1 INTRODUCTION

Engineering is currently going through a period of unprecedented transition, in which the challenges of digitalisation and globalisation of the past half century are combined with the urgent need to reduce the environmental impact of engineering activities (Isaksson and Eckert, 2022, Hallstedt et al., 2022). To address these concurrent challenges, engineers have to think and act systematically and systemically, and be willing to embrace innovative solutions. However, systems that have grown over a long period of time are difficult to change from one day to another, because markets struggle to accept totally different solutions and the resources and effort required for sudden large-scale switch over are considerable. Therefore, companies and legislators need to manage a gradual change through ambitious and manageable goals, to which they carefully assign their efforts and resources.

As Eckert and Isaksson (2022) point out, the challenges are also of enormous importance for academia. Universities and academic communities, themselves often slow to change, need to play their part in generating a knowledge ecosystem in which not only are technical innovations created, but also the tools, methods and processes by which they may be deployed in organisations.

In this context, public and political discourse (and with it funding) often focusses on scientific research seeking to make fundamental breakthroughs, or on technology that shows the feasibility of using new or established science in new applications. The wider issues of how the new science or technology may be deployed, and on the tools, methods and processes for their deployment, receive much less emphasis. Yet it is on these wider issues that the engineering design research community centres its efforts, bridging the gap between science and technology and users and seeking to understand the effort required to turn new or established technology into usable products and services. We understand the challenges and opportunities involved in combining innovation with established technology and legacy designs at multiple levels of detail. This raises the question, why are we not at the heart of the discussion of future industrial direction and funded better when we know we have so much to contribute?

To try to answer this question, this viewpoint paper uses two established classifications - the distinction between exploration and exploitation by March (1991), and the theory of domains by Andreasen (Andreasen et al., 2014) - to argue that research in the engineering design community addresses the necessary research space for industry-enabled transition more fully than science and technology-focused research by itself. In particular, it extends the range of support provided to industry as it negotiates the need for radical innovation combined with incremental design across a wide range of its activities. We contend that explaining this broad coverage of the research space will be useful to our community in communicating its activities to a wider world, and in organising and directing its activities.

The simple but fundamental distinction between exploration and exploitation was used by March in his seminal 1991 paper published in the journal Organization Science, noting that the relation between the exploration of new possibilities and the exploitation of old certainties is a central concern of studies of adaptive processes (March, 1991). March contended that “an appropriate balance between exploration and exploitation is a primary factor in system survival and prosperity”, and explored this issue in the context of organisations. The paper went on to be enormously influential in the organisation science and wider management communities, gathering over 30000 citations and inspiring research in areas ranging from knowledge management and institutional learning to technology and innovation management.

March’s distinction between exploration and exploitation has been widely cited in the engineering design literature (e.g. Veldman and Alblas, 2012), but has perhaps not been as influential in the design community as might be expected in view of its explanatory power. It is perhaps self-evident that designers both exploit existing patterns and knowledge and explore new possibilities and new solution principles, and that the balance in the allocation of effort between exploration and exploitation is enormously important in determining the outcomes of a design process. Is the distinction therefore a useful principle to use more widely in organising the work of the engineering design community, to inform the interactions between that community and its industrial collaborators and to describe its work in wider societal discourse? In this paper we explore this question, but we also go a step further, asking whether by combining March's distinction with a theoretical framework from the design community we arrive at a more useful basis for categorising and explaining engineering design research.

For the design framework we could have chosen from a number of conceptualisations of design (see (Chakrabarti and Blessing, 2016) for a wide-ranging review). We use Andreasen’s Domain Theory because it matches the discourse we see in industry with its emphases on technological fundamentals, on the needs of the user and on the imperatives of production, and also, as we shall see later, because of its system architecting focus.

The two-dimensional categorisation that results from combining exploration-exploitation with Domain Theory may also help the community to organize its activities and where it applies itself. This is important, because the community is currently trying to find its place against a prevailing backdrop of powerful narratives (see McMahon et al., 2021): firstly the focus of 'design thinking' on current and near future needs of the user, arguably pushing technical challenges somewhat into the background, and secondly a technology-centric view of research that may fail to acknowledge the role that engineering and careful design has to play in developing reliable, usable and flexible solutions.

