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ORIGINAL ARTICLE

Future states: design and science for sustainability

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ABSTRACT

In 2017 CERN IdeaSquare collaborated with the Royal College of Art (RCA), London to explore how an interdisciplinary approach to innovation that combines science, technology, design and business might address the global sustainability challenges as embodied in the United Nations's (UN) Sustainable Development Goals (SDG) 2030. This collaboration examined how an interdisciplinary design led model of innovation, that fuses design thinking with scientific discovery, could enable the innovative and potentially disruptive technologies from CERN to address the world's most intractable challenges, and specifically the UN's SDGs. In this paper we explore the nature of interdisciplinary innovation, recent trends in its approach, and describe the way this has been applied, through action research, to generate product service systems that address the UN's SDGs. We describe not only the project outcomes that demonstrate the inventiveness of the CERN IdeaSquare and RCA teams, but also the new knowledge that can be applied to future interdisciplinary innovation projects.

Keywords: Sustainability; interdisciplinary innovation; design thinking.

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INTRODUCTION

In 2017 CERN IdeaSquare collaborated with the Royal College of Art (RCA), London to explore how an interdisciplinary approach to innovation that combines science, technology, design and business might address the global sustainability challenges as embodied in the UN's Sustainable Development Goals 2030 (UN 2015a).

The partnership between CERN IdeaSquare and the RCA examined how innovative and disruptive technologies can help address the world's most intractable challenges by using an interdisciplinary design led model of innovation that fuses design thinking with scientific discovery.

The reason for focusing on the UN's Sustainable Development Goals are that these are the output of the largest consultation the UN has ever undertaken. Over 8 million people were consulted, 70 countries were engaged in the working parties and 193 nations have signed up to them (UN 2015b). The goals set detailed targets and are a compelling and clear global articulation that seeks to bring about a world of prosperous and resilient economies, fair and just societies within the limits of what the world can provide. UN (2015a) considers that the goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges including those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice. These challenges are socially oriented 'wicked problems' (Rittel and Webber, 1973) that requires interdisciplinary approaches that go beyond traditional disciplinary boundaries. The concept of wicked problems provides a useful reminder that not all problems can be solved solely by technical solutions.

In this paper we explore the nature of inter-disciplinary innovation, some of the more recent trends in its approach, and describe the way this has been applied in the project between CERN IdeaSquare and the RCA and the results of this collaboration. We describe not only the project outcomes that demonstrate the inventiveness of the CERN

IdeaSquare/RCA teams, but also the new knowledge that can be applied to future innovation projects.

THEORETICAL BACKGROUND

For more than 50 years designers and scientists have compared and sometimes combined their contrasting epistemologies and, despite a few collisions, can demonstrate that such an interdisciplinary approach can help address some of the more intractable and complex problems.

Buckminster Fuller (1965) used the term the 'Design Sciences' decade for that period in the sixties when innovators from different disciplines sought to combine sciences, technology and rationalism to address complex social and environmental problems. As Herbert Simon emphasised, the purpose was not only to create scientific knowledge of products or engineering components and their interfaces (Simon 1969), but also to systematise the design process and develop rigorous design methods which Bruce Archer led at the Royal College of Art's (RCA) Design Research Unit. (Archer, 1968)

We can trace back the importance of interdisciplinarity in design to Simon (1969), in his call for design to create common ground across the arts, technology and sciences and that designers must deal with the unpredictability of human aspects, which requires designers to work within an ever evolving system.

The pioneering work by Archer, along with the leadership of Professor Sir Misha Black led ultimately to the founding of a double degree course at the RCA combining Industrial Design with Engineering and creating a new programme, Innovation Design Engineering (IDE). The programme has now been in existence for almost 40 years and along side it, an even more interdisciplinary programme of Service Design has been established that combines systems engineering, design, computer science and business. The IDE programme has resulted in the creation of dozens of new business ventures that have been incubated at the RCA and made the RCA the most successful university for generating new and thriving businesses, and resulted in it being awarded a £54m grant by the UK Government to develop its campus and expand its capacity for research and interdisciplinary innovation. Similarly, the Service Design programme has developed an unprecedented number of industry and government partnerships seeking to exploit an interdisciplinary approach to challenging issues in health and education, and the criminal justice system, as well as in financial and retail services, and the transformation of the automotive industry to a mobility services one.

