SYSTEM THINKING & SYNTHESIS MAPPING TO MANAGE PRODUCT MATERIAL SELECTION PROCESS

AN EXPERIMENTAL FRAMEWORK TO PROMOTE THE INTRODUCTION OF INNOVATIVE MATERIALS INTO INDUSTRIAL COMPANIES

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Abstract

Material selection is one of the core tasks in industrial product design practice, since materials are at the basis of manufactured artefacts. Over time, an increasing number of characteristics and attributes have been taken into consideration as competing and influent elements on the product's material decision. However, even if the material selection can be efficiently supported by different methodologies, tools and platforms, still in the industrial strict routine it is difficult to invest the right amount of time in scouting possible new material solutions to upgrade the production line.
This gap between theoretical approach and practical application of new materials influences significantly the shift towards a more sustainable development. In this paper, material selection process has been analysed as a process within a sociocultural system (enterprise). All the collected information have been mapped in cooperation with company employees, to create a visual narrative of the whole work. The result, hence, is a synthesis map that provides a model for professionals to manage an aware material selection activity. The systemic view of the entire material selection process is then discussed: further improvements can be developed in the perspective of sustainable development and industrial/environmental interdependences.

Introduction: Complexity as a prolific context

Among years, in parallel with socio-cultural and technological development, materials world followed its own evolution. Since the human beings started to create and build their tools, human development eras usually took the corresponding material discovery name (Mike Ashby, 2008; Attfield, 1999). From the Stone Age, through the Bronze, Iron, Steel and Plastic Age, we arrived into nowadays, the Anthropocene, an era marked by the massive depletion of resources and interference of human beings in the entire Ecosystem (Crutzen & Stoermer, 2000). This last concept led to a new perspective where interdependencies (Bodin et al., 2019; Osborne et al., 2019) among human decisions, actions, and the ecosystem response, start to gain particular relevance despite to single-focus problems. From step-based, linear approaches sociologists, philosophers as well as designer and scientists are currently struggling with the necessity of finding new ways to overcome the anthropocentric perspective and re-think the world as a whole interconnected essence. We are moving towards a more holistic and systemic way of thinking, implying that it is no more possible to represent a system only by the sum of its parts. Interdependencies, quantities non directly measurable, as well as relationships between

system-parts have been theorised to affect and contribute to the system behaviour (Gharajedaghi, 2012).
The same transition towards more "ecosystem-oriented" approaches is visible both in economics and design discipline as well. Maintaining a systemic perspective is a base point for new economic models such as the Circular Economy one (as well as others before, e.g. Blue Economy model; Cradle to Cradle approach and others).
If we look at design discipline, we can see how it evolved over the years. From a craft-oriented practice, design discipline became a professional and academic discipline, until nowadays, where design can be defined as an iterative, adapting process that synthesises contemporary cultural aspects into its journey (Dorst, 2019; Manzini, 2015) and obviously facing with transitional times towards a more sustainable behaviour (Irwin, 2015).
However, even if product design disciplines and systemic visions are finding some common points at theoretical and practical level, what seems to miss in the intricate literature background is how traditional, necessary, procedures and processes that actually are part of the product design practices could relate to this new system-oriented vision. In order to reflect about how to analyse those internal processes in a systemic perspective, authors will investigate the possibility of interpreting material selection process at a systemic level.

Materials selection: a process into a system

Material selection is one of the core tasks in industrial product design and development since materials are at the basis of manufactured artefacts. In a bottom-up perspective, materials affect the whole production system at several levels. At the beginning of industrial production, materials were perceived as simple constituents of physical artefacts (Cornish, 1987) and material selection was a process mainly focused on technical and functional properties. Nevertheless, over time, an increasing number of characteristics and attributes have been taken into consideration as competing and influent elements on the product's material decision (Figure 1), reinforcing the theories of materials as representatives of human socio-cultural and technical evolution over time (Michael Ashby, 2011; Attfield, 1999).
In this perspective, selecting the prime matter from which "artefacts are made of" gains particular relevance in the product design process.