In addition to its research role, we ask whether such a classification is helpful to engineering companies in guiding their actions. Firstly, we suggest that by examining where effort is currently directed, firms may be encouraged to modify their allocation of resources, and be guided in identifying the directions available to them. Secondly, while tools and methods to support industry are developed by researchers all the time, they are frequently disconnected, and the scope of their intended use is often unclear (Gericke et al., 2020). This makes them difficult to use for industry in isolation, and this may be resolved, at least in part, by improved categorisation.

In the remainder of this viewpoint paper, we first, in section 2, introduce March's 1991 paper and reflect on its influence in the past 30 years. We also introduce Domain Theory and outline its application in design. In section 3 we then develop a classification framework in which exploitation/exploration and domain theory are respectively two dimensions of a classification matrix, giving examples of the fit of design research topics into each cell of this matrix. This analysis has implications for the research and teaching our community carries out, as well as the guidance we could give to industry, which we will discuss in section 4. In section 5 we then explore what the classification suggests are dominant modes of working in various industries, before suggesting where industrial emphasis might change. In section 6 we make a similar exploration for the academic community before asking in section 7 what are the missing debates in our community and presenting conclusions in section 8.

2 BACKGROUND

The business and the engineering design community have often looked at similar topics, such as innovation (see Isaksson, et al., 2019). In both fields multiple classifications exist. For this paper the March classification was selected because it was both conceptually simple and highly influential to both industrial and academic discourse, as traced in various review papers. By contrast, the design community has developed multiple conceptualisations of design, which are coherent and extremely useful for those who understand them and work on related problems, but have maybe not been so universally adopted in the discussions of the field.

2.1 March's theory of exploration and exploitation

March opens his 1991 paper by noting that "Exploration includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, innovation. Exploitation includes such things as refinement, choice, production, efficiency, selection, implementation, execution.", and pointing out that organisations are caught in a tension between the exploration of new possibilities and the exploitation of established knowledge and practice (March, 1991). He develops his arguments around the notion that exploitation and exploration compete for scarce resources, and that there therefore needs to be explicit choices between the two. The bulk of his paper focuses on such issues as the trade-off between exploration and exploitation, the uncertainties and vulnerabilities in exploration (because its returns are systematically less certain than from exploitation), the social context and the dynamics of organisational learning, and the development of knowledge (all issues which are familiar to the design research community). He uses considerations such as the ecologies of competition, competitive advantage and strategic actions to inform his arguments.

There have been a number of reviews of the research influence of March in the intervening years since 1991. These have posed questions for example on the definitions of exploitation and exploration, their relationship with each other (as orthogonal or as ends of a continuum), the role of specialisation in organisations and how organisations strive for balance (Gupta et al., 2006). Regarding the latter point, many organisations today strive for **ambidexterity** – the ability to work equally well in exploitative and explorative modes – while **punctuated equilibrium,** in which isolated episodes of rapid development (exploration) are interspersed with periods of relatively little change (exploitation), is also observed. Reviews have also attempted to map the influence of March on different parts of the research community, noting for example the grouping of citations in clusters including dynamic capabilities and knowledge management, technology and innovation, ambidexterity and performance and international learning and collaboration, as well as the evolution, adaptation and organisational learning community for whom March was originally writing (Wilden et al., 2018).

March's distinctions relate to different skill sets and different mind sets in organisations. Companies need to find a balance, as exploration can make them vulnerable in the short term, by diverting resources from short term potential profits, while a lack of exploration can in the long run erode competitiveness. Some organisations switch between a predominantly exploitative mode and a predominantly exploratory mode. These transitions can be perilous for enterprises, in particular, if they divert resources from R&D to support increased exploitation in the short term (Swift, 2016). However, some organisations become ambidextrous and manage to combine both exploration and exploitation, typically by having separate but integrated R&D departments (O'Reilly and Tushman, 2004). This enables them to manage the mix of incremental innovation, e.g. small innovations to existing products or architectural innovation, making changes to some aspects of their product or organisation - and discontinuous innovation, which may render existing products and ways of working obsolete.

