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RISK ACROSS DESIGN DOMAINS

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1 Introduction

Design processes involve risk: to life and limb if the product is unsafe, to the financial health of the company if the product is late, unsuccessful or simply the wrong product, as well as to the emotions and careers of the designers. Many of the risks are shared universally by all designers, but each different industry and each different project faces its own spectrum of serious and minor risks. Different industries have put their methodological effort into finding ways to mitigate the risks they recognise as important. As part of the Across Design project exploring similarities and differences between design processes in different industries, this paper examines how risks are perceived and handled in different types of design process, and proposes that designers and managers can usefully look to other industries for ways to handle risks that are more central for those other industries.

2 Perspectives on risk

Designers and design managers in different industries are concerned with different types of risk, and conceptualise the risks involved in design in different ways. Design is almost never free of risk, but in many situations the spectre of failure isn't conceptualised as risk – the danger that outcomes will be affected by events that cannot be fully predicted or controlled. As in engineering, software project planning involves risk analysis in assessing the feasibility of delivering a successful product on time and on budget, and the likely causes of disruption [2, 10]. But in large-scale software development, a huge amount of effort is devoted to following methodological procedures for avoiding trouble by ensuring as far as possible that tasks are done completely and correctly [13]. And some software engineering methodologies adopt an iterative approach to design, explicitly recognizing that requirements analysis and interface design will not be perfect first time. But these attempts to avoid the problems that cause a large fraction of big information systems projects to fail are not customarily thought of as risk management.

In engineering design risk is usually seen in terms of risk to life and limb due to technical malfunction or misuse of the product. (see [1] for a review). For those complex systems in which a malfunction might cascade and lead to a major disaster, such as nuclear power plants, safety critical systems experts construct scenarios of possible error and misuse – safety cases, akin to use cases in computer science – and try to plan accordingly [23]. Accident investigators do post hoc risk assessments of processes to understand which risks were taken and why and who might be held responsible [3, 24]. Accident investigators draw a very important, but often ignored, distinction between the risk itself and the action that is taken to interact with this risk. For example a product, such as a space shuttle, has certain technical risks. In the case of the space shuttle Columbia, it was known that there was a small risk associated with the heat shield tiles, but the team, with precedent seemingly on its side, chose to ignore that risk [4]. Dealing with risk is as much a social and political process, rooted in the different perceptions held by different individuals and groups, as it is a matter of robust product or system design.

Engineers attempt to quantify risk but the meaning imputed to these numbers depends upon the context of design and how they are generated. Just how risk is perceived by different participants in design is deeply intertwined with an individual's perception of causality and who is responsible for design decisions. If individuals view particular risks, such as malfunctions in use and/or design tasks taking too long, as a personal responsibility, they will work to mitigate the hazard, rather than attribute them to emergent properties of the overall system. If clear causal connections are identified between actions and the resulting risks, stakeholders are more likely to take actions to reduce the exposure to those risks than if they are only labelled as contributory factors (see [5], [6] for discussions of responsibility; and [7] for a discussion of these issues in connection with the Ladbroke Grove Rail disaster, where a fragmented organizational structure and insufficient communication of potential risks ultimately led to a fatal train crash due to an operator error). The Ladbroke Grove case shows that there are three elements to risk: the objective sources of risk that exist in a process, the subjective risk that the designers and managers see in the process, and the actions that they choose to take to counter these perceived risks. Some risks might be quantifiable in numbers, but how these numbers are interpreted depends on the context in which the design in generated. If a design is perceived as a bold venture or a must-have project, higher risk factors are accepted before the operation as a whole is seen as risky.