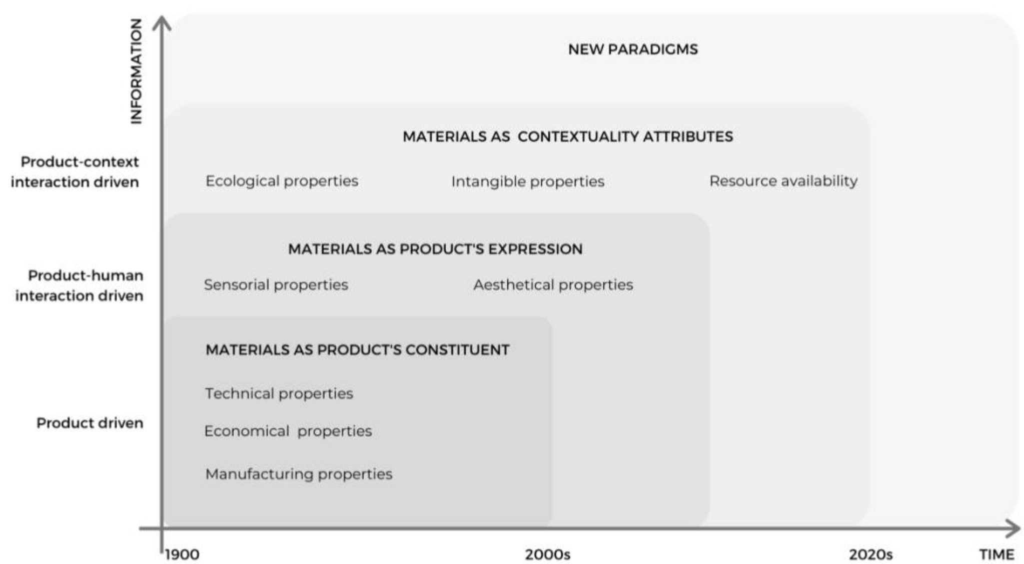

Figure 1 - Graphical elaboration of material attributes evolution over time for material selection in product design

Among years, the number of information considered in material selection grew up, and materials themselves increased in number, growing a multitude of huge alternatives and tangling the material selection activity. In the last 20 years, material science and chemistry advancements lead to the discovery and synthesis of almost more than 160,000 different materials between making a choice (Michael Ashby et al., 2013), and this number is continuously increasing.

In this complex scenario, it became crucial for practitioners to collect and organise all information around materials to pursue an aware selection. Material selection methods and tools have been studied and realised either in engineering and design disciplines (Akin & Pedgley, 2014; Allwood et al., 2011; Braungart et al., 2007; Jahan et al., 2010; Karana et al., 2010; Morseletto, 2020; Ramalhete et al., 2010; Wilkes et al., 2014; Wilkes & Miodownik, 2018). However, even if the information upon new materials are easily accessible and different methodologies, tools and platforms can efficiently support the material selection, still, in the strict industrial routine, it is challenging to employ time in investigating possible new material solutions to upgrade the production line.

This gap between the theoretical and practical application of new materials significantly influences the shift towards more sustainable development. The average gestation time between the research, development and introduction of new material into the industrial flow is estimated to be lasting for several years (Karana et al., 2015, 2016; Markham, 2002), but the current context is demanding for a faster improvement of innovative solutions towards new sustainable development.

Implications of materials choices at an environmental level have been extensively studied to theorise new economic approaches to design and production. If we look for example at the new designs best practices, (e.g. the EU ECO DESIGN GUIDELINES[1], or at the Circular Economy design guidelines[2]) we can see that reflection upon materials is included in the process towards more sustainable production.

To understand how to effectively implement a strong reflection upon materials when in an industrial environment, a systemic overview on the current flux of information for material selection in the Faber S.p.A.[3] Company is here presented. The presented work's primary objective is to analyse the material selection process embedded into an industrial company systemic perspective. Trying to map out how certain decisions into a specific company department also affect decisions and actions carried out by others.

Material selection: a process into a Socio-cultural system

Systemic thinking and Systems oriented design approaches are typically exploited to intervene in complex contexts (Battistoni et al., 2019; Jones, 2014; Sevaldson, 2013), focusing on interrelations between system environment, system inner dimension and the network of relationships between all of the system constituents.

System environment could be generally defined as the sets of variables/elements that the system cannot control, even if somehow they affect system behaviour (e.g. transition towards Circular material use). At the same time, the referring system will be interpreted as a set of interactive variables that could be controlled by participating actors (e.g. company employees working on new products) (Gharajedaghi, 2012). In this study, the system boundary will be arbitrarily circumscribed around the industrial company's material selection process.

