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KEY THEMES IN DESIGN INFORMATION MANAGEMENT

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1. Introduction

A product development process of some sort can be found in virtually every engineering design organisation. Delivering this process are a number of different organisational functions and stakeholders, including engineers, knowledge and information managers, all of whom provide inputs to – or support for – the process of design itself.

This process is usually also supported by an Information Management (IM) system such as Product Lifecycle Management (PLM) or Product Data Management (PDM). In practice, such systems often comprise a collection of information, document management systems and associated procedures. However, IM systems have commonly been developed for one particular purpose, or to support the needs of a particular stakeholder. Whilst more recent efforts have been directed toward supporting the whole design process from the perspective of multiple stakeholders through, for example, customisable user interfaces, the more fundamental issue of what requirements these various stakeholders have is not well understood.

Drawing principally on work conducted in the Innovative Design and Manufacturing Research Centre (I*d*MRC) at the University of Bath, this paper aims to explore the viewpoints of these stakeholders. The viewpoints are then synthesised to identify five key themes, that together form a set of requirements for an IM system that can support the product development process in an integrated manner. Potentially conflicting aspects of the five themes are highlighted and areas for further work identified.

2. Method

This paper explores six diverse perspectives on product development. The perspectives were based on practitioners within industry and represent an input in the form of customer requirements from the sale/marketing function, three perspectives covering the process of design itself, and two support functions in the form of the archive and knowledge managers. It should be noted that the perspectives are not intended to be comprehensive, but were chosen to form a cohesive cross-section of the functions found in modern engineering organisations:

- Marketing Manager – Customer requirements and feedback (input)
- Sustainability Consultant – Assessing/disseminating the impact of legislation (input/process)
- Innovation/Design Engineer – Effect of design and innovation on the process (process)
- Process Improvement Engineer – Improving and introducing new tools and methods (process)
- Knowledge Manager – Improving the use information/knowledge during the process (support)
- Archivist/Records Manager – Capturing and storing information for re-use (support)

For each perspective, several scenarios were developed and styled as a critique of the current problems facing practitioners. Scenarios were adopted specifically to facilitate discussion of the findings by the widest set of researchers and industry stakeholders. The points made in the scenarios were drawn primarily from research undertaken at the University of Bath's Innovative Design and Manufacturing Research Centre (I*d*MRC) and its collaborators over the last decade. Each scenario draws on a number of research projects and empirical studies; the principle sources are detailed at the beginning of each scenario.

3. The Marketing Manager

This scenario is written from the perspective of the marketing manager. This role entails managing information flow between end users, designers and customers, as well as gathering and filtering information about the needs of the end user. Feedback from potential customers is also gathered through workshops and focus groups. The results are then disseminated to the design team and other relevant stakeholders in the form of comments and mock-ups. The following scenario is drawn from [Arikoglu et al. 2008], who performed a detailed analysis of a new product design case, with the objective of improving the shared vision between stakeholders using open innovation platforms.

3.1 Monitoring and Evaluation

Currently, the information gathered is stored separately from official project archives and company-wide IM systems, as integration would be costly. The information is stored by project in chronological order and is disseminated to designers in the form of a report that gives a general summary of the end users' needs and expectations. Whilst this document is used in the early stages of the process, it often contains only small amounts of information relevant to each designer and rapidly becomes obsolete as the design develops. This leads to the design team not sharing the vision of end users' needs; ultimately impacting customer satisfaction.

The 'ideal' IM system is required to support the monitoring and evaluation of captured information and it's dissemination to the relevant designers at a lower level of granularity, not just as summary reports.

3.2 Effective Meetings and Actions

A further issue is that whilst the marketing manager participates in design team meetings, significant time is spent clarifying and reinterpreting what was discussed previously. The meetings commonly involve multi-disciplinary teams, often with a lack of shared-understanding. The level of abstraction at which the design is discussed also varies widely, from issues with a particular part or tolerance, to general design principles and user needs. The problem is compounded by the large variety of information produced during the meeting, much of which is not retained. The information that is retained often lacks context as it was created during a discussion, or from a particular stakeholder viewpoint. However, this information often contains traces forming the only record of, for example, decisions and design rationale.

The 'ideal' IM system would be able to capture and create traces of design review meetings (in terms of decisions and rationale) to enable a comprehensive and shared record of previous meetings. This would reduce the time spent recalling past decisions, foster shared understanding within multi-disciplinary teams and reduce information loss.

