stimulus (Lefebvre *et al.*, 2014). In a broader sense of the term, materials can be defined as functional even when, through proper composition/geometrical control, they can exhibit particular behaviours, e.g. optimising diverse functions through a single material otherwise obtainable with assemblies of products or "reactive" materials (Rognoli *et al.*, 2016).

2.1.2. Bio-XXX materials

Bio-XXX includes all the materials characterised by the "bio" prefix (e.g. bio-based, bio-degradable, bio-compatible…), plus compostable materials.

Bio-based materials derive partially or totally from vegetable biomass, regardless of their ability to biodegrade. On the other hand, the biodegradability process consists in the degradation of the material (in either aerobic or anaerobic conditions) into carbon dioxide, water (or methane), mineral salts and biomass, thanks to the action of microorganisms such as bacteria, fungi and algae (UNI EN, 2002, 2007).

2.1.3. Re-discovered

This category groups case studies reusing production waste or by-products coming from various productions. This generates materials that are similar, corresponding or completely renovated.

Usually named as "from waste" (Sauerwein *et al.*, 2017), re-discovered materials differ from conventional ones since they usually come from a mixture of materials already discarded.

2.1.4. Biomimetic

Biomimicry is the study of the biological and biomechanical processes of nature, as a source of inspiration for the improvement of human activities and technologies (Benyus, 1997; Rossin, 2010).

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Biomimetic materials are defined as man-made synthetic materials that replicate the natural biological behaviours of certain species (Purkait *et al*., 2018).

2.1.5. *Alive*

The materials and surfaces interact more and more with the surrounding environment, until breaking down the boundaries between "animated" and "non-animated" matter. Cell cultures and bacteria can generate (and certain times activate) unusual behaviours that make materials similar to living organisms, i.e. changing over time.Alive materials are part of a new and constantly evolving category of materials, including growing (Camere and Karana, 2017), biohacked and biofabricated materials (Camere and Karana, 2018; Xie *et al.*, 2019). Starting from the metabolic wastes of living organisms such as bacteria, fungi and yeasts, new materials were created that are still being explored.

2.1.6. *Foodology*

Recently, more and more yarns and fabrics are produced from fruit and vegetables waste such as apples, oranges, algae and even milk proteins. FAO (FAO, 2013) estimated that 1.6 billion tons of food are wasted every year. The topic is in the spotlight, gaining increasing attention also from the materials science and technology.
Foodology includes:

- Projects and solutions aiming to raise awareness of the problem of food waste;
- Food-contact materials, which is a rapidly growing trend.

As a result, a wide range of biodegradable materials (possibly consumed together with the product) may reduce the packaging environmental impact, e.g. by replacing synthetic materials. Furthermore, edible packaging can contain additives to extend the product's shelf-life, to improve its nutritional or sensory qualities (flavouring or colouring), or to increase the mechanical or barrier properties.

2.2. Co-design activity

The authors presented the above-mentioned material trends to the learners enrolled to the "Nanotechnologies and functional materials for design" elective course at the Design School of Politecnico di Milano. As part of the teaching-learning activities, the learners (in single or small groups up to three people) selected one trend of interest and explored it through a deepening activity, following either a vertical or a horizontal approach (Figure 3). In the horizontal approach, the theme would be slightly deepened in its variants and the case studies analysed in a larger number to ensure diversity. On the other hand, in the vertical approach, the chosen theme will be deepened on a specific aspect while the case studies will be less and more focused to explore different aspects of the same material.