In recent years in engineering, designers have begun to conceive of failure to finish the product design and development process on time and within budget in terms of risk and have applied risk assessment methods to identify, manage and mitigate that possibility - whatever its source. Here too, socially embedded perceptions and beliefs, as well as the identified possible technical risks, deeply influence the way decisions about risk are made in the design process. The discussion of risk often focuses on the wider risk involved in bringing a product to the market and having it operate safety over its entire lifecycle. The wider risks set constraints for the design process risks and vice versa. The responsibility of designers sometimes goes beyond design itself: in some industries individual designers or small teams are responsible for the entire product development process from identification of market opportunities and businesses cases to production and delivery. A management perspective aims at identifying potential risk at the beginning of a project to manage it out of a process (see [8, 9] for a review of risk management in engineering design, [20] for risk management in the construction industry, [2, 10] for risk management in the software industry). Probabilistic models and process simulations are used to identify areas of risk [11, 12]. A new development in Britain is that the Ministry of Defence as a customer is demanding quantitative best case, worst case, average case risk assessments.

3 Making comparisons between industries and disciplines

Our investigations of the similarities and differences between design in different industries is founded on the belief that the major factors that shape design processes are neither unique to individual products or companies, nor common to all designing; and moreover that some of these factors cut across the conventional categories of industries and professional disciplines. We have proposed analysing design processes in terms of *patterns of designing*: significant groups of causally connected features of a design process, that serve to explain why some aspects of the design process are as they are [14]. (Not the same thing as a design pattern, for which see [15, 16].)

It would be a mistake to treat design domains as homogeneous. There is a huge variety of behaviour in each design domain. As illustrated in Figure 1 even in engineering there is a huge variation in design behaviour and associated risks. Even when studying two design processes in engineering is detail, as such change processes in helicopter design [17] and diesel engine design [18], it is difficult to assess whether differences in observed behaviour arise from the properties of the product (a helicopter is hugely more complex), the people who work on the project (helicopter designers are passionate about their product), the way their teams work (a well gelled team with a good overview in diesel engine design), the project (a new version of a helicopter or a new generation engine), the company (multi-site vs. single location) or the industry sector (aerospace vs. automotive).

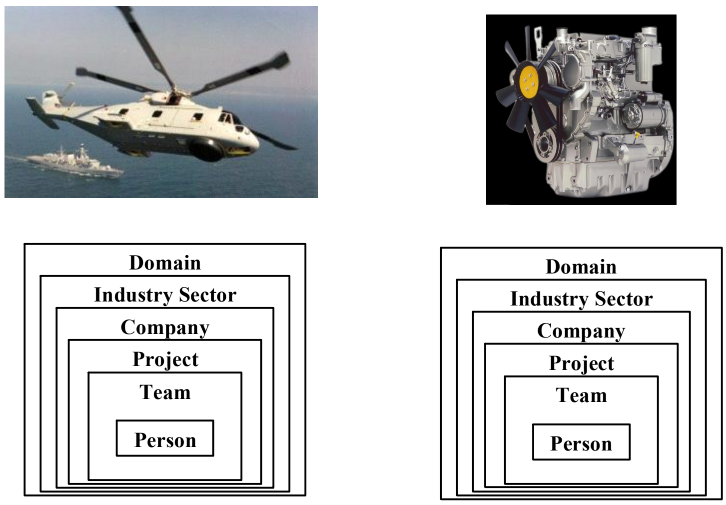

Figure 1 Differences within design domains

3.1 The Across Design project: presentations and interviews

The Across Design project, funded by the Cambridge MIT Institute, has been investigating the similarities and differences between design in different industries, and seeking ways in which best practice can be transferred. The researchers on the project have conducted detailed observational studies of design practice, conducted experiments, and interviewed hundreds of designers in the course of their own past research. The project includes a sequence of workshops where designers with more than 10 years' experience talked about their design processes to an audience of three to five expert designers from other fields and a small number of interested observers, as well as members of the project team. The speakers were asked to discuss one individual project in detail. By design, these workshops were intended to collect narratives and subjective views, while enabling an in-depth analysis of the experiences, opinions and presentations of one or two representatives of each field. We have described how the workshops were conducted in much more detail elsewhere [21, 22].