However, the success rate of interdisciplinary innovation is traditionally poor. There is a record of consistent failures especially when the disciplines are practiced at great distances from one another. In an article published in the Harvard Business *Review*, Lee Fleming's research shows that it is true that the most common outcome of interdisciplinary research is failure (Fleming 2004). Fleming looked at 17,000 patents of all sorts – from medicine to business to design – and his research suggests, and I quote: *"that the ... value of ... innovations resulting from such cross-pollination is lower, on average, than the value of those that come out of more conventional silo'ed approaches."* But, he continues, *"my research also suggests that breakthroughs that do arise from such multi-disciplinary work, though extremely rare, are frequently of unusually high value— superior to the best innovations achieved by conventional approaches."* So we are faced with a conundrum, when interdisciplinary approaches are used, failure is more likely, but when it succeeds, then the value is far greater than conventional approaches.

If this is the case, we might ask how we might mitigate the risks of failure so as to achieve the exceptional gains illustrated by Fleming's analysis. In the 1990's the term Design Thinking emerged (Buchanan 1992), and was later developed through the early

2000s (Brown, 2008) not only for innovation in products and services, but also to address business, organizational and management challenges. Design Thinking is defined by Brown (2018) as '*a human-centred approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success.*' Design Thinking demands an interdisciplinary approach to innovation and with it, it provides a structured approach to problem solving that offers tools and techniques which have been successfully applied in both the public as well as the private sector to address complex social and commercial challenges and opportunities.

Design Practice in Practice

The new paradigm of knowledge production 'Mode 2'. (Nowotny, Scott et al. 2001) suggests knowledge production be socially distributed, application-oriented, transdisciplinary, and subject to multiple accountabilities. It calls for the participation of a wider range of non-scientific actors in the process of innovation (Hessels and van Lente 2008).

Jonas (2014) sees that this new paradigm of scientific inquiry being socially embedded and context-dependent indicates that science is gearing towards a 'designerly' (Cross 2006) process of innovation and change. He considers that if the active, intentional improvement of an unsatisfactory, problematic situation is the primary motivation for scientific inquiries, there is a convergence between design and science. In this sense, design can contribute significantly in this space, as argued by Buchanan (1992) that *'designers are exploring concrete integrations of knowledge that will combine theory with practice for new productive purposes and this is the reason why we turn to design thinking for insight into the new liberal arts of technological culture'* .

Similarly, innovation is seen to be increasingly problem-oriented, normative, socially accountable and transdisciplinary, as suggested by Innovation System literature, e.g. (Edquist 2013). When an innovation is inspired by design, it transcends technology and utility. (Utterback, Vedin et al. 2006)

On the other hand, it has been recognised (especially within design communities) that design has significantly expanded its meanings and connection in recent years. Design no longer concerns only tangible artefacts, but intangible ones, such as services, interfaces, systems and discourses (Krippendorff, 2004). Similarly, Buchanan (2001) proposes a four-orders-system of design to rethink and reconceive the nature of design. The first and second orders of design concerns 'symbols' and 'things', which were central in the establishment of the professions of graphic and product design. The third order of design focuses on how human beings relate to other human beings, and the fourth one focuses on environments and systems.

