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Integrating Sustainable Waste Management into Product Design:

Sustainability as a Functional Requirement

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Abstract

Municipal Waste management is, by definition, spatially organised. In the United Kingdom the national government designates waste collection and disposal responsibilities to the various scales of local government. However, whilst the highest aim of waste management is prevention, achieving this is beyond the scope of local authorities, which deal with the waste stream presented to them as an independent variable. Alternatively, product design offers a potential point of policy intervention, by which the waste stream becomes a dependent variable. This paper innovatively argues that, for eco-design to be effective, sustainable waste management must be established as a functional requirement in the design process.

Key words:

Sustainable waste management; sustainability; eco-design; product design; functional requirement

Introduction

Sustainable development is a notoriously difficult aim, involving the co-operation of a range of public, private and third sector actors across interrelated spatial scales and territories (*e.g.*, Haughton and Counsell, 2004; von Malmborg, 2004). Whilst the politically defined region may be the ultimate scale of governmental focus on sustainable development, it is not necessarily the scale or locus of control over relevant processes (Cox, 1993; Saarikoski, 2000). This paradox is well illustrated by issues surrounding waste management. Recent debates on waste governance highlight the complexity of governance structures with potentially conflicting targets and a frequent shortfall of practice compared to policy (Bulkeley *et al.*, 2007; Nilsson *et al.*, 2009). However, whilst waste is regulated within spatially defined units, its composition and quantity is determined by economic processes operating at different scales to that of municipal waste governance. Previous studies, as with local authorities themselves, largely take the composition and quantity of the municipal waste stream as an independent variable.

The limited potential for the public sector to achieve sustainable waste management (SWM) is implicitly acknowledged by the increasing emphasis on the role of industry in the UK waste strategy (Defra 2007, 2009a, b). Arguing that waste management should be seen in terms of resource conservation, the strategy recognises product design as a point of environmental intervention in product life cycles (*i.e.* 'eco-design'; *e.g.*, Lewis *et al.*, 2001). However, whilst the potential for eco-design in the context of SWM has been identified both theoretically and as a policy tool, the regulatory drivers relate to specific waste streams and seem broadly ineffective (Gottberg *et al.*, 2006).

We explore here the potential for and implications of using product design as a means of making an ‘at source’ adjustment to the waste stream to render it easier to process and reduce environmental risk. Following the terminology of Suh (1990), we argue that sustainability, and thus SWM, should be a functional requirement (FR) in the design process. Achieving this would be a stride towards the redefining of waste as a resource. This paper reviews the spatial framework of waste management policies in the UK; then attempts to re-think the approach to eco-design, building on Suh (1990); and provides initial consideration of the implications of integrating eco-design into the spatial structure of sustainable municipal waste management.

Spatial approach to sustainable waste management

Here, we briefly describe the system of responsibility for waste collection and disposal in England and Wales and its incorporation into the national sustainability agenda, in order to illustrate the lack of governmental control in the area, notwithstanding the elaborate mechanisms in place to promote SWM.

UK waste strategy in the context of sustainable development

In terms of sustainable development, the UK’s waste related objectives are to reduce the amount produced and to use waste as a resource where possible, thereby to “break the link between economic growth and the environmental impact of waste”

(Defra, 2005, p.63). There are two major, interlinked, sets of policies through which these aims are to be achieved (Table 1). The first is the planning framework, and the second specifically the waste strategy, both characterised by complex multi-level governance structures.

--Table 1 about here --

More than simply the regulation of land-use, planning has become critical to the Government's strategy for the implementation of sustainable development across different spatial governance scales (Allmendinger and Haughton, 2009). The planning framework emphasises the importance of the regional scale in planning for sustainable development (Haughton and Counsell, 2004; Raco, 2007), thus consolidating waste management as a matter of regional scale strategic planning (Davoudi, 2009). Regional scale co-ordination of planning in areas such as waste, transport, housing and health is undertaken in England by the Regional Development Agencies (RDAs) with the Local Authorities' Leaders' Boards (LALB); comprising representatives of constituent LAs) and other relevant stakeholders. This is a recent development increasing the influence of RDAs in regional planning, the effects of which are uncertain for the balance of power between different stakeholders and plans for specific policy areas.