Table 1. Classification of participants

Engineering	Diesel engine designer, Jet engine designer, Medical device designer, Automotive designer, Electrical Product Designer
Architecture	Urban Planner, Civil engineer, Architect (2)
Product Design/ Artistic design	Product designer (2), Packaging designer Graphic designer, Artistic fashion designer, Technical fashion designer, Furniture designer
Software	Software designer (2),
Science	Drug designer , Food designer,
Multimedia designer	Film maker, Web designer, Course designers

The participants can also be classified by their present roles in their companies, as well as by their professional background. Most are direct participants in the processes they describe, and either work alone or with a small number of collaborators and assistants. The filmmaker and the graphic designer are examples. Others are senior managers responsible for large complex projects involving hundreds or thousands of direct participants. Such managers are very process-aware because the complexity of what they design demands process discipline in order to meet strict requirements for performance, cost, schedule, regulations, and other pressures. The direct practitioners described what they did themselves and the details of the items they produced, whereas the senior managers described the process by which their items are created as well as their companies' quest for ever better design methods.

3.2 Risks and business models

Some members of the Across Design project team have considered risk in design before. Eckert and Demaid [19] analysed the risk in the knitwear industry based on a sample of 26 companies in the UK, Germany and Italy. They found that the risk for the designing companies depended primarily on their financial relationships with their clients and customers; it also depended on how design choices and purchasing decisions were distributed between designers and buyers for retailers, and whether and how feedback was transmitted from end customers to designers. The highest risk was carried by the leading fashion label companies, because they produced speculative designs based on relatively uncertain fashion forecasting information, while companies who designed and produced to order were exposed to little financial risk, but also limited potential gain. After this study was carried out, many of the companies who had enjoyed limited risks due to a preferred supplier status, lost it and went out of business over a period of two or three years.

4 Generic risk factors

In the traditional engineering literature product risk is seen as risk to life and limb and process risk as the risk of exceeding time and cost allocations. However design is exposed to many more risks. A range of risk factors affect all design processes, but some are more powerful and salient in some industries than others.

4.1 A case study: Self-injection

This was illustrated by the development process presented at an Across Design workshop by a medical device designer who worked for a start-up company developing a needle-free injection device for drugs. An inventor had come up with the idea for the device and developed a successful concept demonstrator. After some initial market analysis investors were found to provide the capital for an industrial development of the product. The potential gains were enormous, as a needle free injection could be administered by the patient themselves, giving patients far greater freedom and comfort, while significantly reducing the cost for the health system by cutting down on doctor or nurse contact hours.

Initially development went very well and a small scale manufacturing prototype was developed quickly. Prototypes were shown to many different pharmaceutical companies, who become interested for several different applications, such as insulin and anti-histamines. However these applications had subtly different requirements. Insulin is often used by elderly patients, who need a mechanism that can be used without deploying great physical strength. On the other hand anti-histamine injections are used as and when required; people would carry the injections in their cars, therefore it would need to be robust and be functional in a Swedish winter and a southern European summer, thus over a temperature range of 70C. Commitments to different clients pushed the company early into multiple versions with different requirements and regulatory obligations, placing great demands on their designers' time. In scaling up the product, they realised that while the prototype had worked fine, some of the components would be costly and not work with the intended production equipment, so more redesign was required. As the company was short of staff more and more people were brought in on a consultant basis until the company experts either dealt with external people or managed the consultants. Money ran out before the company could start the large-scale clinical trials that some applications required. The project got cancelled and staff had to look for new posts. A company in the USA bought the patent and is now trying to develop the product again; they plan to launch in 2007.

This process carried multiple risks: The product had a high degree of technical risk, being very innovative and not yet tested commercially. Elaborate tests and risk assessment was necessary to assure that the product was safe under all its operating conditions. Assuring the safety risk under the highly diversified operating conditions was one of the downfalls of the company. Even if the product had cleared this hurdle it was far from certain whether it have succeeded in the market, because of the wide ranging changes it would have required to the perception, deployment and administration of medication. The process was very risky, because the company had to resolve a high degree of technical risk with limited and external funding while incurring further risk through the degree of customisation. Needing to introduce new people with only partial understanding of the products and its requirements introduced further risk in terms of people's skills and ambitions. Working for the company exposed the employees to a high financial risk – while it provided them with a thrilling opportunity to work on an innovative product, they were well aware of the risk of the not procuring further funding. They believed in the idea of the project and were personally disappointed. At the same time the inventor himself carried relatively little financial risk. He had made his invention, made the money through the patent and moved on the next idea.