In the space of the third and the fourth order of design, a designer's approach to a problem begins with an acute observation of the users and of the system's context and constraints, be they socio-cultural, technical or economic, in what is referred to as the discovery phase. This may involve ethnography, visual anthropology, and the use of participative workshops with users and front line teams. The next phase involves developing insights and framing the problem, often referred to as the define phase to ensure an understanding of the underlying causes rather than the symptoms of the problem and the human as well as technical and economic constraints that will help define the brief. From here, designers move into the ideation phase, exploring through prototypes and visualizations, and with potential users and other stakeholders, alternative potential solutions and how different types of users and stakeholders might interact with those solution concepts; and then concluding with the final delivery phase. In this phase, the prototypes are tested not only in terms of their technical robustness and effectiveness, but also of their fit with users' needs and the broader context of their lives (Stickdorn et al 2017).

This approach is especially powerful when it is used for breakthrough thinking and where disruptive innovation is required, or to address “wicked” problems (Rittel & Webber, 1973; Buchanan, 1992). This is where the nature of the problems and the system’s context may be unclear or highly complex. The challenges and complexity of UN’s Sustainable Development Goals that the project aims to address has this level of complexity and categorized as a “wicked” problem.

Design Thinking as an Integrative Discipline

Design Thinking has become a tool not only for product innovation, but also for business strategy development (Martin, 2009) and service design (Sangiorgi 2009; Kimbell 2011). Design Thinking has led to Service science as a means of service innovation (Spohrer and Maglio, 2004), and organisational and management innovation (Gruber and de Leon, 2015; Boland and Collopy, 2004). It has also been successful in the emergent field of design for policy (Bason, 2014).

As a result of the success of this approach there has been a recent trend for government sponsored innovation laboratories that use Design Thinking as a means of not only developing new services but also formulating policy, creating new policy instruments and contributing to government strategy. These laboratories include Policy Lab, which is part of the UK Cabinet Office, MindLab in Denmark, GobLab (Laborotorio Gobierno) in Chile and others at both city and region level. (Christensen and Bunt, 2012)

The emergence of these centres for policy and service innovation is in recognition that a different approach is needed to tackle the innovation imperative both for policy and services (OECD, 2014). Recent literature argues that linear models of policy making, public administration and service delivery cannot cope either with the ‘wicked problems’ of a complex world or with the increasing demand and expectations of citizens (Colander & Kupers, 2014; Muir & Parker, 2014), so this alternative approach has to come from “beyond policy” opening the boundaries of traditional epistemologies for public policy making and public service delivery.

These policy laboratories and their trans-disciplinary design practice, draw upon the work of Daniel Kahneman Nobel Lauriat, 2002, and his pioneering work on the psychology of judgement and behavioural economics. Burns et al. (2006) suggest that designers are well placed to help solve complex social issues, leading to changes in the way public services are delivered.

It is against this background that IdeaSquare at CERN and the Royal College of Art’s Service Design programme created this collaboration with the goal of addressing the UN’s Sustainable Development Goals. The collaboration’s objectives were to test how an interdisciplinary innovation approach that combines two very different epistemologies, cultures and methods could be operationalised and whether the outcomes could provide not only some new directions in terms of solutions, but also in terms of approaches to innovation.

METHOD AND DATA

The project used an action research methodology, an approach to problem solving employing worker-centred and participatory techniques. It was defined as a methodology to “solve practical problems through a research cycle involving planning, action, and investigating the results of the action” (Lewin 1946).

As suggested by Feast and Melles (2010), action research is recognised in the design field for conducting research through design (Jonas, 2014) or project-grounded research (Findeli 2008). In Jonas (2014)’s view, this type of research is a second order cybernetic mode of inquiry, where the observer “is inside a design/ inquiring system, generating knowledge and change through active participation in the design enquiry”. In this model the object of design is to generate human centred-innovation.

As such, the researchers/authors participated in the planning, action and investigating stages of the project, together with a much larger team involving teams of service design postgraduate students from the Royal College of Art, who are drawn themselves from a variety of disciplines, working with scientists and the Knowledge Transfer team from CERN to develop propositions to address the UN SDGs. As part of the investigation, the solutions they developed were presented at a Symposium and related exhibition to an invited audience from industry, government, academia and the two project partners, CERN and the RCA. Both CERN and faculty from the RCA subsequently surveyed the participants of the project teams, and the organisers, for their perception of the experience. Their comments and the analysis of these as well as the observations made by the researchers/authors is summarised at the end of this paper.