A primary task of the LALBs jointly with the RDAs is to produce a Single Regional Strategy. National planning policy statements and regulations set the framework for regional strategies. These strategies should reflect the national principles of sustainable development[1], whilst taking into account regional requirements and attempting to integrate a vast array of service areas (*e.g.*, economic development, housing, climate change adaptation, *etc*). Within the region, relevant LAs produce plans for specific policy areas. For waste management, the waste planning authorities (county councils and unitary authorities) produce the waste development framework document, which can start to identify specific sites for the development of waste facilities. Finally, supplementary waste development plans can be issued to provide more detail on issues covered in the framework documents. At each level there should be industry, community and other stakeholder engagement, though this is variable and can be contentious, *e.g.*, when energy from waste becomes an option (Davoudi, 2009). Each successively smaller scale plan should reflect the contents of the larger scale plan within the jurisdiction of which it falls, and the larger scale plans should reflect input from and practise at the smaller scales (DCLG, 2006). However, there can be a lack of cross-referencing between the different scales (Davoudi, 2009). Plans are subject to an iterative process of sustainability appraisal to consider that the most sustainable, feasible, approach has been adopted (ODPM, 2005). Here again practice can fall short of policy, as appraisal requirements are technically met but without the degree of reflexivity assumed by the regulations (*e.g.*, Short *et al.,* 2004).

The Waste Strategy for England 2007 lays out the policy for waste management (DEFRA, 2007). Heavily reflecting requirements of EU Directives such as the Landfill Directive, Producer Responsibility, and the Eco-design for Energy Using Products

[1] http://www.defra.gov.uk/sustainable/government/what/principles.htm Accessed 9/4/09

Directive, it recognises a role for product design as a waste management tool, re-emphasised since (DEFRA, 2009a and b). Also emphasised is the need for multiple stakeholder engagement (comprising the private sector as well as community participation, and the waste management industry alongside the public sector). In the UK, waste management has long been the responsibility of LAs. Different levels of LAs (*e.g.*, county and district councils) have a different balance of responsibilities for waste disposal and collection (Table 1).

The Waste Strategy sets LAs stringent targets to meet for recycling and diversion of biodegradable waste from landfill. LAs have made tremendous efforts to influence the way in which residents present their waste (*e.g.,* fortnightly collections, pre-collection separation of materials, or use of manual to highly technical post-collection separation, supported by education campaigns in order to overcome social and economic, as well as cultural and psychological, influences on people's behaviour (*e.g.*, Mee *et al.*, 2004; Martin et al., 2006;). However, whilst great strides have been made in improving Municipal Solid Waste (MSW) recycling rates in the UK in recent years, performance often remains disappointing with many authorities retaining a 'diversion' or even 'disposal' waste strategy, rather than an 'eco-efficiency' strategy (Bulkeley *et al.*, 2007).

Shortcomings of the spatial approach to waste governance

The regional scale has been prioritised as a critical scale for implementation of sustainable development policies in the UK (Gibbs and Jonas, 2001; Haughton and

Counsell, 2004). This follows the well established practice of using the region as a scale for wealth redistribution policies and economic development (Jonas and Ward, 2002). Whilst regional governance structures are therefore well established in the UK, the likelihood of success for regional sustainability policy may be impacted by the policy areas with which they are competing for resources (Raco, 2007). Furthermore, whilst in other environmental policy areas LAs may have found scope for strategic decision making to address statutory concerns in a manner befitting perceived local interests (Jonas *et al*., 2004), this is curtailed by the prescriptive, target-driven, regulation of waste. However, the major weakness in this system of public sector led planning for sustainable development is the lack of power to control delivery, which in large part lies beyond the domain of the authorities in question (Jackson and Illsley, 2007). Whilst responsible for meeting targets (nationally set, but ultimately EU in origin) for recycling and the diversion of bio-degradable waste from landfill, LAs must ultimately deal with the waste received. The influence of the global economy on regional issues (*e.g.,* Cox, 1993) is as important in the field of waste as in economic development. LAs' waste management strategies are impacted both by consumption trends, which influence the inventory of the waste stream (*e.g*., increase in electronic waste), by social factors and by fluctuations in the markets for secondary material, which influence their ability to dispose of the materials which they have a statutory obligation to collect.