Within these multiple risks it is difficult to assign the blame for the company's failure to one particular aspect. Many factors contributed and it is difficult to say for any one of them that had it not existed, the company would have succeeded. This case also illustrates how the risks in a design process are connected. Because the product was highly safety critical, it needed many tests and the process became more complicated. Because the clients had subtly different needs, the company needed to diversify its product range, so the process required more tasks and incurred higher process risk.

4.2 Generic risks

Many of the risks that have been incurred in this example are generic and apply to some extend to all products in all design domains. Figure 1 shows a classification of risks that are common to all design domains. It has no claims to completeness, but draws on elements that we saw recurring in many different design domains. For example all products carry a certain element of technical risk. Even in artistic design domains with comparatively simple products technical challenges need to be resolved, because those determine whether a product will be exceptional. For example in knitwear design the quality of the visual appearance of a garment is often determined by how well patterns are placed onto garments, but the problem can be over-constrained due to the low resolution of knitwear and can require radical redesign. Safety of the product is a risk factor to a varying extent in all design domains. In a safety critical product safety can be an overarching concern, while it might be a background consideration in others. The most frequently referred to process risk in all domains was exceeding the promised time or cost. This is a factor for large engineering firms risking millions in lost revenues as it for freelance artistic designers who don't want to disappoint personal clients.

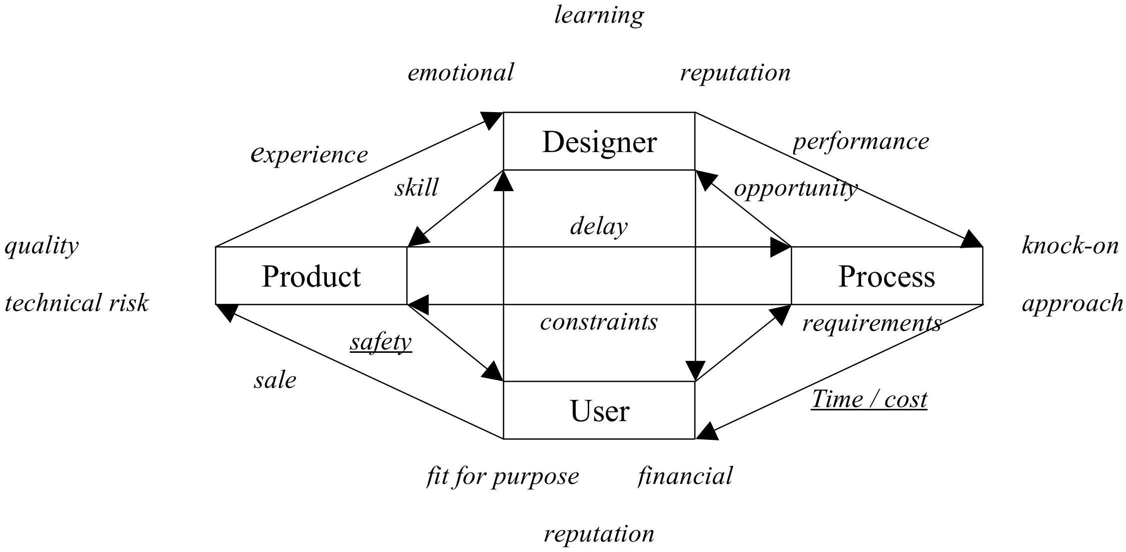

Figure 1. Generic risk factors

5 Influences on risk

A range of generic risk factors can be identified in all design processes, including those shown in Figure 1, but their importance and influence differs radically between processes. In this section we discuss some of the characteristics of design processes that influence their riskiness. Some of the determinants of risk – and how risk is perceived – are closely linked to industry sectors, but others cut across industries and professions.