4. The Sustainability Consultant

This scenario involves a sustainability consultant whose main responsibilities within the organisation are i) to provide training on the eco-design tools and process of the company, ii) to set environmental targets and budgets for projects, iii) to disseminate changes in environmental policy or legislation and iv) to create and communicate eco-design best-practice. These scenarios draws on empirical insights from two studies by O'Hare et al. (2007).

The first study involved benchmarking the environmental and innovation performance of companies in the South-West of England. Workshops attended by multiple stakeholders were held with six companies. This assessed the companies New Product Development (NPD) process, their innovation culture, environmental supply-chain pressures and the actions they had already taken. The second study implemented eco-innovation tools within six companies of various sizes. Interviews with the design team helped to gain understanding of the key requirements for eco-innovation tools.

4.1 Tool Implementation

The consultant had been asked to deploy and measure the impact of Life Cycle Assessment (LCA) software. This involved organising training sessions to introduce the LCA software. Within these sessions the designers seemed keen to use the tool within their work, however, the actual usage was poor. From interviews, it became apparent that because the designers had not had an opportunity to apply the tool to a real project within the first few weeks after the initial training, they had forgotten how to use it and were reluctant to spend time re-training. In terms of disseminating good practice from the use of LCA, identifying and valuing instances of successful re-use was only possible through anecdotes, which were not distributed widely.
The 'ideal' IM system would support and reinforce the introduction of new design tools. The IM system should be able identify cases of eco-design good practice within the company and provide a means to value and disseminate them appropriately.

4.2 Design for Legislation

The second issue arising from the studies was how the consultant could help designers keep abreast of developments in environmental legislation, such as the Eco-design of Energy-using Products (EuP). This legislation sets targets for environmental aspects such as the standby energy consumption of products which could require significant changes to the design of the product's electronics. Hence it was vital that the information was disseminated in a timely manner. An additional concern was that the EuP Directive could - in future - require the company to perform an assessment of the environmental impacts of their product offerings. Whilst the consultant was confident that the task could be achieved, there was concern about potential inconsistency in the presentation and levels of detail of information gathered from across the supply chain.
The 'ideal' IM system would support the consistent and comprehensive gathering, structuring and organisation of product information across globally-distributed supply chains to comply with new legislation in a verifiable way.

5. The Innovation/Design Engineer

This section considers the knowledge and information management issues observed from working within an innovation department. They take the form of two scenarios from the innovation department manager and their designers. The Innovation department supports designers at the early stages of the design process and are responsible for managing NPD projects. Their roles are to generate, facilitate and manage creative ideas that suit both the needs of the customers and the company's technical capabilities. The following scenarios were constructed from participatory action research from within an innovation hub conducted by Howard et al. (2008) and are supported by other I*d*MRC research, largely working with the aerospace industry.

5.1 Analysing the Task

In previous empirical studies it has been shown that clarifying the task takes 35% of designers time, of which 21% consists of searching and absorbing information [Lowe et al., 2004]. It is often the case in engineering, design and new product development companies that designers will receive a design brief or task from sources external to their department, which cause numerous information and knowledge management issues. In this scenario, on multiple occasions a partially formed brief was set by the business sector or marketing department. The project manager was then introduced to the project and a formal brief document was created, moving from a 'Wish List' to a 'Technical Requirement Specification'. This was then presented to the project group, who then responded. Many knowledge management issues arose during this process, particularly with regard to: the background/origin of

each requirement; whether the requirement is a demand or wish; the requirement's maturity; whether the requirement is for the customer or the business capabilities; whether project was set by customer, aimed at a customer or uses a virtual customer and whether the requirement addresses the problem or invokes a solution.
The above points were observed on numerous occasions during a two year period of participatory action research. It must be noted that these issues were not only observed by the researcher but also by the designers on many occasions, as shown by selected quotes in Table 1:

Table 1. KM Issues with Project Briefing in Innovation Projects

Project	Supporting quote	Issue with brief
1	"Is the compote more like a jam?", "No I think it's more like a yoghurt"	Lack of background
2	"She [the customer] said it's a must but I'll have to check with the packaging technologist"	Lack of context
3	"Should we show them what they want or what would be different"	Lack of maturity
4	"I can imagine changing the brief to …" "yeh, I thought he was actually trying to get us to solve …"	Lack of clarity
5	"We have to have bowed out sides… hmmm… why exactly was that? Maybe we don't need them"	Lack of explanation
6	"We can think of new things… but would be good if we already had IP on it"	Company vs customer

The 'ideal' IM system would allow complete transparency of the information contained within the brief. Where requirements and constraints are cited, context must be provided about their maturity and importance. Separation of requirements for the various stakeholders would be of use.