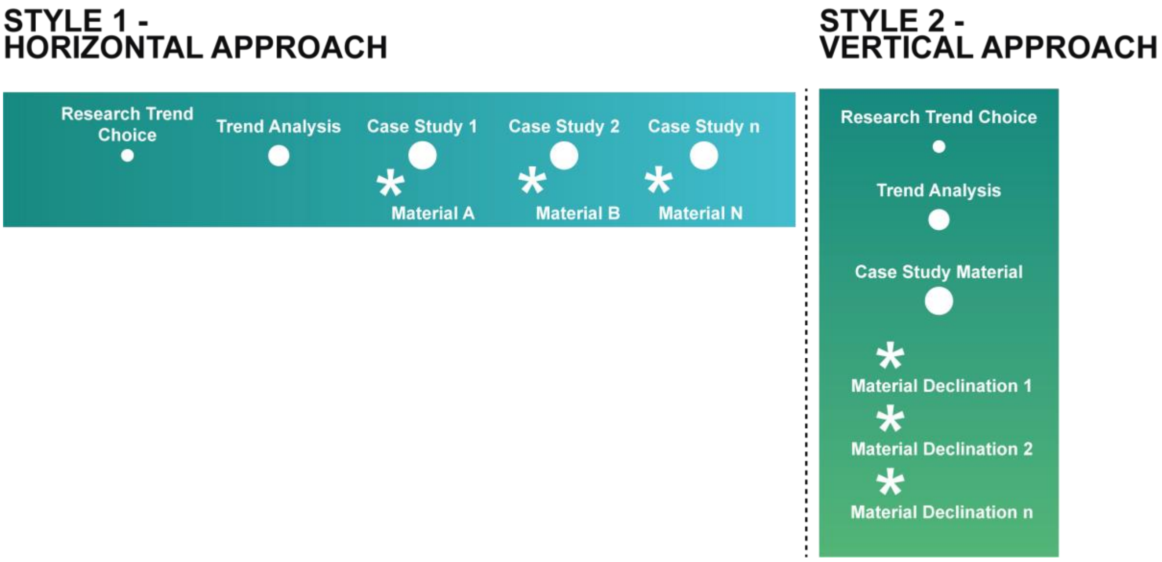

Figure 3. Deepening activity proposed styles to follow

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Case studies retrieval was an essential part of the didactic activities, allowing the students to be up-to-date with the new technologies, processes, and materials. Most importantly, open discussion during classes may improve transversal skills of the students, i.e. stimulating both critical and comparative analysis on the retrieved solutions, further fostering the discussion on the presented material trends.
As outcome, they produced a written elaborate in which case studies had to be reported to support their argumentation. Additionally, all the case studies created a collection available to the students that was subsequently reviewed by the authors and re-elaborated as a restitution - which the students could use for parallel or following courses. An "enquiry format" guided the analysis and description of the case studies in terms of technological transferability, technological maturity and possible other deploys (Figure 4).

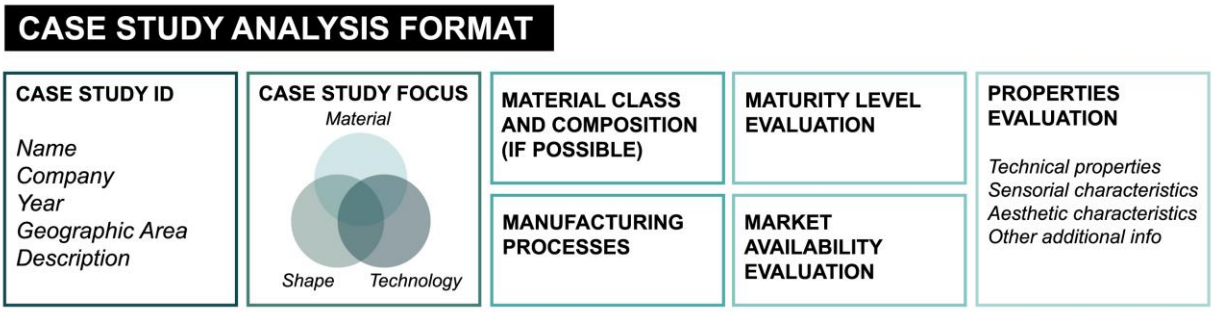

Figure 4. Case study analysis provided format

As an optional work, the learners had the chance to produce an Instagram carousel related to both their elaborate and case studies to be published on the research group's profile, to be shared with the extended community (composed by both the enrolled students and the public and businesses).

2.3. The necessity of visualising information

The mapping activity is an intrinsic and useful practice in design creative process: keeping trace of the collection, elaboration and interpretation of information allowed the development of several heuristic and pragmatic tools, methods and strategies (Dorst, 2019). By providing a critical description of the retrieved case studies, the class provided a systematised analysis of several different materials, clustered by the material research trends. At this point, the researchers were able to review the results and cluster them as follows:

1. The data provided by students was catalogued in an indexed table through the main categories of the case study schedule provided to the class;
2. The matrix fulfilment allowed the researchers to build a database of case studies;
3. The complete database was deployed to realise graphic visualisations to effectively describe some dimensions concerning the new material categories defined by the authors.