5.1 Risks depend on requirements

Risk is ultimately about the ability to meet all the requirements that are placed on the design. These can be hard requirements that are explicitly stated and non-negotiable, or soft and tacit, or implicit in modes of use that are not fully recognised or understood by the designers. Requirements don't just arise from the desires of customer, but also from the needs of the customer's business or from wider society. Exposure to risk varies with subtle prioritisation of those requirements.

Scale is an important factor in risk. The larger or more complex a product is the more likely it is to require a complex design process. Among the Across Design cases, the risk involved in designing a self-injector was smaller than the risk in designing an entire jet engine. While it might not be very risky to design a simple garment, putting together an entire collection of garments in a timely fashion is difficult and incurs high risk. Related to scale are process characteristics such as the combination of expertise required for the creation of the product and the division of labour between individuals and teams. More complex products with wider ranges of application expose design processes to higher risk, when the designers are not fully aware of the potential technical risks. The recognition that a product is safety critical changes process properties through the imposition of tighter requirements for validation and testing and for process quality assurance. Legal requirements constrain both products and their development processes; for example the design of a web page is far less constrained by legislation than a diesel engine or a building, but institutional websites in Britain and elsewhere have to conform to disability discrimination legislation.

A factor underlying the way the Across Design speakers described their processes was the extent to which different aspects of risks to products and processes are measurable and describable in a formal way. This is related to how far the important characteristics of their products, and the requirements they have to meet, could be defined formally and measured. The engineering designers had carefully worked out ways to test the technical risks in their products and to a lesser extent in their processes, whereas the Across Design fashion designer – as she pointed out – had been utterly unprepared for any business considerations in her field; while she was aware of the risks, she did not have the skills to assess them.

5.2 Characteristics influencing risk

A number of factors influencing the nature of risk in design can be viewed as dimensions on which products and processes vary.

- **Overconstrained problems versus underconstrained problems**. Usually hard problems in engineering are challenging because hard constraints and requirements are in conflict; this is the situation that forces innovative designing. Indeed TRIZ assumes that constraints are in conflict. By contrast soft constraints and requirements can be relaxed to permit the use of standard solutions. Designing in artistic fields faces the opposite challenge: problems are often underconstrained, so that designers need to make more-or-less arbitrary assumptions and fundamental choices to give themselves tasks that are defined tightly enough to be tractable. The difficulty and risk lies in using ill-defined requirements for emergent behavioural characteristics, to formulate problems whose solutions will meet those requirements.

- **Negotiability of risk**. Is the risk in the design process negotiable or is the risk given absolutely? Safety critical factors, such as flight safety parameters, are set in legislation and can not be negotiated. The onus lies clearly with the design company, whereas other risks can be negotiated between different stakeholders. Does the design firm carry the risk or their client? In engineering this can be traded-off up and down the supply chain, in architecture the negotiations can take place between the architects, the builders and the clients.
- **Flexibility of the point of delivery**. Some processes have rigidly fixed deadlines, while other products can be introduced when the product is ready. Textile machinery companies work on a four year cycle around the key machinery exhibition. If they miss this deadline and fail to have at least working prototype, they miss out on revenue over the next four years to the next exhibition. These companies need to take considerable risk with innovation and later validation and verification to meet their targets. Other products such as buildings are finished when they are finished; some are subject to penalty clauses but financial loss can be traded off against other risks.
- **Release schedules**. Some products, such as much software are incrementally released and then extended and revised, whereas other products have a single release point. For example in architecture both patterns apply; one-off buildings are single releases, but developers often release domestic buildings in phases to incorporate feedback from customers. Incremental releases allow companies to include feedback from customers and allow companies to manage their risks actively, by deciding which features are or are not included in a release.
- **Comparison with competitors**. Some products are assessed by objective criteria, while other products are assessed against the quality of competing products. For example textile machinery is a very competitive market with a handful of companies competing for the same orders. As the companies are frequently compared, companies are obliged to introduce a plethora of features, because their competitors do. As many new features are patented, this requires innovation thus incurring higher product risk as well as the risk of losing market share. Products that are developed before they are sold are often assessed in comparison before a purchase decision is made. On the other hand many companies, especially those that work on contracts, develop products once they have an assurance of revenue; products are compared to competitors as benchmarks.
- **Objectivity of Evaluation**. Some products are evaluated objectively against pre-set criteria; for instance jet engines are measured against detailed project specifications. Other products, such as many artistic designs, are evaluated subjectively and tacitly by the designers or a small group of people. However a single product can have objectively evaluatable characteristics and risks, such as weight and load conditions, and subjectively evaluatable ones, such as product aesthetics. While the latter might be a minor aspect in engineering compared to other risks, it can have a huge impact when overlooked. The engineers at our workshop, who were all concerned with managing technical risk, commented that for them the focus on customer satisfaction and fashion by the product designers was a useful reminder of these more tacit characteristics.
- **Absolute or relative Failure**. In some cases it is very clear-cut whether a design has failed or is successful, for example when a part breaks in testing. However at other times the notion of failure is a matter of degree, for example when an engine does not meet the full performance targets and is certified for a lower number of operating hours. Failure