We now turn to consideration of the potential for using product design as an explicit tool to effect a transformation of the MSW stream in order to promote SWM.

Product based approach to sustainable waste management

Product design has been suggested as an appropriate intervention point in a product's life cycle at which to implement environmental goals including SWM practices (Graedel and Allenby, 1998; Giudice *et al*., 2006; Pongrácz, 2009). We first review the underlying principles of design and then analyse how the application of design theory would benefit the implementation of eco-design.

Eco-design

The objective of eco-design (also known as Design for the Environment (DfE) and including a range of other terms commonly known as micro-concepts) is to "design products with the environment in mind and to assume some responsibility for the product's environmental consequences as they relate to specific decisions and actions executed during the design process" (Lewis *et al.*, 2001; 16). Eco-design is difficult to argue against in principle, but in practice it is challenging to achieve. First, the 'environment' has many facets which do not all have the same design implications (e.g., minimising energy consumption; extending product life, recylability); therefore, there is a question of prioritising the issues of concern. In the current UK waste strategy, carbon emissions reduction is a higher priority than resource management. Second, there is uncertainty over the science of many environmental issues making the agreement on potential solutions difficult to achieve (*e.g.* Kikuchi, 2006; Crawley and Ashton, 2002). Third, as is commonly the case in Life Cycle Analysis (LCA), there would be a need for an enormous amount of product life cycle data and expertise to apply a waste-related (or other) strategy (Finnveden, 1999). Fourth, there is the need to integrate eco-design in the design process (Grüner *et al.*, 2001) and fifth, significantly, there has to be preparedness amongst industry so to do. Each area is problematic. However, numerous authors argue that a product's life time environmental impact is largely determined at the design stage (*e.g.* Kurk and Eagan, 2008). This is especially true regarding waste management. Other areas of potential environmental impact (*e.g.,* carbon emissions) may be substantially governed by the consumer's use of the product, over which the design may have little influence. However, all products ultimately require 'disposal' in some manner. Constituent materials and the manner in which they are assembled are controlling factors in determining the most suitable disposal strategy, and these are ultimately determined at the design stage (whether or not disposal was a formal consideration in the design process). We observe that scant attention is paid to this in practice (Deutz *et al.*, 2009); also Kurk and Eagan (2008).

In recognition of the potential utility of eco-design, product based policy interventions to promote SWM have emerged in the EU primarily in the form of the Producer Responsibility Directives. However, the promotion of eco-design by the Producer Responsibility Directives is indirect: the regulations seek to 'encourage' eco-design via targets for materials recycling and recovery (Deutz, 2009). For products governed by the WEEE Directive, this drive is likely to increase as revisions to the Energy Using Products Directive, promoting eco-design in the interest of energy conservation, place increasing emphasis on solutions that do not contradict existing waste management considerations. However, there has not been a concerted effort to apply product design as a tool for SWM. Given that an estimated 98 % of items are disposed of within 6 months of their manufacture (Datschefski, 2001), disposal should be carefully considered in the design stages of all products, not just specific waste streams or niche products for the environmentally conscious consumer.

Much attention in the eco-design literature has been focused on the development of tools, by which consideration of a product's environmental impact over its life cycle could be could be built into the design stage (Graedel and Allenby, 1998; Baumann *et al.*, 2002; Waage, 2007). Whilst these may offer important insights to process, uptake has so far been limited. Recent studies have examined organisational issues relating to the implementation of eco-design (*e.g.*, Johansson and Magnusson, 2006; Kivimaa, 2008) and indicate that implementation is closely related to regulatory requirements (Ackerman, 1999; Boks, 2006; Gottberg *et al.*, 2006). Academic studies of eco-design are typically normative in outlook, but for companies with multiple design criteria to meet already, eco-design is far from an intuitive approach. It is important to understand how the broader design process works. Suh (1990) has argued that the design process in industry is operating in a sub-ideal manner that limits the potential for designers to find optimal solutions. Trying to co-opt a process that is already flawed for a policy initiative is likely to produce disappointing outcomes. Therefore, whilst the potential for eco-design as a resource management tool has been identified, its implementation, as discussed, has so far been extremely limited. We next explore design theory, then its integration with eco-design.