3. Results

A total of 74 different case studies were collected and systematised. To provide a contemporary overview, the students were recommended to prefer case studies no older than 15 years. Hence, the case study collection is populated by case studies from 2006 to 2021.
The amount of case studies collected depended on the number of attendants, single or group activities and from the students' discerning criteria to evaluate as exhaustive for the proposed work a certain number of case studies. However, on a wider perspective, the case study analysis provided some interesting insights on materials research trends for design discipline, resumed in following paragraphs.

3.1. Overall considerations

The case studies are mostly related to the USA territory (24 entries), followed by Italy (17 entries).

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According to the analysed case studies, it may be observed how the selected trends followed a certain course (Figure 5).

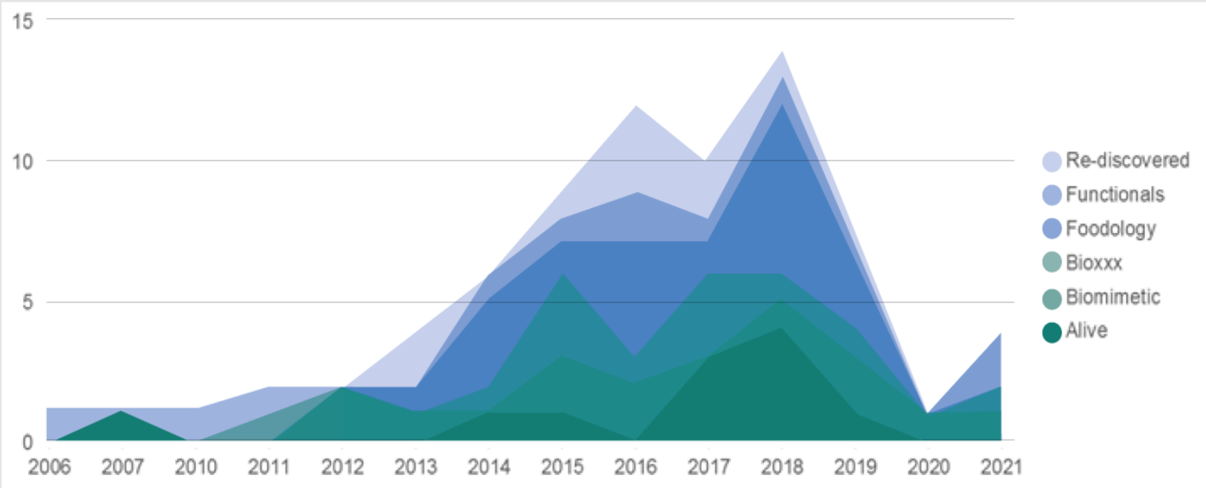

Figure 5. Material research trends evolution over the years according to case study basin

Case studies emerging in the Functional trend are the oldest, and over the years, they have been of growing interest in the last 10 years. Re-Discovered materials, on the contrary, grew in the last few years, depicting an impellent necessity of creating new materials from waste. Following the same trend, Foodology materials showed a great increment, while Bio-XXX and Biomimetic materials maintained a constant research interest according to the analysed case study basin. Alive, instead, represented the most emerging trend: although a small number of case studies was collected, it seems how research is raising its interest in alive materials. The plot highlights a sudden dip for 2020, that could, perhaps, be related to the global pandemics situation.

Over the years, the maturity level of the new material trends proposed slightly changed alongside the number of trends (Figure 6).