2.2 Theory of Domains

There are many different theoretical conceptualisations of design. While some focus on the designer, the use context, or the degree of confirmed knowledge, we use Andreasen's Domain Theory (Andreasen et al. 2014), because it aims at understanding design viewpoints on artefacts in a systematic way, described by three system models based on how the artefact is used, how it functions and how it is made from parts. These models correspond to Andreasen's three domains: (1) the **activity** domain, focusing on how the product or system is used, how the user interacts with it and creates an effect through its use (2) the **organ** domain, focusing on how the product or system functions, considering functional units operating according to physical, chemical or biological phenomena to achieve the functions of the product or system, and (3) the **part** domain, focusing on how the product or system is realised through the manufacture and assembly of physical parts. The domains are also different perspectives on a system in which innovations can take place. The activity domain covers user interaction and the context in which the user carries out his or her actions, and also considers stakeholder interactions through the life cycle of the artefact. The organ domain looks at functions and the fundamental solution principles through which they are implemented in combination. The functions might be achieved by different organs that carry out the same core functionality, for example a car might have different types of engine or motor, which all carry out the core function of providing power to the car. The part domain includes the physical parts and materials, through which the artefact is realised and behaviour is enacted.

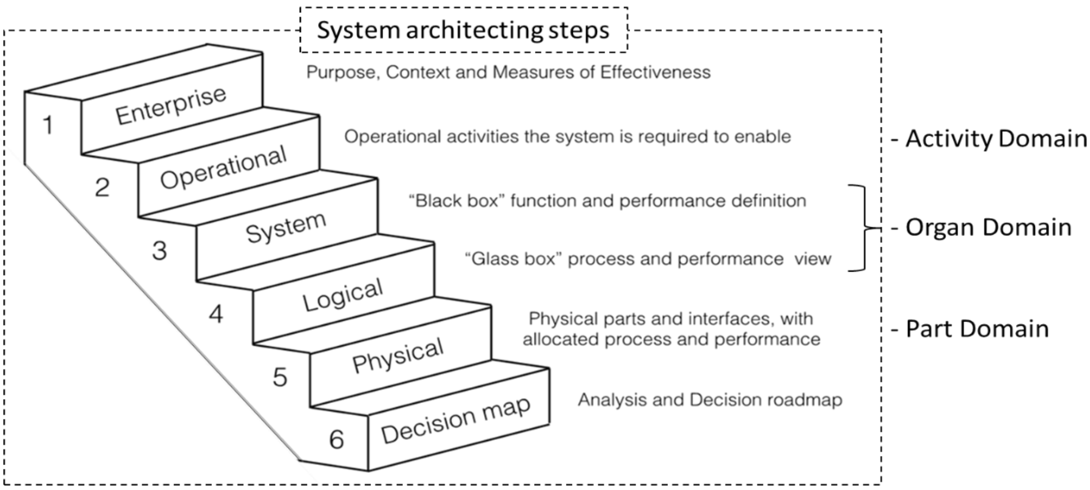

Figure 1. The six steps of system architecting (adapted from Sillitto, 2014)

Domain Theory has been developed and extended over more than 50 years, with application in machine, mechatronic and service design amongst other fields, and extensions to the theoretical framework including in design modelling (Andreasen, 1994). Domain Theory has also been influential in system architecting, where for example the central four steps of Sillitto's six-step process for architecting systems (Figure 1) correspond to the activity (operational step), organ (system and logical steps) and part (physical step) domains.

3 AN EXPLOITATION-EXPLORATION-DOMAIN CATEGORISATION

Just as March notes that organisations have to decide how they will divide resources between exploitation and exploration, so too do they have to apportion resources between the three domains of domain theory. What are the respective merits of allocating resources to understanding better how the artefact will be used, to how it might function or how it will be made? What are the possibilities for innovation from exploration in each of these domains? And what of the tools, methods and other approaches that might be used in each domain and for operation in exploitation and exploration modes? These questions suggest that there may be merit in combining March and Andreasen's categories. In this section we explore how different design research topics might fit into such a framework, but also how these relate to the applied engineering sciences.