Design theory

Design is a multi-dimensional and complex activity. The spectrum of design activity is often seen as a continuum from soft to hard, from industrial design to engineering design, from art to science. Suh (1990), attempting to theorise the process of design, made an important contribution that is useful to understand the shortcomings to design practice and, thus, suggests a potential point of incorporation of SWM into a functional design process.

The intellectual space that envelops all of the potential solutions to a design problem has been termed the design space (Ulrich and Eppinger, 2008). Critical to widening a design space to include a broad range of solutions, and thereby increasing the chance of finding a solution that satisfies as many demands possible, is an understanding of what the product in question is required to accomplish, *i.e.*, its functional requirements (FRs). These requirements should not be confused with design parameters, which are only variables used to describe the FRs of the design problem (Suh, 1990). For example, given the task of designing a kitchen chair, a designer ought to note the FRs of safety, load support and intended posture. In contrast, the minimum strength required of the materials involved would be a design parameter (DP). As Suh states: “In an acceptable design, the DPs and FRs are related in such a way that specific DP can be adjusted to satisfy its corresponding FR without affecting other functional requirements” (pg 48). A potential design solution for a kitchen chair might, for example, involve an object with four legs, but this is by no means *necessary*. Starting the design process assuming a four legged object would automatically close off consideration of potential designs which might have better served the FRs (or allowed a different choice of other design parameters). That is, to maximise the design space, the design intent should be defined by its FRs (Figure 1), which are then to be met by physical solutions prescribed by the design parameters. Design, then, is the creation of synthesized solutions in the form of products, processes or systems that satisfy perceived needs (*i.e.*, meet the design intent) through the *mapping* between the FRs in the functional domain and the DPs of the physical domain (Figure 1). More classical and structured design models, *e.g.* Pugh (1995) or Pahl and Beitz (1996), focus on the identification of customer needs being the basis of design parameters / criteria without explicitly identifying the FR.

--Figure 1 about here--

Whilst Suh's approach is conceptually fundamental to a sound design process, consideration is required in implementation. Is there a truly successful paradigm for dealing with creative processes on a systematic and scientific basis based on 'principles' and 'laws'? Commonly 'design' studies have only a handful of *concepts*, thus representing a constricted 'design space' (e.g., Deutz *et al.*, 2009). Within a *large design space* there will be a large number of potential designs and / or the number of design parameters is large, as is the number of values they can assume. The larger number of ideas and concepts generated, the greater the probability that the best solution will be found.

Techniques promoting divergent thinking can be used to generate and use the design space. . Referred to as 'early stage tools' in Table 2, these enable engineers to 'think outside of the box' in generating design concepts. On the other hand, at appropriate times, convergent thinking is needed, to narrow the design space and thereby converge to a solution within boundaries defined by relevant criteria. The later stage tools in Table 2 include many which relate specifically to the environment, and also health and safety and product quality. Whilst some of the later stage tools have become an accepted feature of the design process, initial empirical work indicates that the early stage tools are commonly overlooked (Deutz *et al.*, 2009). This brings significant dysfunctionality to the design process: designers are seeking an apparently simple solution, without having properly formulated the design intent. For example, designers may brainstorm a limited number of concepts based on a perceived need which does not actually meet the underlying, possibly unacknowledged, FRs.

-- Table 2 about here--

Convergence (*i.e.*, narrowing the range of potential solutions) happens within the design process, typically three times, representing the main phases of conceptual, embodiment and detail design (Figure 2). Embodiment, in general, defines the range of values acceptable to each design parameter, whereas detail design selects the optimised value for each design parameter. Applying later stage tools without the full exploitation of the early stage tools implies trying to achieve an outcome limiting the environmental burden by adjusting the design details. However, this can be too late in the process as the fundamental features of the product will already be determined. It is important to observe the narrow sections at the beginning and end of the process representing the 'problem definition' and converged preferred solution.