[1] Ecodesign - Sustainability Guide https://sustainabilityguide.eu/ecodesign/ Accessed: 2021-01-29
[2] The Circular Design Guide https://www.circulardesignguide.com/ Accessed: 2021-01-29
[3] https://www.faberspa.com/ Accessed: 2021-01-29

The identified referring system is a socio-cultural system: by definition (Gharajedaghi, 2012), those kinds of systems are characterised for being purposeful and composed by purposeful individuals. It becomes essential to align the interests of the purposeful members of the system itself and the broader environmental purpose to work in harmony for common objectives.
In this perspective, obtaining consensus from the parts is fundamental for the alignment of the multi-minded socio-cultural system (Gharajedaghi, 2012).
At this point, in order to investigate how the material selection process changes when analysed into the referring system, the following methodological path has been adopted.

Methodology

First of all, the material selection process has been extensively analysed through a literature review activity to enlighten existing procedure methods. Over time, the material selection process evolved from a linear, functional asset to a more holistic one (Piselli et al., 2016).
After this first, explorative phase, an in-depth activity into the selected industrial context has been conducted by involving the company personnel into the material selection process definition. It followed an intensive and reiterative activity of co-working and, in the end, a necessary synthesis activity to reorganise the information acquired in the first two phases of the research has been provided to both the research group and the company research partners as well (Figure 2).

Research activity	Methodology	Insights	Results	Needs
Desk Research	Litterature review	Existing material selection methodological pattern		Verify correspondance in Industrial context
	Analysis of material selection online tools		Existing methodologies refer to a precise material selection user	
Field Research	In site observations & interviews (qualitative analysis)	Innovation resistance level	Need for understanding material selection process workflow	Mapping information flow through internal workflow
	Questionnaires (quantitative analysis)	Material selection procedure evanescent	Need to transform material selection process into a coperative activity	Mapping relationships between different actors
	Workshop (Participatory action research)	Material selection perceived as a cooperative task		
Research Synthesis	Synthesis mapping of material selection process	Enlightening information management and relationships between actors	Procedural workflow promoting a flexible material selection process	

Figure 2 – Research Methodological path

The importance of involving stakeholders in the research

As previously mentioned, when working into a socio-cultural system, it is crucial to set-up a common ground of knowledge to align every member of the system's purposes.
In the very first beginning, two different inquiry episodes have been prepared and realised into the company. Through unstructured interviews to nine employees of different departments and an online questionnaire (spread through 30 experienced employees at the guidance of several departments), it has been possible to understand and frame the material selection process as perceived into the company. This preliminary activity, lasted several months, has been fundamental to figure out the basis on which building up a common knowledge about the material selection topic. Moreover, to help people

reflecting and expressing their opinion on a specific topic becomes extremely important for the engagement of the same people in the further developments of co-working (Jones, 2018).
Therefore, to create a collaborative and engaged co-working activity (as the material selection will be afforded), two workshops have been organised, involving the research team and the company stakeholders as well. Socio-cultural systems could be prolific in cooperative activities only if dialogues for understanding diverse necessities will be carried on and set up as the primary system (Jones, 2018).
In this perspective, a first workshop into the company has been organised to build the common ground for the definition and the understanding of material selection process consequences upon a product design activity.
In a two half-days intensive activity, where participants had both a frontal presentation experience (to share objectives, research purpose and theoretical background) and few hands-on activities for testing the existing tools, have direct experience with some material samples and demonstration on how to use specific material selection tools.
The eleven participants involved in the workshop came from all the different company departments.
Three main directives for the workshop have been followed in order to keep high the attention:

- Provide clear presentations;
- Provide physical material samples;
- Provide ready-to-use-tools for gathering material-related information.

The main activities where employees have been involved were:

- Completion of a "*desiderata"* schedule in order to collect all the information needed for each department.