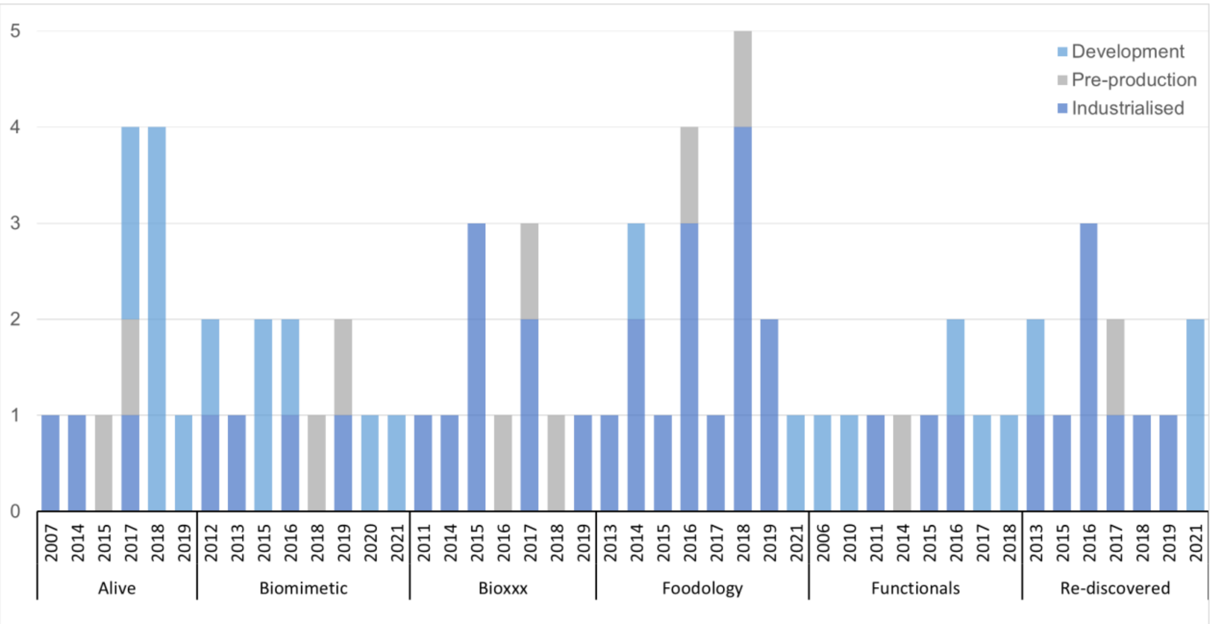

Figure 6. Material research trends maturity level evolution according to case study basin

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Considering that the number of case studies collected for each trend was different, the numbers showed in Figure 6 were somehow considered less than the evolution trend itself. It is interesting to appreciate how case studies concurring in the same class generally showed an increasing industrialisation level over the years, as a confirm of industry adoption of new solutions. Taking as a reference the case studies specific focus, it was possible to verify their distribution according to different variables, such as material, shape, technology or a combination of these elements (Figure 7).

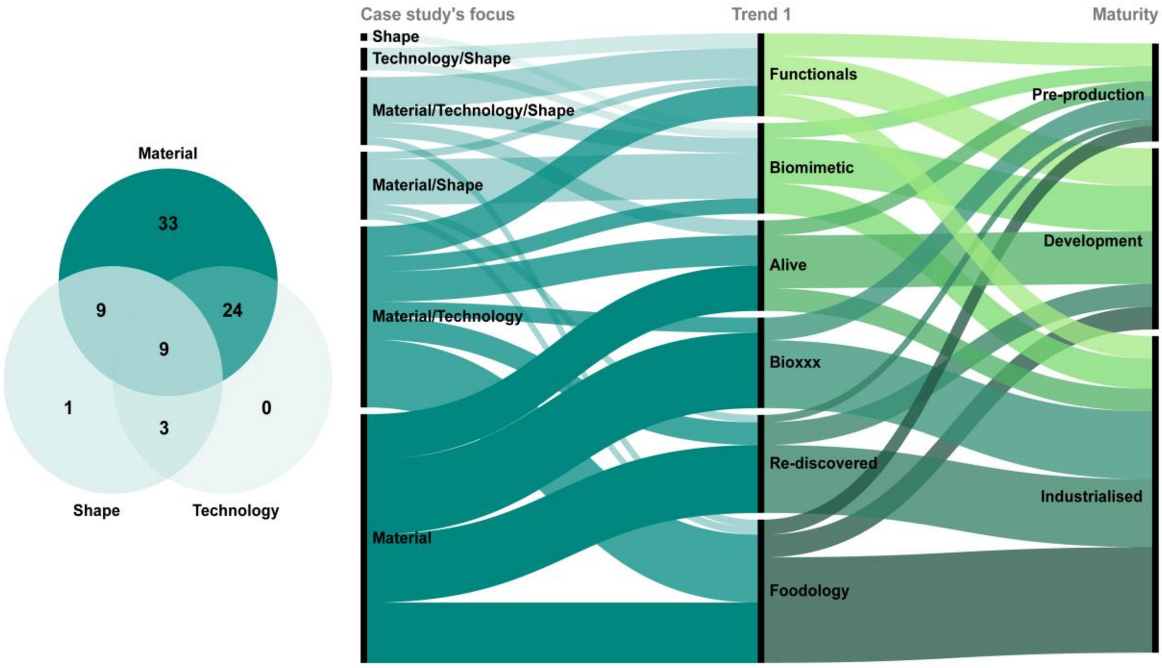

Figure 7. (Left) Case study focus distribution; (Right) Case study focus overlap with case study trend and maturity level

Most of the cases focused on the material and its properties. Entries with the focus only on the shape or technology were almost none. However, when the technology interacts with the material, it acquires greater relevance by ranking second. The case studies in which the material-shape and material-shape-technology interaction is important were on an equal footing, followed by shape-technology.