The project was undertaken in six distinct phases – Scoping, Orientation, Interchange, Ideation, Development and Dissemination. (See Figure 1)

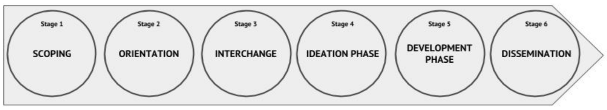

Figure 1: Project Phases

1. Scoping

The initial scoping was undertaken by senior members of faculty from the RCA and the Executive team at IdeaSquare at CERN. The goal of this phase was to identify which of the scientific innovations that had emerged from CERN including current areas of interest as well as recent applications of CERN technology by CERN's Knowledge Transfer team might be relevant in terms of their maturity, comprehensibility, and utility for applications that could contribute, and the emphasis is on 'could', to the UN SDGs. A set of technologies was selected by the combined team who then organised the team and briefed the participants on the project structure and provided a relatively open ended brief to encourage the designers creative contribution.

2. Orientation

The Orientation phase involved setting up interdisciplinary teams from within the RCA drawing upon a cohort of postgraduate design students that come from a wide range of backgrounds – from computer science to philosophy, from product design to psychology. 17 designers were selected and each was assigned one of the 17 UN Sustainable Development Goals on the basis of their personal interest, previous work or project activities undertaken at the RCA and skill base. They were asked to explore the nature, underlying causes, UN targets and national and international initiatives to address their assigned SDG. Similarly, the scientists and Knowledge Transfer Team at CERN were informed about the project, briefed on Design Thinking and asked to prepare to provide a briefing for the designers on their scientific and technological domain and the scientific innovations that could play a role in this initiative. The following areas were selected for initial investigation – Cryogenics, Sensor Technology, Hyper-vacuums, Gas and Particle Detection, Robotics, Data Science and AI, Spectroscopy. The goals of the project were documented in a shared brief, that identified how the designers and scientists would work together and specifying the objectives and principle deliverables from this shared initiative.

3. Interchange

The designers visited CERN and after a first day visiting the principle experiments and control rooms at CERN and the Large Hadron Collider and Anti-Matter Factory, they were introduced to the cafeteria at CERN and asked to mingle and socialise with scientists at CERN, explaining their project and exploring the roles and areas of expertise of the scientists they met. The goal of this activity was to enable the serendipitous exchange of knowledge and interest, collisions not of particles but of ideas, of different creative cultures, and develop potential sources of inspiration for the designers.

The designers were then briefed each morning on one or more of the scientific and technological domains, and then in the afternoon they explored how each of the SDGs could benefit from the technology they had just heard about. This was repeated throughout the week and by the end of the week, from the matrix of technologies and SDGs, the designers were asked to present back to the RCA faculty and CERN team:

- Their first reflections on the SDGs they wished to focus on
- The technologies they believe could contribute
- Their initial ideas on how those technologies might be applied in the form of a product, service system proposal

4. Ideation Phase

The design students then returned to the UK and used Design Thinking (Brown, 2009), and specifically a service design approach, to reflect on what they had learned, research further the SDGs and then examine the target users and communities that would benefit. This involved researching their actual needs and the environmental, economic, socio-cultural or political context in which any solution might be constrained. The designers were asked to create different levels of prototypes from visualisation and storyboarding, simulation and modelling through to operational prototypes. They were asked to test the concepts that emerged both with the scientists they had met as well as with the target communities or at least people who were expert in those domains and to iterate based on the input they received. The individual teams were mentored by two representatives from CERN, Prof John Wood and Dr Markus Nordberg, and interacted with the scientists and UK experts from academia, government and industry to refine their ideas. The process they used was in 4 stages, i)explore the human, societal and environmental aspects of their domain, ii) develop key insights and define the opportunity, challenges and constraints associated with that domain, iii) generate systemic concepts that could address that opportunity and prototype, test, refine or pivot and select a proposition to explore more deeply, iv) develop a detailed proposition including consideration not only of its potential impact but also a high level business model that could demonstrate its potential economic sustainability.