--Figure 3 about here--

Sustainability as a functional requirement

An efficient design process must be underpinned by the careful selection of FRs, utilisation of early and later stage design tools to both uncover the conceptual design space and converge on the perceived optimal solution. Following the above reasoning, we argue that the ideal point of intervention in the design process to promote SWM would be to establish sustainability as a FR. Adopting sustainability at the level of a FR renders environmental considerations integral to the conceptual design space. The given priority for sustainability is a political choice and likely to vary over time and between countries. Furthermore, it is important not to pre-determine the most suitable route to sustainability for a given product. Given 'sustainability' as a FR, alternatives such as 'energy recovery' or 're-use' could equally map against 'sustainability' as a FR. The decision of which option to pursue would then be made for the specific product. Conversely, having a characteristic such as product 'disposability' as a FR would predetermine the resource management approach selected, thereby arbitrarily limiting the number of design concepts generated. Significantly, what appears to support sustainability is not always the case. For example, recycling is not necessarily an environmentally or economically efficient strategy (King *et al.*, 2006). Implementing the proposed approach to eco-design in the context of SWM brings to the fore issues of policy formulation, regulation, organisation and information and co-operation, to which we now turn.

Combining the spatial and product approaches for sustainable waste management

A significant extension of the application and improvement to the quality of eco-design requires that its principles be merged with the approach to design analysed above. In this section we consider the implementation of this approach to eco-design in conjunction with the spatially organised waste management structures.

An informed life cycle approach requires the bringing together of organisations from along the supply-disposal chain to co-operate for the first time, or in new fields (Deutz, 2009), *i.e.* other than a simple service provision/use, sale/purchase of product, regulator and regulated. As with other sustainable development initiatives, our proposed approach to product design implies co-operation of public and private sectors, across multiple scales of governance. Furthermore, companies themselves are complex organisations participating in global supply chains (Vermeulen and Ras, 2006). The fundamental difference to the present arrangements for waste management in the UK is that the waste stream should be seen as a dependent variable, to be adjusted by an iterative procedure involving consideration of the ultimate requirement for disposal. We are thereby attempting to bring an element of regulatory control into the system.

Implementation would likely involve an iterative process of adjustment. Whilst it is important for Government / regulators to recognise the FR, it is another matter for Government or LAs to put in place the infrastructure to realise the design intent in meeting the FR of ‘sustainability’, for example facilities to reprocess materials. Conversely, design needs also to take into account the technical and social requirements of processing waste. This can be seen as SWM exerting a ‘customer pull’ on design, to be taken into account alongside the priorities of the literal customer for the product. Importantly, an iterative process of consultation with customers throughout the design process is a standard procedure (*e.g.*, Pugh, 1995; Pahl and Beitz, 1996). This approach implies the necessity for a strong regulatory 'push' to counteract the market or cost driven 'pull' towards the most commercially viable solution, as suggested by empirical studies of eco-design (Hauschild *et al.*, 2005). Only if sustainability as a FR is embedded in the regulatory framework, will associated design parameters / criteria be included in any consideration by designers in the convergence towards the eventual solution.

Targeted research and development could increase the number of technically viable solutions and associated design parameters, further broadening the design space and helping to ensure the existence of appropriate environmental solutions. For example, R &D could increase the range of applications of biodegradable material. However, at different stages of the design process there is a need for convergent thinking. The critical point here is the compliance with the identified design criteria seeking to produce the optimised design solution. In other words, with sustainability as a FR, any optimal solution will have met the chosen criteria (*e.g.*, recyclability or safe disposal *etc*).