Figure 7 clearly shows how certain material trends (e.g. Bio-XXX, Re-Discovered and Foodology) showed the highest number of entries and the highest level of industrialisation, meaning that the materials proposed in these categories could be effectively deployed in design projects. Although generally found as products, Alive materials represent the highest share of case studies in development, meaning a trend of growing interest to be followed in the upcoming years. Functionals and Biomimetic materials were mainly associated with shapes and technologies. Although developed earlier compared to other trends, Functional and Biomimetic case studies were mainly in a development phase, suggesting that the research requires higher effort to transfer them to an industrial level.

Possible mixture among different case studies is proposed in Figure 8. Some case studies overlapped in between different material research trends, highlighting how the research on certain topics is in ferment. For most of the case studies no intersections were identified; nevertheless, the trends with the most interactions were Foodology, followed by Alive, Bio-XXX and Re-discovered. In addition to being the trend with more case studies, Foodology has intrinsic characteristics that overlap with both Re-discovered and Bio-XXX, since they are mostly waste materials and of natural origin. The Alive, on the other hand, are more intertwined with the Functional and the Bio-XXX, working as a bridge between them. Generally, however, such

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reduced overlapping extent suggests that the material trends (thus, clustering) is a good descriptor at present. Indeed, large overlapping areas mean that case studies may be clustered as belonging either to one or another one, thus requiring a revision of the division.

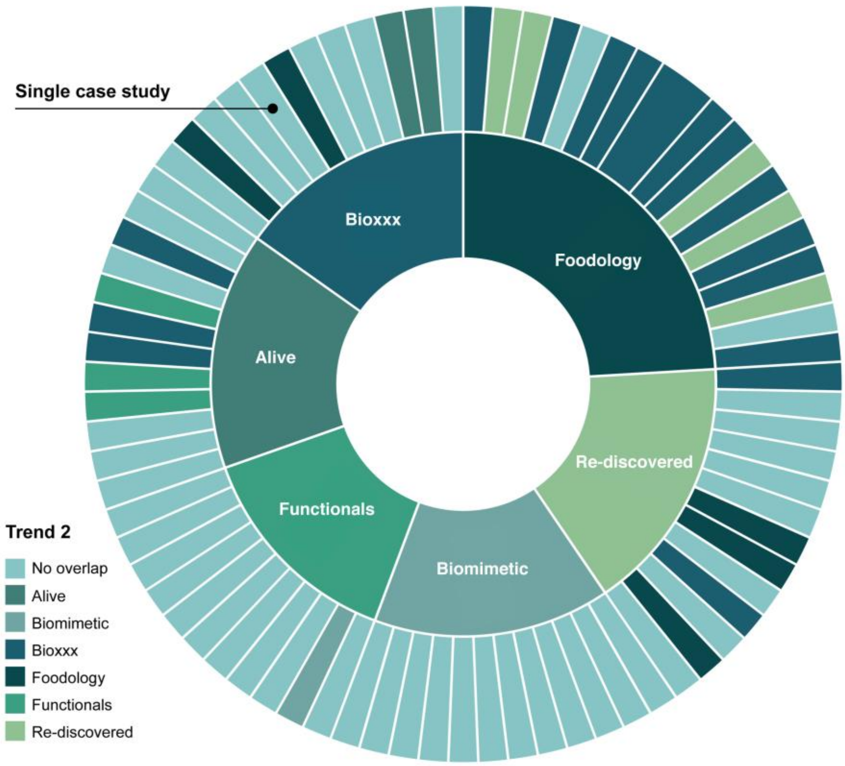

Figure 8. Case study clustered per primary trend and possible overlaps with other trends

4. Discussion and conclusions

The case study collection activity was carried out by students using familiar tools to them, though not attaining to e.g. the ones traditionally used by engineers. Indeed, the groups generally visited online material databases for design alongside company websites, googling them on the internet. Therefore, certain material information (such as technical properties and material composition) was not always accessible either for the technical level of the reported case studies or the unavailability of certain information (mainly for materials in the development or pre-industrialisation phase).