- **Exploration in the organ domain** encompasses a good deal of design research concerned with conceptual design – including ideation, functional modelling, concept generation and evaluation – and also topics such as novel architectures. In the applied sciences, the new discovery of natural phenomena, and exploration into how these might be used in novel technologies, would come into this category.
- **Exploitation in the organ domain** encompasses much work in design space search, especially design optimisation and robust design. It may also include much work in process modelling, for example using the design structure matrix to determine appropriate sequences for the design of given arrangements of organs, for example in the design of gas turbine engines. In the applied sciences, a lot of fundamental work concerns understanding the behaviour and enabling the modelling of particular organs (for example looking at the behaviour of hydrodynamic pumps or of electronic devices) or architectural arrangements (e.g. aircraft performance mdodelling).
- **Exploration in the part domain** includes investigating novel manufacturing processes such as the application of additive manufacturing (AM) or composite materials and also investigating novel architectures for manufacturing e.g. in the move from chassis to monocoque construction for automobiles. An example of scientific work in this category might be exploration of extreme ultraviolet lithography for semiconductor fabrication.
- **Exploitation in the part domain** would again encompass techniques for understanding the impact of variations within a design space such as 6-sigma and probabilistic design techniques and tolerance design. Standardisation and aspects of product family/platform design concerned with standard parts and size ranges would also come into this category.
- **Exploration in the activity domain** encompasses activities including problem reframing but also topics such as product-service systems design concentrating on novel service applications of artefacts.
- **Exploitation in the activity domain** may be considered to include topics like ergonomics, user interface design and user studies, for example of patterns of movement in buildings, where the intention is to assist in the improvement of some existing artefactual arrangement.

Gupta et al. (2006) note that, from some viewpoints, exploration and exploitation are ends of a spectrum and it is clearly possible to identify examples in each of these categories that do not perfectly fit the allocations suggested above. Similarly, a number of topics arguably cover multiple categories. For example, knowledge management may be considered to largely support exploitation but may be found in all three domains. Likewise, 'design for X' can be considered mainly to involve exploitation of accumulated knowledge in some particular topic, and is found widely in the part domain (e.g. design for many manufacturing technologies), and also in the activity domain (design for disassembly, UX design, inclusive design), but in so doing it may enable exploration of novel approaches. Debate is needed to understand the classifications better.

Let us consider as an example the allocation to these categories of activities aimed at developing the application of battery technology for electrical storage. The scientific search for new battery chemistries comes into the organ domain exploration category, but so would considering how energy storage can be incorporated in different artefacts and systems, especially to replace applications using fossil fuels, or exploring new cooling arrangements for cells, both very much design applications of exploration.

Equivalents in the organ domain exploitation category are electrochemical thermal modelling studies and cell design optimisation respectively.
In the part domain, design applications abound. Exploration might include exploring whether cells can be incorporated into the structure of an artefact, or exploring different manufacturing processes for the realisation of cell components. The identification of battery families and their realisation through a product platform strategy, or improved tooling to effect more economic manufacture, would, we suggest, be examples of design exploitation in the part domain.
In the activity domain there is much work to be done in learning how storage technologies are used in everyday life, for example in scheduling charging of vehicle and home batteries, or adjusting household tasks to suit the availability of power. These would be examples of exploitation in the activity domain. Considering how electrical storage might be incorporated into the lives of communities in developing countries, and how it might so contribute towards the electrification of household or business activities, falls more readily into the exploration category.

4 A COMMENT ON TEACHING AND RESEARCH

Teaching and research at many engineering-science focused universities has concentrated on development and promulgation of scientific understanding in the organ domain e.g. what are the fluid mechanic principles supporting flight or the thermodynamic principles of heat transfer. To this end, teaching and research is often directed at the technical foundations of the technologies that are exploited in the organ domain. This focus is particularly strong where the university department has a well-defined disciplinary focus, such as aerospace engineering or automotive engineering. In many areas of engineering the structure of the organs or artefacts and their basic functionality are well established, for example the main organs of a traditional car have changed little for a very long time; so that that there was little need for the exploration of new functions except at sub-system level where additional functions are added to the vehicle, such as in-car entertainment systems and power train emissions control.
Design thinking research has traditionally focussed strongly on the activity domain. By involving and engaging the user, the research aims to understand the user’s need and to create (the concepts for) new solutions in conjunction with the user. The technical implementation or challenges are often put into the background. The spirit behind design thinking is frequently one of joint exploration, even though the outcome might not be highly innovative. If similar tasks were carried out in a different way, they would sit in the exploitation space.
Specialised engineering disciplines like manufacturing engineering or materials engineering are typically positioned in the part domain, where they interact directly with the underlying sciences. They teach and research general principles that can be used in different applications. Some universities also offer specific training in machine elements, in particular in the German speaking world, which would include principles of fasteners and other material joining devices.
In principle, engineering design research does cover the entire space of the matrix described above, but there are distinct clusters. Much of the research on tool and methods development is focused on the organ domain on the exploitation side. Furthermore, while many aspects of engineering are based on analytical sciences, much knowledge, in particular around users and in the activities and processes in the part domain, is very much based on heuristics. There are a number of areas where less teaching and research occur, that are nevertheless critical in addressing the challenges that we are facing:

- Exploitation in the activity domain: understanding what users need from incrementally developed products and, maybe more importantly, what users might be willing to accept if serious savings or behavioural changes are required.
- Exploration in the combined organ and activity domains around how established systems might be fundamentally rethought and redesigned. This is particularly important in light of the increasing interconnection between different products and services, for example as transport companies are increasingly thinking in terms of door-to-door transport experiences and the balance between personal and public transport is shifting.