5.2 Being Pushed the Right Information

During the design process there are many known knowns (pushed output, 48%) and known unknowns (pulled input, 15%). However, the real problem lies with the unknown unknowns (pushed input, 9%) solved through serendipity, discovery and information push, and the unknown knowns (pulled output, 8%) solved through creative thought. During an audit (a snapshot of 1000 information uses) in a innovation department, it was observed that only 15% of the information was pushed to designers (see Figure 1), with the amount of information left to procure hard to judge. However, it was apparent that the designers want to be 'pushed' the right information to both understand the problem and to generate ideas rather than relying on serendipity. To this end the designers arrange regular design review meetings in order to attain unanticipated but vital information from colleagues and stakeholders. Information push may not be limited to increasing the efficiency of the design process but may also be used to increase the design space through information stakeholders about changes in capabilities and their possible impact. Research by Campbell (2007) showed information push tools could be useful to designers and engineers, but there was still a need for more sophisticated capture and interpretation of their computer interactions.
It has also been shown that brainstorming performance is increased (both in terms of quantity and quality of ideas) by prompting the designer with information to stimulate creativity. Using case based reasoning in order to find more suitable stimuli yielded better results in terms of the ideas being generated. This supports earlier predictions on case based reasoning for conceptual design.

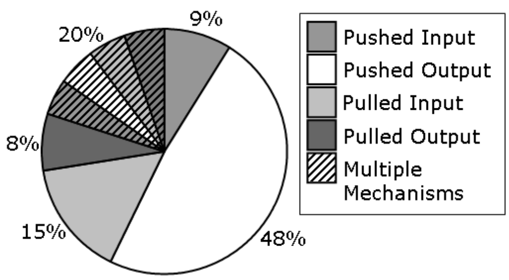

Figure 1. Information use mechanisms

The 'ideal' IM system would identify actions and information needs, pushing useful information to the designer. It would also identify the characteristics of the tasks and prompt information and related previous solutions.

6. Process Improvement Engineer

This scenario focuses on a process improvement engineer. Their role is to optimise the performance of design tools, teams and processes. This remit includes the evaluation and implementation of new or existing techniques and promoting good practice between various user groups. This project space could consist of a variety of teams at different stages - it is not limited by geography and often incorporates diverse cultural and specialist inputs. This scenario draws principally on the research of Cash et al., [2009] which presents a synthesis of existing empirical studies using multiple methods, with the aim of identifying key issues and how these can be mitigated. The scenario also draws on Howard et al., [2008] as described in Section 5.

6.1 Context and Appropriateness

During large projects where new tools or techniques are needed it has often been found that uptake of techniques amongst teams is limited and there are often major implementation issues. There has also been feedback from engineers that there is often conflicting guidance and best practice is not clear [Cash et al. 2009]. This seems to stem from the various perspectives business units have on the project information. In attempting to address these problems, it was found that the distributed business units approach solutions in different ways that are often unrecorded, ad-hoc and rarely quantified. This leads to, for example, a proliferation in file formats and structures, which makes it difficult for different business areas to communicate effectively. It has also been found that process improvement lessons are often not applicable across the company as a whole due to cultural differences and the unclear or simply unrecorded nature of the context in which they were successful. In addition to this, different business units use the information in different ways, often leading to confusion or incorrect use of information. In attempting to tackle these issues it has become increasingly important to be able to assess the contextual factors surround the information in order to judge its appropriateness and applicability.

The 'ideal' IM system would clearly capture the rich contextual background of any process improvement learning. It should also identify, simplify and distribute - within a standardised framework - meaningful and appropriate information to all relevant stakeholders.