The specific actions they undertook in this phase were specified as follows in the project brief:

- Carry out desk research to understand SDGs and identify opportunities for product service systems that could create a transformational opportunity to a known and well defined challenge
- Identify a particular area where you or a member of your team may have specific knowledge, experience from previous projects or links to organisations that could be relevant to one or more of these domains
- Visit to CERN for briefing by KT Group and then work with CERN KT Group and Idea Square as well as other stakeholders to understand how these new and disruptive technologies could make an impact on one or more of SDGs
- Identify key stakeholders who help or hinder sustainable development entrepreneurial ventures, in the public, private or third sector on their journey from ideas to impact
- Map out the existing challenges including people's lives affected by these sustainable development issues as well as the organisations trying to address them. And, identify the problems, challenges and opportunities that exist for and within these environments.
- Use co-design workshops to identify opportunities for design interventions either by tackling the existing experience or creating a new design approach.
- Use feedback from these sessions to develop a greater degree of specification than your earlier projects, validating your design solutions with key stakeholders.

5. Development Phase

Following the initial concept development, students visited CERN once more, and with this input they revised their solutions before presenting their final proposition to a combined group of faculty from the RCA, scientists and members of the Knowledge

Transfer Team from CERN. The activities performed by the designers in this phase were as follows:

- Design a product service system that is highly granular so that it can be delivered by a organisation and show how it would benefit not only the recipients of the service or product service system but also the organisation delivering that solution
- Build a functional prototype for all or one specific part of the product service system and visualise/describe the rest of it.
- Test your design proposition with users, before documenting the service with a detailed blueprint and a viable deployment plan.
- Describe a business model that demonstrates that the service could be commercially feasible, either through return on investment or return on social capital.

6. Dissemination

In order to disseminate the outcome of this collaboration, the RCA and CERN ran a symposium, *Future States*, which brought together industry, public sector and government to review not only the innovative outputs from the project, but also the new processes that it pioneered in interdisciplinary innovation.

At the symposium the designers presented the outcomes of these projects which include applying CERN innovations to improve earthquake detection, tackle the issues of micro-plastics in the world's oceans and create a more sustainable alternative to HFCs in air-conditioning

The speakers at the symposium included the Head of innovation for CERN Markus Nordberg, who introduced the project along with Dr Nick de Leon, Head of Service Design at the RCA. Sir Brian Hoskins, Chairman of the Grantham Institute for Climate Change, discussed the important role that innovation plays in tackling Climate Change, Justin McGuirk, Chief Curator for the Design Museum, spoke about the capacity of design to drive change, and Alison Boyle, Keeper of Science Collections at the Science Museum presented a paper discussing social engagement with science. There were also papers on sustainability and design from Dean of the School of Design Professor Paul Anderson, Fellow of the Royal Academy of Engineering Professor John Wood and Dr Ronald Jones, Senior Service Design tutor at the RCA.

All the solutions were exhibited at the Royal College of Art and over 5 days the exhibition was visited by over 1000 members of the public. Over 150 representatives from academia, government, scientific and cultural institutions and industry attended the full day symposium and the presentations presented that day, along with the details of the propositions were shared publicly and have been downloaded hundreds of times within the first months following the symposium.

RESULTS

The project resulted in six concepts, as summarised here.. Each concept closely addresses at least one of the SDGs as indicated at the back of each description.