becomes more difficult to define when objectives are not objectively definable, including aesthetic issues of style.

6 Risk across different design domains

Risk is seen differently in different design domains. This section reports on the Across Design workshop participants' own perceptions of the risks they face. Depending on the degree of reflection about their processes, some talked about where risk manifests itself, and others where risk originates. Many of the risks that affect designers are not generated by them or through design, but are result from the wider business context in which they operate. The engineering designers were most explicit about risk and most focused on risk, but they are mainly concerned with the risk in the design process and have tools to work on it. They need risk assessment to cope in the larger business context and to manage their teams. Our other designers operate in much smaller teams with wider responsibilities.

6.1 Mechanical engineering

The engineering designers at our workshop discussed risk most explicitly. For them risk management is becoming a major way of talking about their design activities. They saw much of their design process in terms of the risks they needed to manage in the process and reduce in the product. As the case of the medical device designer shows, engineering design can be subject to risk from a multitude of directions. The major concern of the all of the engineering designers was to eliminate the safety risk of the product. As an example the jet engine designer explained in great detail all the tests they carry out to reduce the risk of a engine being damaged by bird strikes. These tests were necessary to be sure that the engine would survive a bird strike, but also to be able to demonstrate that the company had done all it could to eliminate that risk. Next to safety, technical reliability was seen as a major risk factor, partly in terms of the long-term reputation of the company, but also directly as financial liability for the company, which carried the entire financial risk of the design process. Therefore it is essential for a company to know when to abort an unsuccessful project; it needs to review projects at set gateways, or in the words of one senior engineer:

"Let's have a look at what you've got for this design at gateway one. And basically this is a 'go/no-go' game"

The discussion of process risk followed two lines of argument, relating to the tradability of product and process risk. On the one hand the risk lies in the time it takes to design a product at a given quality, which can not be negotiated. On the other hand companies have been given launch dates or non-negotiable process schedules, and their risks lies in the quality of the product that they can guarantee. For example a helicopter needs to be tested in a certain way to guarantee a certain number of flight hours, however it can initially be certified to a lower number of flight hours. Of course a product needs to have reached a certain quality standard in order to be releasable and some faults inevitably lead to delays in the release at potentially very high cost.

On one level the personal risk of engineers is tied up with the fate of the product, as their jobs depend on the financial success of the business, as the fate of our medical devise designer illustrates. Failure and unsatisfactory projects reduce job satisfaction. However on another level the personal risk and the project risk can be divorced. Individuals can excel on unsuccessful projects and can show up their shortcoming on a project that was very successful overall.

6.2 Civil engineering

The risks under which civil engineers operate are in many ways similar to those of mechanical engineers. Again the foremost concern is the safety of the product. The civil engineers are responsible for the long time survival of a product and need to identify and handle its safety risks. They have a well-worked-out set of procedures and mathematical methods that they can use, so that risk elimination is a matter of routine. When our civil engineer was asked how he handled the multiple risks in his field, he replied:

"But, I mean, that's okay, I mean that one's fairly easy to handle really. [Laughs] I mean you can, you just make sure that it's all okay, yes."