5 HOW DOES THIS CATEGORISATION GUIDE INDUSTRY?

Categorisation may also help industrial companies to map their design and development work, to identify where there are opportunities for innovation, and to find those parts of the research community’s work that may be relevant to them. In this regard, we suggest that in recent decades there has been a great emphasis in many engineering companies on exploitation in the organ domain, i.e. with the continued and incremental development of established solution principles, with innovation through explorative changes at sub-system level and in the part domain (this corresponds very much to the variant and adaptive design modes of Pahl and Beitz (1996)). A number of patterns may be recognised in such developments:

1. Improvement in the fundamental understanding of the behaviour of technologies used in the companies' designs, and new analytical methods for their modelling e.g. power train performance and efficiency in automotive technologies, improvements in aerodynamics and aerostructures in aerospace.
2. Intermittent exploration in the organ domain to identify functional additions to established solution principles, for example to deal with adverse behaviours (e.g. emissions control), to provide improved control (e.g. smart controls for a heating system) or to add user features (e.g. entertainment or information systems in vehicles). As noted by Smaling and de Weck (2007), complex products are rarely designed from scratch, but instead innovative technology is infused into an established design. The downsides of this approach include increasingly complicated artefacts, manufacturing systems and supply chains as sub-systems are added, and the need for careful change propagation among the many interlinked design activities associated with the multiple functions and sub-functions.
3. Developments in the part domain, in part to address the challenges of increased complicatedness, that include the exploration and subsequent exploitation of novel materials and manufacturing processes (e.g. composite materials in aerospace, different alloys in automotive engineering), but also design for manufacturing and assembly approaches and extensive use of architectural tactics such as product family and platform design in order to effect economies of scale.
4. Technology substitutions, either in the organ domain, for example in the replacement of internal combustion engines by electric motors, or, in the part domain, material changes such as substituting composite materials for aluminium alloys.

In many cases (especially category (2)) these changes result in 'feature creep', with changes introduced to give a product a competitive advantage or to entice customers to replace products that are still well able to fulfil their core functionality (Elliott, 2007). The benefit to customers can be social rather than functional (Thompson and Norton, 2011). For example, much of the complexity of current cars comes from the embedded electronic systems. While some do improve the core functionality of transporting people, many others, like the systems associated with passenger entertainment, do not. This corresponds to an addition of organs. Overall, this has led to a vast increase in the use of resources but no substantial improvement in the fundamental ways problems are addressed. This feature creep has also, in many cases, through the 'rebound effect', acted to reduce the effectiveness of improvements that have been made (Lorna et al., 2000). For example, instead of cars becoming lighter and using more efficient engines, as anticipated in the 1990s, they have often become heavier and often use more fuel, as more and more features that require energy or add weight are routinely added to cars, and purchasers choose large vehicles such as SUVs. Ma et al. (2015) argue that, in the case of incremental innovation, customers are often more attracted to innovation in the periphery than the core of the product, i.e. in additional organs. The addition of features gives consumers the illusion of progress without adding substantial long-term improvements; and without setting the changes in motion that are required to meet societal needs.

Technology substitution, by contrast, is often done to improve the fundamental performance of the artefact in some way. Electric traction is used to reduce carbon intensity of transportation in the use phase. Composite materials are used to reduce structure weight and achieve improved fuel efficiency. While such measures help, especially to reduce environmental impacts, it may be that they are not sufficient, and that radically different approaches to need satisfaction for the user may be needed. This might be achieved for example in transport through radical changes: use of alternative transport mechanisms altogether, or substantially changing the way users interact with vehicles for example through car sharing and lifestyle changes. This goes beyond the current dominant approach of exploitation in organ and part domains combined with sub-system innovation (exploration) in those two domains and instead considers radical explorative change in all three domains. This signals that companies need to consider explorative and exploitative design change in all three domains: they need to be **domain ambidextrous**. For survival, a new balance between exploration and exploitation needs to be found, across the full domain spectrum of a companies' products, and the research community needs to help companies in finding and enacting this rebalancing.