- *Orbis* – Early prediction and detection of earthquakes using Muon Tomography and related support and recovery services to enable cities in earthquake zones to continually monitor seismic activity and changes in the geological structures and bring forward the recovery planning and evacuation of citizens. The solution comprised of a network of low cost Muon detectors to enable the equivalent of a CT scan of the earth's crust which the designers built and tested.
  (SDG Goal 11: Sustainable cities and communities)
- *Coldbox* – using CERN innovative solar powered cryogenics to enable low cost cooling in the food supply chain to reduce food waste, carbon emissions and leakage of HFC.s and enable economic growth in the food and agricultural sectors in developing economies without the attendant growth in carbon emissions, and at a cost point and service model suited to a more distributed food production model (SDG Goal 1: No poverty; Goal 2: Zero hunger; and Goal 3 Good health and well-being)
- *Corallo* – a technological and service solution to stop micro-plastics entering the ocean from clothing through an analysis of the flow of plastics into the ocean from the fashion and textile industry and proposes an intervention in waste water management plants to filter the

micro-plastics and then recycle them and avoid them entering the food chain, landfill or oceans. (SDG Goal 14: Life below water)

- *Shiva* – a solution for a more sustainable fashion industry that uses proton beam spectroscopy to monitor the provenance of textiles throughout the entire supply chain to assure the public of the ethical and environmental conditions under which the clothes they purchase.
  (SDG Goal 3: Good health and well-being; Goal 9: industry, innovation and infrastructure; and Goal 12: Responsible consumption and production)
- *RASA: Radon Detection* – a product service system that enables real time radon detection and continuous monitoring along with alerts and actions that can be taken to reduce radon levels. The monitoring and mitigation service is combined with a public health awareness service to reduce risks of Lung Cancer.
  (SDG Goal 3: Good health and well-being)
- *Agri+, Sustainable Agriculture and Precision Farming in Africa* – This project focused on how an industry 4.0 approach could empower small scale farmers in Africa, South America and Asia by exploiting precision farming techniques and enabling them to have better information on markets so they can respond quickly to changing preference. The service proposed helps individual farmers to understand they land better, and help them to treat their soil correctly by installing sensors and measuring the parameters in soil, such as PH, humidity and fertilisers, exploiting the fiber-optic sensor of CERN's FOSS4 Irrigation. The project focused on the tea industry in Kenya which lacks both power and network infrastructure, but demonstrated how this could be overcome and could achieve a leap frog effect in Kenya's tea industry. And how this approach could then be replicated to other crops and regions.
  (SDG Goal 2: Zero Hunger; Goal 8: Decent work and economic growth; Goal 9: Industries, innovation and infrastructure; Goal 12: Responsible consumption and production; and Goal 15 Life on land).

These concepts received highly by the CERN team and other stakeholders. The way each concept addresses the SDG goals demonstrates the wickedness of these challenges, reflecting the diversity among the stakeholders in the problem. It also shows the effectiveness of interdisciplinary innovation in approaching wicked challenges.

Feedback

In addition, the participants were surveyed following the completion of the project and their comments and the survey results are described.

Following the 17 project participants from the RCA completed a survey. The scope of the interviews and survey were to understand:

- The overall process of this project, and how that can contribute to improving our understanding more generally of the challenges of interdisciplinary innovation
- The process by which knowledge gained in a scientific context for one purpose might be translated into impactful solutions that go beyond the specific goals of the organisation
- The technical feasibility, commercial viability, and value or desirability of the project outcomes in order to assess the relative value of this exercise beyond the educational contribution of working with CERN
- The merits of incorporating scientific knowledge, methods and an awareness of the culture of scientific discovery for designers and similarly, the awareness of design thinking within the scientific community

The survey addressed their overall experience in terms of the process, the project outcomes and the dissemination of the work and the project through the Future States symposium and exhibition.

Feedback on the Process

The RCA designers were given a very open brief but some of them suggested that a more prescriptive brief, perhaps identifying specific technologies, would have been suitable given the short time scale involved and the need to both identify which of the SDGs to focus on and which technologies to apply provided almost too many options. There were also comments that those project teams that settled very early on a CERN technology and then built a proposition around that to address an SDG we more effective than starting with the SDG and identifying a technology that could address that need as there were just too many options.