The other side of this is that the civil engineers are held responsible when they overlook potential risks because they underestimate the strengths or interaction of factors, as the recent Millennium Bridge fiasco in London showed. The process risk of the civil engineers is mainly contractual. They need to meet the obligations of their contract, but rarely hold the sole responsibility for the process, as this is shared with architects and building firms. The latter also usually hold the financial risk of building projects. As with mechanical engineers the personal risk to a civil engineer can be separated from the success of the project. Obviously the risk of structural failure is the responsibility of the engineer, but if a product fails commercially or does not meet public approval the blame will not be assigned to the civil engineer. However the reverse is also true: credit for the success of a building goes to the more public figure of the architect.

6.3 Architecture

Architects are work directly with their customers and their main risk lies in not meeting customer approval. As their products are so public, they often have to please multiple audiences: their clients, the users of the building, and the public who sees the building. A large part of their risk management lies in identifying the needs of their stakeholders and brokering a compromise between those different stakeholders.

The responsibility of the architect lies in the functional and aesthetic appeal of their buildings, not the technical and safety aspects, that are covered by the civil engineer. The process risk of architects can be comparatively small, because the buildings often don't have a fixed finishing date and within the process the architects often operate very early, so that there are buffers in the overall process. Once a project has been procured the overall financial risk often lies with the developer. The great financial and personal risk of the architects lies in the procurements of contracts. The success of previous projects increases their chances of getting new projects, but maybe more significantly failure decreases their chances. One of the mechanisms of contract procurement for buildings is through competitions, where several architects are invited to submit designs for a development or respond to an open call. The architect needs to put significant time and creative effort into each tender, often with little chance of getting the order (for the big projects hundreds of architects might submit plans). Winning a competition can bring great kudos, and lead to the contract for the detailed design. But architects often win and still don't build the buildings, either because they get cancelled or because they don't have a sufficiently high reputation to be entrusted with a large contract.

6.4 Artistic design

Artistic designers are in a similar position to architects that the risk of their projects can be very personal and emotional. For example young fashion designers need to raise the money for a first collection and present their work to have it scrutinised by a highly critical public. As our fashion designer pointed out they risk being very scarred emotionally. In artistic design domains products are often selected within companies on the strength of the belief the designer has in them, since there are few if any objectively measurable criteria. Artistic products need to meet their customers' needs, but also their customer tastes. They are dependent on the developments of fashion, which are fickle and hard to predict. Some artistic products, such as knitwear, have up to two years lead time. However if designers get their prediction wrongs, customers won't buy the product. Products are often targeted at a particular market, for example our graphic designer designed a brochure for 16–18 year olds, and needed to get a real sense of what type of design would appeal to this age group. At least in graphic design she knows exactly what can be manufactured and how it will be manufactured. In product design and many aspects of fashion design, manufacturability of the product is a major concern. The designers are responsible for producing a design that can be manufactured reliably and cheaply while appealing to the market. For example one of our product designers designed a small mechanical medication dispenser, which needed to appeal to a wide range of clients, operate intuitively, and at the same time be cheap and easy to manufacture. There is a great variation in the way process risk and financial risk occurs in artistic design domain. Clothing and to a lesser extent some consumer products are extremely seasonal, with launches of collections and tight schedules of sales and restocking with different collections. Toys and some consumer products are largely sold around Christmas. Missing delivery deadlines can have disastrous consequences. For example fashion collections are stocked immediately after the sales; the clothes that arrive first might well get into the display windows. What arrives too late gets tucked into a corner. For companies producing these kind of products time to market is the greatest risk factor. Other artistic designers work with clients with whom they can negotiate delivery dates and are exposed to much less risk. These clients also often carry the financial risk, while those designers who produce their own products or work towards tenders carry the financial risk.