Well intentioned policies are dogged by issues of non-compliance and poor enforcement. We suggest, therefore, a specific regulatory framework which would give a voice to the (socially determined) priorities of SWM as a 'customer' in the design process. In terms of the actual intervention point, there is scope to decide upon where the responsibility or burden of compliance lies, *e.g.* is it in the individual or a nominated post such as a chief designer? How will such regulatory reform be measured? The legal duty perhaps is analogous to As Low As Reasonably Practicable (ALARP) in UK Health and Safety legislation (HSE, 2006). The designer would show that the environmental impact via the chosen design parameter is ALARP, implying sustainability of the product were the best it could be. From a regulatory perspective, specific measures would also need to be defined for LAs. The importance and complexity of formulating regulations are recognised, but cannot be addressed here.

Thus by focussing on FRs, we are trying to shift attention on environmental issues and sustainability towards conceptual design space as illustrated in figure 1. The opening of a sufficiently broad design space may enable the identification of design options in areas of overlap between the customer pull and technically viable design in terms of SWM.

Conclusion

The use of design to minimise environmental impact has been largely ineffective in terms of SWM (*e.g.* minimising waste landfilled). Design offers a strong policy intervention point to enhance SWM by placing ‘sustainability’ as a functional requirement in the design process. At present, regulations and laws are silent on FRs. The targets in place for producers do not map to the desired areas of performance, and hence represent a sub-optimised system. By contrast, the innovative approach proposed promotes the use of the early stage design tools and greater interaction with the 'customer' / 'user' of the disused product ('waste'), thus enabling identification of alternative materials flows and enhanced new product sustainability. Within this framework, designers would be able develop design criteria closely coupled to regulatory targets, *e.g.*, related to minimising waste. The organisational requirements of the proposed approach to design would be considerable and would likely need to be driven by a strong regulatory push. Considering appropriate mechanisms for this requires further research into how the design process functions in companies and how environment is incorporated into it. Additional research is necessary into how to express the waste management 'customer' requirements, formulated in the complex context of multi-level spatial governance, in a form compatible with design requirements.

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Table 1: Governance of waste management in England.

Scale	Constituent bodies	Relevant function	Example: planning	Example: waste
Supranational	EU	Environmental protection and harmonisation	Strategic Environmental Assessment Directive	Waste Framework Directive; Landfill Directive;
National	National government: Department of Communities and Local Government: Infrastructure Planning Commission: Defra: Environment Agency:	National regulations Oversees planning policy: Oversees sustainable development incl environmental protection Consulted on plans/projects with potentially significant environmental impact	Planning Policy Statements and Guidance Oversees applications for 'nationally significant infrastructure projects'	Waste Strategy for England 2007 Regulates waste operators via environmental permitting regime
Regional	Local Authority Leaders' Boards; Government Office, Regional Development Agency; input from Local Authorities, Local Strategic Partnerships, regulatory bodies, industry,	Regional Single Strategy	Regional scale waste requirements planned in conjunction with other sectors (e.g., energy, transport, housing etc) and subject to sustainability appraisal	

	conservation bodies			
Local	Unitary authorities, county councils district/metropolitan councils	Local Development Framework: Plans (e.g., waste) subject to sustainability appraisals	Review and decide on planning applications relating to specific projects	Waste collection and/or disposal Statutory targets to meet for recycling household waste;
Site specific	Public and/or private bodies	Proposing a development covered by above regulations/plans.	subject to environmental impact assessment and permitting	Individual waste facilities, e.g., energy from waste or recycling centre

Design Concepts & Tools Checklist **(Not Exhaustive)**
• ***<u>Early Stage (excluding sub-processes)</u>*** – Mission statement, systems thinking (holism, mess to difficulty, emergence, rich picture, inference maps, multiple-cause maps, other diagrammatic methods, hard and soft-systems modelling, needs, metrics, binary dominance method, product design specification, quality function deployment, (negative) brainstorming, benchmarking, conceptual design, design approaches such "form follows function" and axiomatic, synectics (analogies), morphological charts, product creativity templates (attribute dependency, replacement, displacement, component control), objectives trees, interviews, focus groups, observation, functional & user decomposition, product (modular or integral) architecture, BOM. • ***<u>Later Stage</u>*** – Multi-Attribute Decision Analysis, DfE (& micro-concepts), Design for Manufacture & Assembly, (various) prototyping, Failure Modes and Events Analysis, Hazard and Operability Studies, Eco-Compass & other environmental impact tools, Best Available Technology Not Entailing Excessive Cost, Best Practical Means, Best Practical Environmental Option, Environmental Impact Analysis, LCA, Material Selection Indices, Hazards & Risk Calculations (QRA & F-N "Farmer" curves) with alternative dose-response models, Tolerability of Risk , Reliability Analysis, Probabilistic Safety Analysis.