In order is to retain the creative opportunity they commented that the brief should not be too prescriptive, however one suggestion was for a short initial co-creation activity between scientists and designers to explore possibilities and potential directions, and short list both the candidate technologies and specific opportunities for a more in-depth analysis.

The designers also commented on the need to have more direct engagement with scientists making it a more collaborative effort, once a team has identified a concrete direction, and where more detailed explanations of the technologies can be made available, especially at a level comprehensible to a layperson. There were a number of comments associated with making the experience more interactive and having more direct involvement as well as pre-briefing of the scientific community. There were further comments about making the sessions with scientists more discursive rather than a talk or lecture format without interaction. One of the comments sums this up as “many of the presentations overlapped in content and were not necessarily tailored to an audience of non-physicist designers… it could have been a lot more inspiring and exciting for both sides if we'd had some actual intellectual exchange … (and) maybe some brainstorming sessions”

The implications of this are to deepen the pre-briefing for both sides and structure the sessions on technology as knowledge sharing seminars and workshop format where applicable, as well as the need for adopting a language that is more inclusive while recognising the complexity of the science.

The value of the second visit to CERN to share the initial concepts and get technical feedback was questioned by the designers with a feeling that it could have been done by Skype or equivalent, and that it would have been more valuable to present individually to the different and relevant scientists rather than too a small group from IdeasSquare. This suggests a reflection on the project format and the pre-planning of any return visits to CERN so that the relevant scientists can schedule this in their agendas. It also suggests trying to incorporate a more collaborative approach rather than the sequential approach of a technology briefing by CERN scientists, opportunity identification and ideation by the designers and then reviewing of concepts by CERN before refining them at the RCA and presenting them back to the scientific community.

Feedback on the Solution Outcomes

The designers were in general very satisfied with the desirability of their solutions and how they addressed real and compelling needs as well as their potential impact on the SDGs. The areas they felt needed more work were around their solutions’ technical feasibility as well as commercial viability and creating a sustainable business model. Almost all of the students stated that they were eager to continue the development of their solutions should further funding be available. They also gave feedback on the technical risks on a spectrum of radical high risk to safe. The assessed their solutions as being towards the radical end of the spectrum but none were considered at the extreme radical end of the scale.

The implication of this is that greater involvement with the technology teams, not just at the start and the end of the project, but through the ideation and testing phase would help address the technical feasibility issues, as well as to encourage the students to take perhaps greater risk and use their creativity to develop more radical propositions. The second is that entrepreneurial input, especially in the latter stages to develop a business model, and a high level business plan could address the viability concern. Finally, engaging with technology investors as well as grant awarding bodies for early stage ventures could create opportunities for the potential commercialisation of the solutions.

Feedback on Dissemination

The final feedback from the designers was associated with the Symposium. The comments about the Symposium related to the quality of the presentations and the speakers as well as the audience. These included: “Very interesting and engaging”, “More critical” and "a chance to talk with diverse disciplinary people." While the opportunities for feedback during the symposium sessions were limited, students commented very positively on the opportunity to present their work in the exhibition. "We received so much feedback from the users, experts and people… (though) it would have been good to have some more feedback from the scientists and designer in the symposium". Other comments included how the symposium could be made more effective by bringing in potential investors or people working in the industry to give feedback and create the opportunity for seed funding.

The Symposium and related exhibition format was very well received by the audience which was drawn from industry, academia and the public sector. Comments included how "imaginative", "inspiring", "the solutions are so complete in their thinking, so well researched, and the technical depth so unexpected" as well as comments about the overall importance of interdisciplinary innovation models where designers play a lead role.

The comments from the designers highlight the value of having a format that enabled them to exhibit their work as well as present it in a more formal context of the Symposium sessions. The audience that the seminar attracted was very diverse, but consistently at a high level with representatives from senior roles in other universities, museums and public institutions. The opportunity in future dissemination events is to include potential project funders from industry, the Venture Capital (VC) and Angel communities as well as award bodies. It could also be valuable to present this within CERN in a similar format, and use this as a means of inspiring scientists to consider how their innovations might be applied to opportunities beyond CERN and make a contribution to the grand challenges we collectively face.