6 CONTRIBUTIONS BY THE ACADEMIC COMMUNITY

Ambidexterity is also required from the many researchers who are passionate in contributing to addressing societal challenges. Highly influential academic research is often that which is both on the forefront of debates (exploration), but still well connected to existing bodies of knowledge (exploitation). In engineering design, influential research often takes many years to be recognised as it is matured through different publications and projects. This makes academic research far from agile unless new elements addressing societal challenges can be interwoven with established research. While this might be a suitable strategy for individual researchers it does not guarantee that the community of researchers collectively provide the support that industry and society need. While some groups, such as the Design Society's Special Interest Groups, have carried out road-mapping exercises, there is little evidence of collective planning for research activities required to address societal needs more systematically.

Research remains patchy. However, it is an open question whether we are lacking ideas or the ability to implement existing ideas holistically. Design research for a very long time has put a lot of emphasis on creativity and the generation of new ideas. While there is a lot of research on idea generation, it often addresses under-constrained problems, where designers first need to engage in a process of discovering the constraints of the problem or establishing the user needs. However, many engineering problems, in particular in addressing societal challenges, are over-constrained. Engineers need to understand and discover more of the constraints and engage in a process of prioritising constraints and negotiating acceptable solutions to reach a point where very well-defined problems can be solved (see Stacey and Eckert, 2010). Creativity in the exploitation space is much less well understood and the notion of creativity that pushes for novelty does not suit many engineering contexts where a clever fix with the minimal amount of interference is required to make problems go away (Eckert et al., 2012).

Much research is directed at exploitation in the organ or part domain where technological replacements for unsustainable systems are developed that enable us to adapt existing systems without much apparent concern with the systemic feasibility. Radical changes sometimes occur in ways that are effectively hidden to the end user. For example, electric cars are radically different to internal combustion-engine cars but don't feel like a totally different device and that means that people can handle it. This, and the desire to retain the use of expensive distribution assets, may have motivated the proposal to replace gas with hydrogen using the existing gas infrastructure, even though the production of hydrogen is currently hugely fossil fuel intensive and a switch over would not be possible without running at least some of the infrastructure in parallel. Similarly, policy makers and the automotive industry are pushing for the widespread use of electric batteries when there is increasing evidence that the required materials, such as cobalt or lithium, may not be sufficiently available.

Some of the barriers to a fruitful interaction with social challenges comes from the nature of the university system itself. A view of progress is at the heart of the university system. Students are recruited with the promise of progress on a personal level. Research funding is frequently directed at the areas where governments see the potential for growth. Researchers jump into up-and-coming topics and are biased towards well-constructed but reductionist research with publications reporting on success rather than failure. There is a bias towards exploring the potential rather than the limitation of technologies in research and in teaching, for example there is a huge buzz in the moment around electric aviation, however the likelihood of electric flights over long distances is very limited. One of the underlying issues is that we are rarely encouraged to explore the interdependence between different systems and the effects of operating at different scales.

7 THE MISSING DEBATES

The progressive digitalisation of society and the challenges of sustainability mean that firms and wider society needs to devote more time and resources to exploration across the domain spectrum. In the organ domain, are there new technologies that can be incorporated into useful artefacts to reduce our environmental impacts, or can we rearrange existing technologies to achieve this? Can we work in the part domain to identify how we might build our artefacts in such a way that our economies can be more circular, and what would be the implications of this in the activity domain? In this regard how can we continue to exploit the benefits of digital technologies while avoiding the massive dispersive use of critical materials that these now entail (Hoffman et al., 2018)? And in the activity domain, can we rethink how we use our engineered artefacts in all aspects of our lives to reduce the many negative impacts of our societies?

In the design research community, we need to redouble our efforts to provide the tools, methods and frameworks to enable this exploration. Can we also carry out the sort of mapping of our work into clusters that was carried out by Wilden et al. (2018) to explore how well we populate the cells of the classification matrix? We might also explore how we might modify and extend the classification. For example, Problem space, Social space, Institutional space (PSI) theory (Reich and Subrahmanian, 2015) suggests that we might divide the activity domain into those parts influenced by social considerations, the way we live and work, and those concerned with institutional issues of regulatory frameworks, and business and national organisations.