6.2 Clarification and Issue Identification

There have been major implementation and understanding problems for both tools and techniques developed from research. Despite implementation guidance existing, it is often not used correctly or is incomplete. In addition, it is often unclear how academic research can be incorporated into the industrial context and how industrial research should be carried out to produce meaningful, widely applicable process improvements [Cash et al. 2009]. It has also been found that when new tools or techniques are introduced, there are few metrics for assessing their impact that are both simple and robust. For example, the effect of different stakeholder's perspectives and their influence on the success of a project are hard to quantify. As a consequence, problems are often attributed solely to the new process despite there being other possible root causes. In terms of human factors, engineers commonly fail to see the benefits of new tools or methods and revert to older practices, or find new ways of subverting the new system.

The 'ideal' IM system would support the development of new metrics and implementation of rigorous, systematic guidelines that help identify problem root causes and propagation patterns across the whole company. In doing this, it should actively support and reinforce the benefits of the new tools or methods to improve uptake.

7. The Knowledge Manager

The role of the knowledge manager is to promote collaboration and facilitate more effective communication. From his perspective, the engineering design process is one aspect of the wider workflow for producing a solution. This workflow encompasses diverse disciplines, from multiple departments and companies. The first scenario draws on research by Lowe et al. (2004), introduced in Section 5, and by Wasiak et al. (2009) that applied a taxonomy to an email corpus to investigate the content and role of email in engineering. The second scenario draws on research by Cloonan et al. (2008), that explored how to enable information sharing from a trust and power-balance perspective through 25 semi-structured interviews with practicing engineers.

7.1 Information loss

Lowe et al. (2004) revealed that engineers spend 35% of their time during design activities searching for and interpreting information. Further to this, 40% of that information was drawn from engineers' own document stores, arguably because of the difficulty of accessing the 'official' records. Many large products, such as aircraft, are in service for over 30 years, with identifiable teams lasting for decades. Allen (1977, pp.42-43) identified that the natural turnover of staff in such projects causes a continuous churn of the knowledge 'held' by the members of a project. Compounding this is a related information management problem associated with personal archives such as correspondence, that lack structure, organisation and metadata, and are therefore not easily reused [McAlpine 2010].

Concerns have been raised that it was not possible to track back through a project and understand why a particular decision was taken; numerous discussions and decisions are lost in the many sources that often fall outside the official archive. To confirm the severity of the problem, an audit of a particularly critical project revealed that as much as 32% of the emails exchanged involved problem solving discussions. In addition, a number of the engineers interviewed expressed difficulty in finding information in projects to which they have recently been assigned. Many engineers indicated that they were not able to identify the engineers within the company who could help them understand aspects of the project, or why particular decisions were taken [Loftus et al. 2009].

The 'ideal' IM system would facilitate problem solving discussions, allowing for the explicit representation of rationale alongside product data whilst capturing and storing these processes. It is also thought necessary that the system be able to point engineers to key individuals involved, and their relationships with projects, tasks and documents.

7.2 Trust

In project review meetings, engineers expressed a dissatisfaction with the success of their relations with certain suppliers. The personal aspects of extra-organisational relationships are not something that have been formally recognised as being something needing support. A series of interviews [Cloonan et al. 2008] identified two main problems: disappointment resulting from the other side's failure to deliver, and worries about the extent and nature of information that could be shared. Face-to-face 'networking' was seen as of crucial importance in developing personal trust. One engineer described *"having a drink with people"* as "*worth more than 1000 novel team building exercises"*, suggesting that current IM systems do not engender trust in information provided and do not have sufficiently transparent trust strategies, meaning the extent of re-use may be limited.

The 'ideal' IM system would support the sending and receiving of information from external parties, promote timely delivery and clearly link people with information. Guidance and monitoring to ensure transparent information exchanges with external parties is also required, as is some indication that a particular relationship is failing or under-performing.

8. The Archivist/Records Manager

The archivist's role is typically to manage and develop the archive of relevant design documents, both for re-use in future projects and also for legal and quality system compliance. This scenario has been constructed from a number of empirical studies focussing on extensive observations of information management issues in a range of organisations, principally Hicks et al. (2006) (who studied information management in engineering via detailed interviews in 10 UK-based SME's with the objective of identifying key issues) and McAlpine (2010) who conducted a range of studies into the use and content of engineering logbooks with the aim of improving the management of informal information sources.