6.5 Multimedia design

Manufacturing consideration apply to a much lesser extent to the Across Design project's multimedia designers, who produced films, web pages and course materials. For each of them it was vital to understand their customers' tastes, needs and interests. The web designer we encountered went through a careful requirements analysis of her client's needs as well as an analysis of the target users of the website. Based on this she had to develop a style for the website that met the brand image of her client, as well as the current fashion in web pages amongst the target users. In a similar way the film director and the course material designer had to pick up on the style of currently popular multimedia. All these designers had to structure the way their materials were presented around a small number of key ideas, that their customers could relate to. If too many ideas were pursued customers lost interest; once they lost interest they moved to alternative sites or programs and could not be recaptured. All had fixed deadlines and needed to have a product ready at a given time. All of them depended largely on finding their material, rather than generating it, though this was less true of the web designer. The filmmaker developed the key ideas for the programme and then looked for the materials in archives and went on location to film. He had little influence on what the people he filmed did, and then had to compensate by providing missing information through expert interviews, which were unscripted, and carefully constructed narratives. Here the greatest risk lies in not finding the required materials. For all designers the personal risk was closely associated with the success of the product in terms of the follow up orders they would receive. However the immediate financial risk lies with their client or the film company.

6.6 Software design

The way the web designer works is very similar to the way some software designers work. In software design requirements elicitation and process management are recognised as the greatest risk factors in design processes. Requirement engineering methods place great emphasis on redesigning the business process in which the software operates together the software itself, to avoid failing to meet customers needs or locking in bad procedures. Achieving effective management of requirements risk in software has involved major cultural shifts in attitudes as well as development methodologies [see 25]. Software projects are notorious for running over time and over budget, because companies underestimate the effort involved in developing and integrating their software. Software development methodologies place as great an emphasis on process management, risk assessment and systematic design techniques as engineering domains [for instance 13]. The personal and financial risks are similar to those in engineering.

6.7 Food and drug design

By contrast manufacturing and validation are the overriding risks in food and drug design. Food designers often develop the flavour or texture of a new product very quickly through experimentation in a sample kitchen, or as in the case of our witness start with a given artisanal product. They spend considerable effort working out how to produce this on an industrial scale and guarantee its performance over its target life span. As in safety critical engineering, they needs to be able to prove that the product will still be safe for human consumption under extreme circumstances, such as over-consumption or inappropriate storage. In the development of new products patents are generated and competitor patents need to be avoided. The product risk lies in missing customers' taste and producing unsafe products. Drug designers start by experimenting with compounds in the hope of finding an effective compound. Once one has been found, that has not already been patented, a long series of tests are conducted to reduce the risk of side effects in marketed products by filtering out inadequate candidates. In both cases this validation process is extremely expensive and carries a significant financial risk of failing to produce a reliable product. In drug design, the chance of developing a successful new drug is so low that a drug designer only expects to develop two or three powerful new drugs during a career. For each project the gain in reputation can be very high, but the risk of diminishing career chances is low, unless obvious mistakes are made, because of the low expectations of the industry.

7 Learning across the domains

The risks designers face are a key driver for developing tools and techniques to support the design process and reduce those risks. The risks recognised as crucial correspond to different industries' methodological strengths. Industries and professional communities can learn from each other by examining the strategies used to mitigate lesser risks in fields where they are crucial.

A detailed discussion of the risk reduction techniques in different design domains has been beyond the scope of the Across Design project and beyond the scope of this paper. However, here are some key examples of approaches that are potentially interesting to engineering companies.

- The fashion industry has a well worked out process for trend prediction: understanding what the market will require at a particular time, by studying forecasting materials, trend shows and related products in shops, to generate mood boards of new styles and trends.
- Software engineers have well worked out techniques for establishing and managing user requirements, have experience with prototype-quickly-and-revise design methodologies, and understand the need to redesign the business process in which the software is deployed at the same time as designing the software to fit it.
- Architects see themselves as the key negotiators of requirements between different stake holders and develop presentation specifically for this purpose
- Artistic design domains acknowledge the emotional risk of unsuccessful designs for the designers, and at least to a limited extend support each other emotionally.
- The food industry is acutely aware of how much a working prototype is far removed from a manufacturable product, and recognises the process of generating a manufacturable solution as a creative process in its own right.

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