The engineering design community has had little impact on innovation in the activity domain, which has been taken up by business school or social scientists, who may not have the understanding of the innovation needs in the organ and part domains. Only by linking the three domains it is possible to capitalise on what exists already and to maximise the use of existing resources.

We suggest that the impact of the design research community would increase if research activities were better integrated and coordinated. The community could engage in road mapping activities and aim to develop a collective statement how societal challenges might be addressed in an inclusive and holistic way. This would enable individuals to link their research to a bigger picture and a clearer articulation of the goals of the community. The impact would also increase if individual research activities were put better into the context of existing research. This goes beyond the obvious in that increased citations add to the academic rigor and standing of a field. Road mapping is also a mean of identifying where there are gaps in the research, as in the example of creativity in over-constrained situations. Well-articulated gaps might also be a way to attract funding to this community.

Finally, the community also needs to create fora in which it can debate the direction the field needs to take. Many individuals have visions and have similar discussions to the authors of this paper, however as these fall outside the pattern of usual academic discussions, these are often shared informally and a debate across the community does not take place. We need to generate a space for our community to bring in different fields and lead the thinking processes.

8 CONCLUSIONS

For many years the distinction between exploration and exploitation has guided both companies in their actions, and in the allocation of scarce organisational resources, and the research community in categorising investigations of organisational behaviour. This paper has argued that combining this distinction with the activity, organ and part system models of Domain Theory will be helpful in giving further guidance to companies about directions for innovation and where to allocate their resources. Furthermore, a categorisation of design research will help indicate where that research is able to assist industry in its endeavours and thus how it may be found by industry and matched to its needs. Demonstration of the broadness of reach of its activities will assist the design research community in explaining the societal value of its research.

REFERENCES

Andreasen, M. M., (1994), "Modelling—the language of the designer", *Journal of Engineering Design*, Vol. 5, pp. 103-115. https://doi.org/10.1080/09544829408907876

Andreasen, M.M., Howard, T.J., Bruun, H.P.L., (2014), "Domain Theory, its models and concepts", In: Chakrabarti, A., Blessing, L. (eds), *An Anthology of Theories and Models of Design*, Springer, London, pp. 172-195. https://doi.org/10.1007/978-1-4471-6338-1_9.

Blessing, L.T. and Chakrabarti, A., (2009), *DRM: A Design Research Methodology*, Springer, London. https://doi.org/10.1007/978-1-84882-587-1_2

Chakrabarti, A. and Blessing, L.T., (2014), *An Anthology of Theories and Models of Design*, Springer, London. https://doi.org/10.1007/978-1-4471-6338-1

Eckert, C., Stacey, M., Wyatt, D. and Garthwaite, P., (2012), "Change as little as possible: creativity in design by modification", *Journal of Engineering Design*, Vol. 23, pp. 337-360. https://doi.org/10.1080/09544828.2011.639299

Eckert, C., Isaksson, O., Hallstedt, S., Malmqvist, J., Öhrwall Rönnbäck, A. and Panarotto, M., (2019), "Industry trends to 2040", In. *Proceedings of the Design Society: International Conference on Engineering Design*, Vol. 1, July 2019, pp. 2121 - 2128. https://doi.org/10.1017/dsi.2019.218

Elliott, B., (2007), "Anything is possible: Managing feature creep in an innovation rich environment," IEEE Int. Engineering Management Conference, Lost Pines, TX, USA, pp. 304-307, doi: 10.1109/IEMC.2007.5235049.

Gericke, K., Eckert, C., Campean, F., Clarkson, P.J., Flening, E., Isaksson, O., Kipouros, T., Kokkolaras, M., Köhler, C., Panarotto, M. and Wilmsen, M., (2020), "Supporting designers: Moving from method menagerie to method ecosystem", *Design Science*, Vol. 6. doi:10.1017/dsj.2020.21

Greening, L.A., Greene, D.L. and Difiglio, C., (2000), "Energy efficiency and consumption - the rebound effect - a survey", *Energy Policy*, Vol. 28, pp. 389–401. https://doi.org/10.1016/S0301-4215(00)00021-5.