DISCUSSION AND CONCLUSIONS

We have summarised the new knowledge from the project with six key findings that can guide not just future projects that involve interdisciplinary innovation involving scientists and designers but may be more generally applicable. They are as follows:

1. *Managed Serendipity:* There is an appetite within the scientific community to see their scientific discoveries and technology innovations being applied to opportunities beyond CERN. However, the project identified that the current model relies more on serendipity than an analysis of strategic opportunities and issues such as the UN SDGs at one extreme or Elon Musk's Hyperloop and its need for hyper-vacuum technologies on the other.
2. *Focusing and intensifying the "Radar":* There is therefore an opportunity for Knowledge Transfer teams to undertake a systematic review of what might be referred to as "Grand Challenges", potential industry and governmental partners and effectively scout for science and technologies that could contribute to resolving these challenges within organisations like CERN.
3. *Start with the problem*: A design led approach that starts by deconstructing the challenge, and understanding of the needs and constraints of the key stakeholders associated with that challenge, can be a more fruitful way of defining the opportunities that a scientific discovery or technological innovation might resolve. Starting with a technology and looking for a problem to fix tends to result in applying a distorting lens on the problem that is shaped by the possible solution. This has implications to knowledge transfer programmes in general within scientific organisations.
4. *Mutual Understanding:* Importance of pre-briefing and orientation – it was evident from the experience, both of the students as well as from the scientific resources of undertaking better pre-briefing of each party to enable a deeper understanding of each others capacity and approaches
5. *Spaces, Places and Visualisation of Ideas*: The IdeasSquare space created an environment that was distinctly different from the rest of CERN and more conducive to the exploration of ideas and the generation of concepts in an uncritical manner. Those ideas once reflected upon and synthesized, could be scrutinised rigorously, but without those conditions it is hard to enable creative concepts and ideas to emerge. Importantly, the RCA students' capacity to develop those ideas through visualisation, story telling and prototyping so that the systems concepts could be understood in their entirety was crucial in generating confidence within

the scientific community of the robustness of the ideas

6. *Translating Ideas to Impact*: The process of dissemination is not yet fully complete, but the symposium enabled the ideas, concept solutions and innovation approach to be shared with interested parties beyond CERN and within academia and industry. However the opportunity remains to publish and exhibit the outputs of this work as well as build upon it, and use publications such as this to share alternative approaches to identifying opportunities for the technologies that emerge from CERN and linking them to global social, environmental and economic challenges. As a next step it is important to share these outcomes with industry and governmental partners not only as sources of inspiration but as concepts that could be taken further. In this case, consideration might be given to creating a venture incubator and business accelerator as part of the Knowledge Tansfer (KT) function, where emergent concepts can be supported to a point where the private sector might be ready to invest, or partner in their development.

This exploratory action research project has piloted a design-led interdisciplinary approach to address grand challenges and has demonstrated its relevance. A larger project is planned between CERN and the RCA, based on the learning from this project. These changes are considered:

- To bring in a wider spectrum of design disciplines into the collaboration to include Fashion, Textile, Product, Vehicle and Interaction Design. First, this will help to test the relevance of the process to a wider design community; as such, strengthening the potential of interdisciplinary innovation. Secondly, the engagement with various design disciplines is likely to encourage solutions achieved through various medias beyond product service systems that service designers rely on.
- To create a mechanism encouraging reflection throughout the project, in order to capture knowledge emerging from the practice. The overall purpose of these projects is to develop a methodology/process for scientists and designers to collaborate for grand challenges. The learning arriving from doing contributes to our knowledge about interdisciplinary innovation practice in general.
- To strengthen the involvement of the technical teams from CERN through a more regular mentorship scheme allowing them to take part in the whole process. This helps the designers in the process of ideation and development; and gives the CERN teams the opportunity to closely observe the process and to contribute to the solutions.

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