The collected case studies were analysed through different drivers; however, the consequent outcomes were firmly biased by the research methodology adopted (e.g. keywords, browsers, sources in general) combined with the different visibility that some materials and products have on different communication channels. Consequently, the reported case studies also manifested a geographical concentration: most of the reported case studies were localised in Europe (particularly in Italy) and in the USA. If unbiased, that would mean that Europe is a leading region in the research and development of innovative materials. The strong presence of European case studies may also be justified by the high number of research funds (e.g. CEAP 2.0 and New European Green Deals related funds) for new materials and research focused on the recovery, reuse and up-cycle of material resources (thus, the increasing interest emerged for Foodology and Re-discovered trends).

The relapses of the material research trends monitoring are not just direct in depicting the current state of the art on the topic but become even more interesting when it comes to research inputs of both thesis works and academic research. A constant monitoring over time of material research trends is a fundamental step to increase curiosity and instil critical material deploy reflections upon students.

In conclusion, the presented procedure will be repeated in time, in order to monitor the new materials research trends. This activity will allow both students to build up curiosity and critical thinking when

finding new material solutions for their projects, but also to consolidate materials research trends over time, contributing in the definition of possible innovative material classes.
Unfortunately, the data referred to only one course; hence, to effectively evaluate its repeatability, the authors will apply such methodology over the incoming years. Despite this, the back-office work may reduce in time, due to integration of new results from literature and feedback from open discussion in the classroom. At present, the work focused on the activity of designers, used to look for product case studies. It may be interesting to involve science and technology courses held in the School of Engineering to test the format with students with different background.
Regarding the tracking of new classes, the authors did not find the need to define new ones, since all the retrieved case studies well fitted the six defined in this work. As an advantage, the methodology allowed the authors and the students to transcend the assignments to elaborate considerations about the market and evolution of the trends, though it was not generally possible to compare the results with traditional material classes due to the unavailability of technical properties for the retrieved case studies. Therefore, future works may implement the case study template, possibly deleting or changing the "Technical properties" section.

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References

Antonelli, P. (1995), Mutant Materials in Contemporary Mutant Materials in Contemporary Design Design, available at: www.moma.org/calendar/exhibitions/455 (accessed 29 July 2019).

Antonelli, P. and Burckhardt, A. (2020), “The Nery Oxman Material Ecology Catalogue”, The Museum of Modern Art, The Museum of Modern Art, New York, New York, p. 177.

Ashby, M.F. and Johnson, K. (2003), “The art of materials selection”, Materials Today, Elsevier, 1 December.

Ashby, M.F. and Johnson, K. (2014), Materials and Design: The Art and Science of Material Selection in Product Design: Third Edition, Materials and Design: The Art and Science of Material Selection in Product Design: Third Edition, Butterworth-Heinemann, available at:https://doi.org/10.1016/C2011-0-05518-7.

Benyus, J.M. (1997), Biomimicry: Innovation Inspired by Nature, Morrow New York, available at: https://www.harpercollins.com/products/biomimicry-janine-m-benyus?variant=32117835366434 (accessed 22 June 2021).

Bergström, J., Clarka, B., Frigo, A., Mazé, R., Redströma, J. and Vallgårda, A. (2010), “Becoming materials: Material forms and forms of practice”, Digital Creativity, Vol. 21 No. 3, pp. 155–172.

Brownell, B. (2017), “Transmaterial Next: A Catalog of Materials that Redefine Our Future”, p. 288.

Camere, S. and Karana, E. (2017), “Growing materials for product design”, EKSIG 2017: Alive.Active.Adaptive, No. August, pp. 101–115.

Camere, S. and Karana, E. (2018), “Fabricating materials from living organisms: An emerging design practice”, Journal of Cleaner Production, Elsevier, Vol. 186, pp. 570–584.

Clèries, L. and Rognoli, V. (2021), Material Designers, available at:https://doi.org/http://materialdesigners.org/wp-content/uploads/2021/03/MaDe-Book-1.pdf.

Dorst, K. (2019), “Design beyond Design”, She Ji, Vol. 5 No. 2, pp. 117–127.

Fao. (2013), “Food wastage footprint: Impacts on natural resources - Summary report”, available at: www.fao.org/publications (accessed 5 October 2021).