Gupta, A. K., Smith, K. G., and Shalley, C. E., (2006), "The interplay between exploration and exploitation", *Academy of Management Journal*, Vol. 49, pp. 693-706. https://doi.org/10.5465/amj.2006.22083026

Hallstedt, S.I., Isaksson, O., and Öhrwall Rönnbäck, A. (2020), "The need for new product development capabilities from digitalization, sustainability, and servitization trends", *Sustainability*, Vol. 12. https://doi.org/10.3390/su122310222

Hofmann, M., Hofmann, H., Hagelüken, C., and Hool, A. (2018), "Critical raw materials: A perspective from the materials science community", *Sustainable Materials and Technologies*, Vol. 17, e00074. https://doi.org/10.1016/j.susmat.2018.e00074

Isaksson, O. and Eckert, C.M., (2022), "Designing innovation–the role of engineering design to realise sustainability challenges", *Proceedings of the Design Society*, Vol. 2, pp.1021-1030. https://doi.org/10.1017/pds.2022.104

Isaksson, O., Eckert, C., Borgue, O., Hallstedt, S.I., Hein, A.M., Gericke, K., Panarotto, M., Reich, Y. and Öhrwall Rönnbäck, A.B., (2019), "Perspectives on innovation: the role of engineering design". *Proceedings of the Design Society: International Conference on Engineering Design*, Vol. 1, pp. 1235-1244. doi:10.1017/dsi.2019.129

Jarratt, T.A.W., Eckert, C.M., Caldwell, N.H. and Clarkson, P.J., (2011), "Engineering change: an overview and perspective on the literature", *Research in Engineering Design*, Vol. 22, pp. 103-124. https://doi.org/10.1007/s00163-010-0097-y

Ma, Z., Gill, T. and Jiang, Y., (2015), "Core versus peripheral innovations: The effect of innovation locus on consumer adoption of new products", *Journal of Marketing Research*, Vol. 52, pp. 309-324. https://doi.org/10.1509/jmr.13.0337

March, J.G., (1991), "Exploration and exploitation in organizational learning", *Organization Science*, Vol. 2, pp.71-87. https://doi.org/10.1287/orsc.2.1.71

McMahon, C., Eckert, C. and Fadel, G., (2021), "Towards a debate on the positioning of engineering design", *Proceedings of the Design Society: International Conference on Engineering Design*, Vol. 1, pp. 3169-3178. https://doi.org/10.1017/pds.2021.578.

O'Reilly, C.A. and Tushman, M.L., (2004), "The ambidextrous organization", *Harvard Business Review*, Vol. 82, pp. 74-83.

Pahl, G. and Beitz, W. (1996), *Engineering Design: A Systematic Approach*, Springer, Berlin. http://doi.org/10.1007/978-1-4471-3581-4

Reich, Y., and Subrahmanian, E., (2015), "Designing PSI: an introduction to the PSI framework", *Proceedings of the International Conference on Engineering Design*, The Design Society, Milan, pp. 137-146

Sillitto, H., (2014), *Architecting Systems, Concepts, Principles and Practice*, College Publications, UK

Smaling, R. and Weck, O.D., (2007). "Assessing risks and opportunities of technology infusion in system design", *Systems Engineering*, Vol. 10, pp. 1-25. https://doi.org/10.1002/sys.20061

Stacey, M. and Eckert, C., (2010), "Reshaping the box: creative designing as constraint management", *Int. Journal of Product Development*, Vol. 11, pp. 241-255. https://doi.org/10.1504/IJPD.2010.03396

Swift, T., (2016), "The perilous leap between exploration and exploitation", *Strategic Management Journal*, Vol. 37, pp. 1688-1698. https://doi.org/10.1002/smj.2423

Thompson, D.V. and Norton, M.I., (2011), "The social utility of feature creep", *Journal of Marketing Research*, Vol. 48, pp. 555-565. https://doi.org/10.1509/jmkr.48.3.555

Veldman, J., and Alblas, A., (2012), "Managing design variety, process variety and engineering change: a case study of two capital good firms", *Research in Engineering Design*, Vol. 23, pp. 269-290. https://doi.org/10.1007/s00163-012-0135-z

Wilden, R., Hohberger, J., Devinney, T. M., and Lavie, D., (2018), "Revisiting James March (1991): whither exploration and exploitation?", *Strategic Organization*, Vol. 16, pp. 352-369. https://doi.org/10.1177/1476127018765031