The importance of visualising materials selection process through synthesis maps

At this point, a relatively high amount of information emerged from the diverse methodologies with which material selection process has been explored together with the system stakeholders. According to Meadows (2008): *"Words and sentences must, by necessity, come only one at a time in a linear, logical order. Systems happen all at once. Their elements are connected not just in one direction, but also in many directions simultaneously. Pictures work for this language better than words because you can see all the parts of a picture at once."*
In order to share all the collected and represent the relationships between information, methods, tools and actors involved in the material selection process, a mapping activity has been settled to create a visual narrative of the whole work and at the same time defining the referring system boundaries(Jones & Bowes, 2017; Sevaldson, 2011).
Mapping activity is a common practice in the design field. However, not every kind of map has the same purpose, due to the different focus in the node-links hierarchy (Davies, 2011; Eppler, 2006).
Synthesis maps, among others, has been chosen as the best visualisation mode to foster learning or knowledge sharing constructively and systematically, in order to deploy its natural purpose of being a tool thought to be used to depict processes and relationships between all the stakeholders involved into the system (Jones & Bowes, 2017). Moreover, those kinds of maps help to create a model of processes and actors based on a language agreement, a base for continuous conversation and engagement into the topic (Jones & Bowes, 2017).

Results

During the first of the two workshops held together with the company employees, it has been investigated and defined a shared vision of a general internal information workflow (Figure 3).

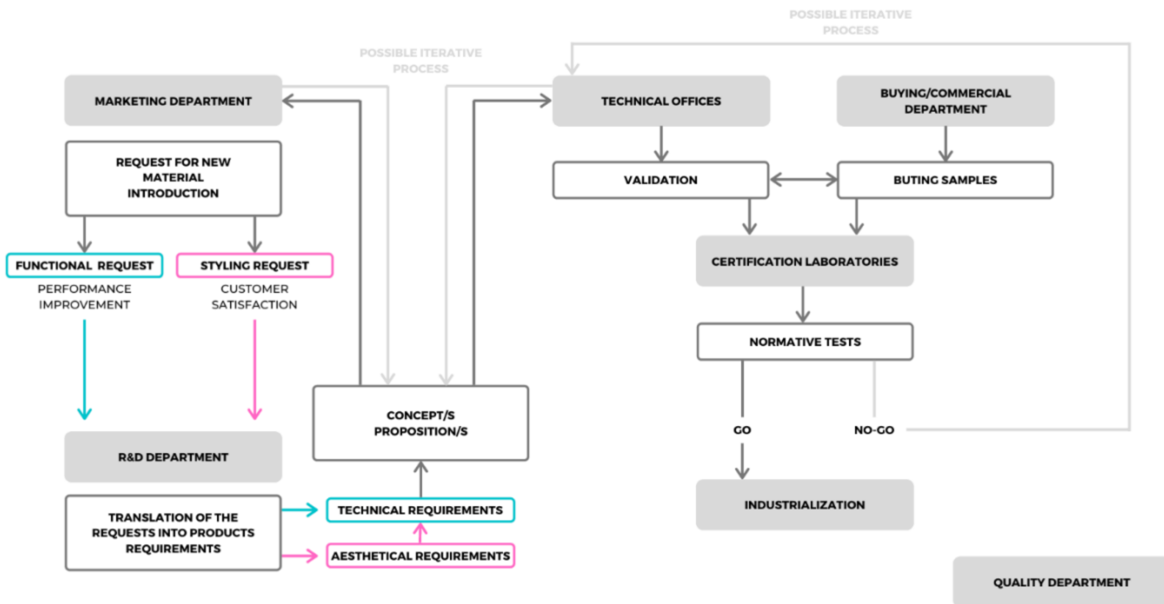

Figure 3 – Co-designed internal information workflow and subsequent identification of possible iterations and parallel flows.

However, this first, necessary step was not the main focus of the cooperation: to have a shared vision of the internal workflow was a critical step to create a shared, common knowledge about the possible material selection process journey.

By overlapping data obtained by the workshop, some literature concerning the management of industrial flows (Browning et al., 2002; Krishnan & Ulrich Karl T., 2001; Unger & Eppinger, 2011) and the three main steps concerning material selection activity(Mike Ashby & Johnson, 2003), a secondary mapping of the workflow in which material selection task occurs as a collaborative activity is represented in Figure 4.