Genovesi, E. and Pellizzari, A. (2017), Neomateriali Nell’economia Circolare, edited by Ambiente, E., Edizioni Ambiente, available at: http://www.edizioniambiente.it/libri/1143/neomateriali-nell-economia-circolare/ (accessed 26 June 2019).

Genovesi, E. and Pellizzari, A. (2021), “Neomateriali 2.0 nell’economia circolare”, Ambiente.

De Giorgi, C., Lerma, B. and Dal Palù, D. (2020), The Material Side of Design. The Future Material Design Cultures., Umberto Allemandi.

Karana, E., Pedgley, O. and Rognoli, V. (2014), Materials Experience Fundamentals of Materials and Design, Elsevier, Butterworth-Heinemann, available at:https://doi.org/10.1016/b978-0-08-099359-1.01001-8.

Lefebvre, E., Piselli, A., Faucheu, J., Delafosse, D., Del Curto, B., Colombo, S., Magaudda, P., et al. (2014), “Smart materials : development of new sensory experiences through stimuli responsive materials”, 5th STS

Italia Conference A Matter of Design: Making Society through Science and Technology, No. March 2015, pp. 367–382.
Papile, F. and Del Curto, B. (2021), “IMPROVING THE MATERIAL SELECTION PROCESS IN PRODUCT DESIGN ACTIVITY: AN OVERVIEW OF MATERIAL REPOSITORIES”, EDULEARN21 Proceedings, Vol. 1, pp. 7574–7580.
Papile, F., Marinelli, A. and Del Curto, B. (2019), “MULTISENSORY MATERIAL EXPERIENCE ROOM”, MDA 2019 | 3rd International Conference of Environmental Design | 3-4 October, Marsala (Italy), Marsala, Italy, October 3-4, available at: https://docs.google.com/document/d/1tJ7mHf-r967k1_jBHenxM465X-4e3_3PEIrQ-cK9VfY/edit (accessed 10 July 2019).
Peters, S. (2011), Material Revolution. Sustainable and Multi-Purpose Materials for Design and Architecture, Material Revolution. Sustainable and Multi-Purpose Materials for Design and Architecture, De Gruyter, available at:https://doi.org/10.1515/9783034610773.
Purkait, M.K., Sinha, M.K., Mondal, P. and Singh, R. (2018), “Biologically Responsive Membranes”, Interface Science and Technology, Vol. 25, Elsevier, pp. 145–171.
Rognoli, V., Ferrara, M. and Arquilla, V. (2016), “ICS_Materials: materiali interattivi, connessi e smart”, MD Journal, Vol. 2 No. SINAPSI. DESIGN E CONNETTIVITÀ, pp. 44–57.
Rossin, K.J. (2010), “Biomimicry: Nature’s design process versus the designer’s process”, WIT Transactions on Ecology and the Environment, Vol. 138, pp. 559–570.
Santi, R., Elegir, G. and Del Curto, B. (2020), “DESIGNING for SUSTAINABLE BEHAVIOUR PRACTICES in CONSUMERS: A CASE STUDY on COMPOSTABLE MATERIALS for PACKAGING”, Proceedings of the Design Society: DESIGN Conference, Vol. 1, pp. 1647–1656.
Sauerwein, M., Karana, E. and Rognoli, V. (2017), “Revived beauty: Research into aesthetic appreciation of materials to valorise materials from waste”, Sustainability (Switzerland), Vol. 9 No. 4, available at:https://doi.org/10.3390/su9040529.
UNI EN. (2002), “UNI EN 13432”, available at: http://store.uni.com/catalogo/uni-en-13432-2002 (accessed 13 November 2021).
UNI EN. (2007), “UNI EN 14995”, available at: http://store.uni.com/catalogo/uni-en-14995-2007 (accessed 13 November 2021).
United Nations. (2021), “The Sustainable Development Goals Report”, United Nations Publications, pp. 1–56.
Vallgarda, A. and Redström, J. (2007), “Computational composites”, Conference on Human Factors in Computing Systems - Proceedings, No. May 2014, pp. 513–522.
Xie, J., Ping, H., Tan, T., Lei, L., Xie, H., Yang, X.Y. and Fu, Z. (2019), “Bioprocess-inspired fabrication of materials with new structures and functions”, Progress in Materials Science, available at:https://doi.org/10.1016/j.pmatsci.2019.05.004.

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