8.1 Volume and Value of Information

Like many engineering organisations, a large proportion of the products are variants of existing products and may be in service for long periods. The archivist is often asked to archive a variety of types and formats – such as reports stored electronically, older paper reports, CAD drawings, data from analysis software etc. [McAlpine 2010, p.88] A recent audit of engineers' file types revealed over 140 different file formats of electronic files [Hicks et al. 2008]. In addition to these, they are often given paper logbooks, meeting minutes, financial information, and even photographs and videos.
However, it has been difficult to decide if such information is of value, and if so, how much? For example, do they archive only the final stress data, or intermediate points to help understand the process? From a business perspective, there is an ever increasing cost of storage with seemingly little value created. What is the point of keeping these records if it is cheaper and easier to do the work again? There is also increasing pressure to demonstrate - and ideally quantify - how the archive adds value to the business, as currently, methods rely heavily on anecdotes and very basic metrics. Much of the guidance for how long to keep the records often comes from legislation such as the UK Data Protection Act (1998), not from any assessment of its potential usefulness or value (which in itself has proven very difficult [Zhao et al. 2008]).
The 'ideal' IM system would include a method to assess the value of the information held and record the value (in terms of costs avoided or value added) when the information is re-used. Critically, this greater transparency and consistency should be used to promote a greater amount of 'pro-active' re-use of the information.

8.2 Fragmented Records

The second problem is that the archive often does not represent a complete record. For example, products also generate information after they are manufactured, through in-service, maintenance and upgrade information. This information is not currently linked to the project record of the product *as designed* in a comprehensive way, instead being maintained in multiple separate databases. Further, it is known that many key decisions are made collaboratively, or stored in 'personal' or local team stores such as logbooks or shared spreadsheets, which are lacking in context and are rarely available to the wider organisations. For example, the formal reports contain significantly different information to the associated 'informal' logbooks, with a significant loss of process-related information such as records of meetings and project management information [McAlpine 2010, pp.116]
The company also makes use of subcontractors, who have a much larger role than they did before in terms of advice and technical information about the parts and assemblies they provide. They maintain their own records and are reluctant to give this information in a form where it can be easily re-used in other contexts as they want to maintain their (revenue generating) relationship with the company.
Ultimately, this mix of many different types of paper, digital sources and myriad storage systems (not all under the control of the archivist) has led to typically high levels of *information fragmentation*. As a consequence, many engineers view the archive as a 'black hole', which means many seem to keep their own personal archives, either instead of - or in parallel to - the official company archive. Engineers only access it when they have to - usually in response to a problem and not 'proactively' at, for example, the beginning of a project. The majority of requests are for past reports and CAD drawings, but engineers often commented that they still cannot use them to solve the problem, as there is a lack context or rationale. To find out this information, they often still have to rely on the memory of colleagues involved in the project (if they can locate them) [McAlpine 2010, pp.96].
The 'ideal' IM system requires a strategy and framework for the integration and storage of all types of record. Current IM systems are usually optimised to a particular type of information – usually structured, formal digital records. Linked to this is the requirement to be able to record the context in which the information was created and the rationale behind it. It is also important that any system has the ability to separate product and process-related information to afford more flexible re-use. For example, the products may be completely different, but there can still be valuable lessons about the process, such as methods to overcome a particular problem.

9. Discussion

In this section the requirements arising from each of the scenarios are summarised and the key themes are extracted. The aim is to identify key issues that an information management system must tackle to support all stages of the product development process.

9.1 Summary of Scenarios

From the scenarios found in previous chapters the key requirements for the information management system have been extracted and used to populate Table 2:

Table 2. Summary of key requirements for the information management system

Archivist/Records Manager	Innovation/Design Engineer	Knowledge Manager
Integrated framework for capture Separate product / process Add context to rationale and records Justify/quantify cost and benefits of re-use Facilitate 'provocative' re-use of records through push Use meta-records for further learning	Identify needs and push information Transparency / tractability of briefs Pushing updated capabilities Push from internal and external stakeholders Ability to realise new opportunities due to increased capabilities	Link individuals to projects, documents and tasks Facilitate problem solving discussions Explicit representation of rationale Promote, guide and monitor trust
Process Improvement	**Eco-design Facilitator**	**Marketing Manager**
Capture detailed context of the study/implementation of tools Highlight specific factors that were critical to project outcome Collate, synchronise and simplify the cases and push to relevant people	Support and re-enforce new design tools Monitoring and push of relevant new information (legislation) Identify and disseminate best practice Standardised representations for information across global locations	Continuous updating of customer and user feedback Supporting a consistent shared vision with design team Ability to link and record many types of information and artefacts to support faster shared understanding