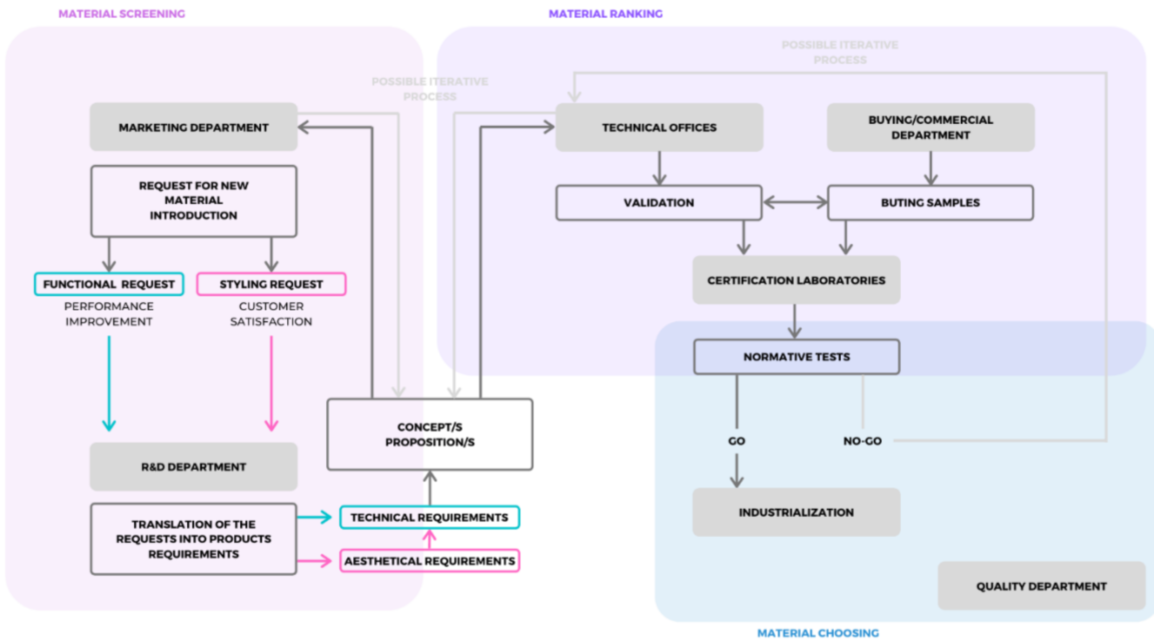

Figure 4 - Overlapping between the workflow, the typology of flow and the main material selection steps.

In this second visualisation, the shared vision of the workflow and the different steps of the material selection process overlapped to actors and activities are visible. In this way, a new shared vision of the material selection consequences at several stages of the workflow has been defined. After clarifying with the stakeholders how the material selection theoretical phases could overlap to the defined workflow, and once defined and agreed a common vision of the process into the system, the extended research group has been able to share a common vision of the process within the system.
However, even if the second visualisation showed a possible interpretation of the material selection process embedded into the socio-cultural system, it was still not enough to represent the process' development within the defined socio-cultural system in practice.
Thus, a third level of information was needed in order to translate this new vision into practical, tangible activities. An implementation linked to practical activities of every stakeholder into the workflow has been added to the visualisation, to enrich the map. This activity has been crucial in order to present at the employees audience a precise vision of the real tasks, related to material selection, that actually every company departments affects or investigates with its own work.
Thus, in Figure 5, the last visualisation created with the company employees is presented.