9.2 Key Themes Arising

The following five 'key themes' have been synthesised from Table 2. These themes do not cover all the requirements raised in the scenarios but instead capture the key and repeating requirements from the multiple perspectives explored through the scenarios. Whilst some of the themes may appear obvious, the contribution of this paper is a) presenting these relatively diverse aspects explicitly and in a single place and b) synthesising the sources of empirical evidence from which they were derived. It is also worth noting that many support the aims (or at least sentiment) of other research, such as the n-dim project [Subrahmanian et al. 1997], which also identify multiple cultures, tools and disciplines as characteristics of engineering design that must be addressed by design support tools.

Context and Rationale Capture: This theme is identified as an important issue in the majority of scenarios presented above and in Subrahmanian et al. (1997), but is applicable and useful from all perspectives. This is considered a vital element of an information management system and crucial to support re-use, decision making and understanding of design information.

Information Push: This has been identified as an important function due to the difficulties in communication between various departments and stakeholders, particularly when developing a product concurrently. As it is often the case that each stakeholder in the design process is not aware of what is needed to be known, questions are very difficult to frame.

Continuous Feedback and Updating: Product development is often an extremely complex, highly iterative process. Tools and methods attempting to improve the design process often go unmonitored once implemented, or are not implemented at all. It is argued that assessing feedback from the process is vital to both validate and optimise tools and methods whilst also identifying areas for improvement, future investment and the lessons learned from previous research.

Active Support for Teams: Related to information push and in a similar way as the n-dim project [Subrahmanian et al. 1997] asserts that engineering design is a social process, it is suggested that an integrated product development IM system should actively support design teams. This could be achieved through a common platform that integrates information with the people that created it. For example, this could link products, decisions and documents to people and their contact details, providing transparency for all stakeholders. This may help to identify any conflicting variables in the product model whilst providing a communication platform to make modification and design changes to the product.

Integration Beyond Traditional Boundaries: The scenarios provide evidence that a product's development is still hampered by traditional organisational boundaries, hindering concurrent design. It is argued that an integrated IM system where all stakeholders work on standardised product representations from multiple viewpoints will facilitate effective collaboration and higher levels of trust between functions.

10. Conclusions

It has been argued that information management systems commonly used in the engineering domain (such as PLM and PDM systems) have grown from a particular perspective, or to meet the needs of a particular stakeholder. Although more recent commercial offerings having increased flexibility in terms of the types of information and how the user interacts with it, managing the vast amounts of information generated in the product development process still presents a number of important challenges that software vendors alone are not well placed to understand.

This paper has attempted to take a bottom-up view of the requirements of a range of stakeholders from a typical engineering organisation. Based on significant empirical research undertaken at the University of Bath's Innovative Design and Manufacturing Research Centre (I*d*MRC), collaborating universities and organisations, six scenarios have been constructed to represent the main information management challenges facing today's large engineering organisations.

Perhaps surprisingly (given the diverse nature of the roles from which the scenarios were constructed), five key themes have been identified. These are intended to inform the specification of (or research into) new, integrated engineering information management tools and methods to better support not just engineers and designers, but the organisation as a whole. However, there are a number of inherent trade-offs in implementing these themes in practice, which give rise to corresponding research questions and challenges:

Context and Rationale Capture: How can the context be captured effectively when possible future re-use scenarios are largely unknown? i.e. how much context is enough and how much effort does it require to capture?

Information Push: How can relevant information be pushed to members of the product development team and other stakeholders whilst not increasing existing levels of 'information overload'?

Continuous Feedback and Updating: Could continuous feedback and updating at all stages of the design process actually increase performance and creativity, or does it hinder reflective thinking and lead to 'paralysis by analysis'?

Active Support for Teams: Similarly, is there really any benefit in linking information and the process by which it was created to the people that created it? Would this blurring of information and communication systems reduce or increase complexity?

Integration Beyond Traditional Boundaries: Does allowing multiple viewpoints of the design and the design process really promote shared understanding between functions, or just perpetuate shared misunderstanding? How can complex supply chains be both deeply integrated and flexible?

Finally, from a wider design research perspective, our challenge concerns how such challenges can be overcome through the development of rigorous methodologies and associated methods to study designers, and measure the effectiveness of the resulting tools and methods in a holistic and integrated manner.

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