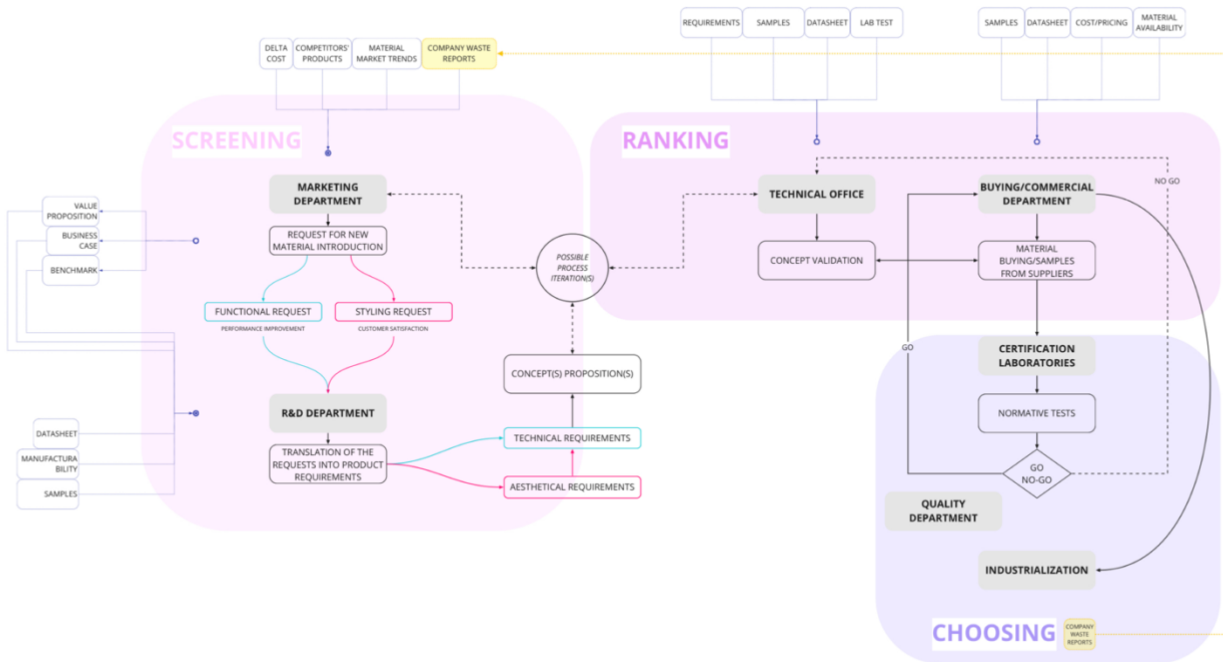

Figure 5 - Overlapping between the operational workflow, the main material selection steps, and the different departments' tasks on material-related information.

In this last synthesis map, not only relationships between actors and material selection steps are represented, but also some necessary information for each department has been displayed. The necessity of this final enrichment emerged directly in the second co-working workshop activity. By expressing each departmental need and, consequently, sharing those necessities with the colleagues in a co-creation asset, it has been possible to figure out a well-contextualised picture of the new possible approach for material selection, tailored on the socio-cultural referring system nature.

From Figure 5, we do not only assume that the synthesis map is a visual representation of a process within a system, but we are also able to see the material selection process in a new shape. As described at the beginning of this study, the material selection process evolved mainly into design and engineering fields. In this new visualisation, material selection could be interpreted as a multidisciplinary activity thanks to the intense process framing activity conducted into the referring field. In this meaning, a new possible path for the materials management emerges: the process refers no more to a single department, but can be managed by considering diverse material information at various workflow steps, providing an accurate and aware information management activity.

As a result of a constructivist process, the final synthesis map has been commonly recognised by the stakeholder as a reliable source for monitoring the possible introduction of novel materials into the internal workflow.

Discussion

The main output of this work is a framework of the entire process of material selection in which information, tools, methodologies and actors are represented. Hence, the result is a synthesis map that provides a model for professionals to manage an aware introduction of new and traditional materials into the production. By realising a synthesis map (Jones & Bowes, 2017), all the information needed from industrial employees to manage a proper material selection activity is visualised and considering different stages of the design process. Even if the result has been commonly recognised as a reliable picture, future activities within the company will be organised to test the visualisation as a guideline, by simulating the introduction of new material into the workflow. So, new workshops and new activities in the field will be organised.

Once validated, the synthesis map will be again reviewed to investigate the work's generalizability and be also applied into similar socio-cultural systems contexts.

This new visualisation becomes promising when we relate the process of selecting materials into the socio-cultural referring system (the company) but if we relate this process to influences in the system environment (e.g. the transition towards Circular Economy). By having an aware vision of the process and the internal information flow, it is possible to visualise how different variables introduced in the workflow will run into the system itself. In this way, the authors hypothesises that introducing new materials in the production will not be perceived as a risk, but could be gently followed along the whole production line, enlightening and pointing out possible problems and, then, solutions. From a broader perspective, this synthesis map will be improved to visualise in the same artefact also the affection of material choices in the immediate "outside", working at the system-environment boundary. This further analysis will provide a solid base to create a shared vision also about the interdependencies occurring between company choices and the environment, increasing an aware material selection approach not only through an "internal" perspective but also on an external one, towards a more sustainable development-oriented practice (Vezzoli et al., 2014).

Further developments of the research will be pursued by maintaining an active and iterative collaboration with the stakeholders to refine the visualisation and common ground knowledge.

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