Table 2: Concepts and tools checklist for the early and later stages of the design process**.**

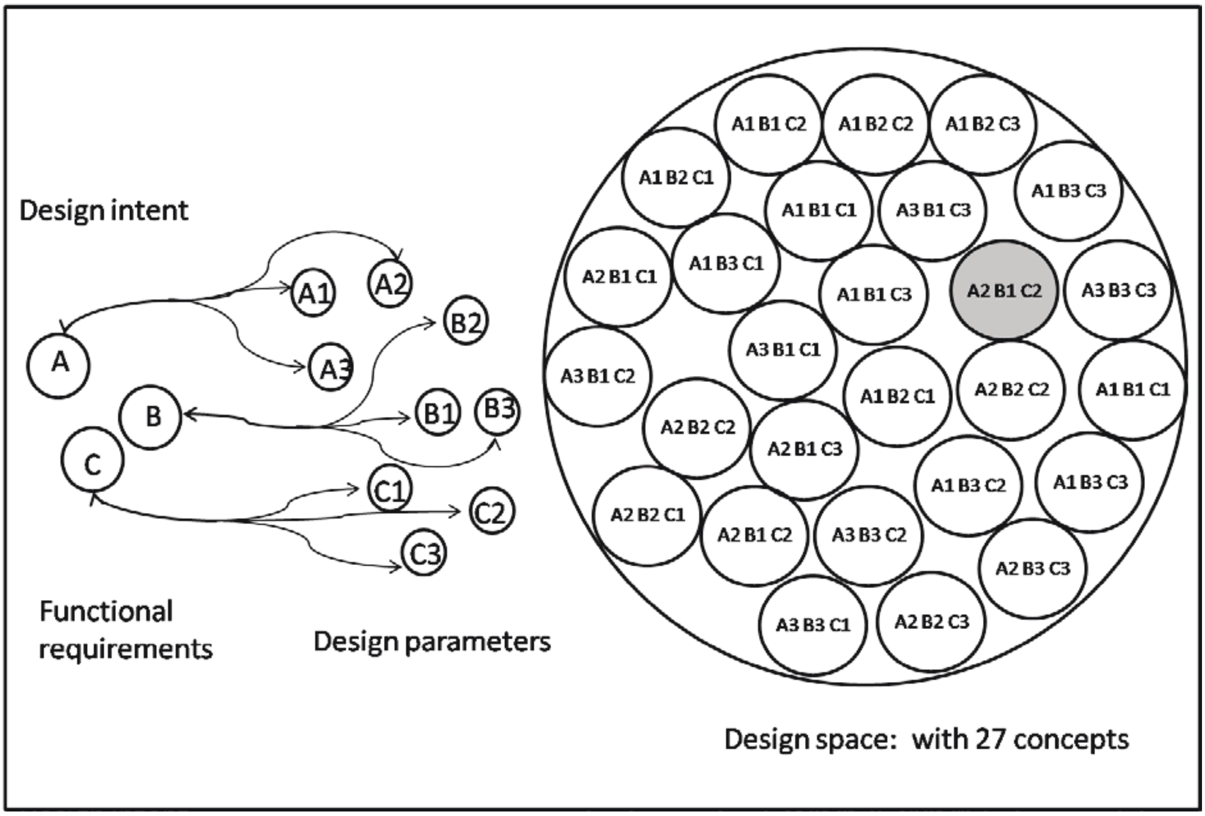

Figure 1: Relationship of design space to FRs. The three FRs each map onto three design parameters, producing a maximum design space comprising 27 concepts. Framing the design intent with the assumption that certain design variables were requirements, rather than possible solutions, would have eliminated portions of the design space, thereby reducing the likelihood for finding the optimal solution (shaded).

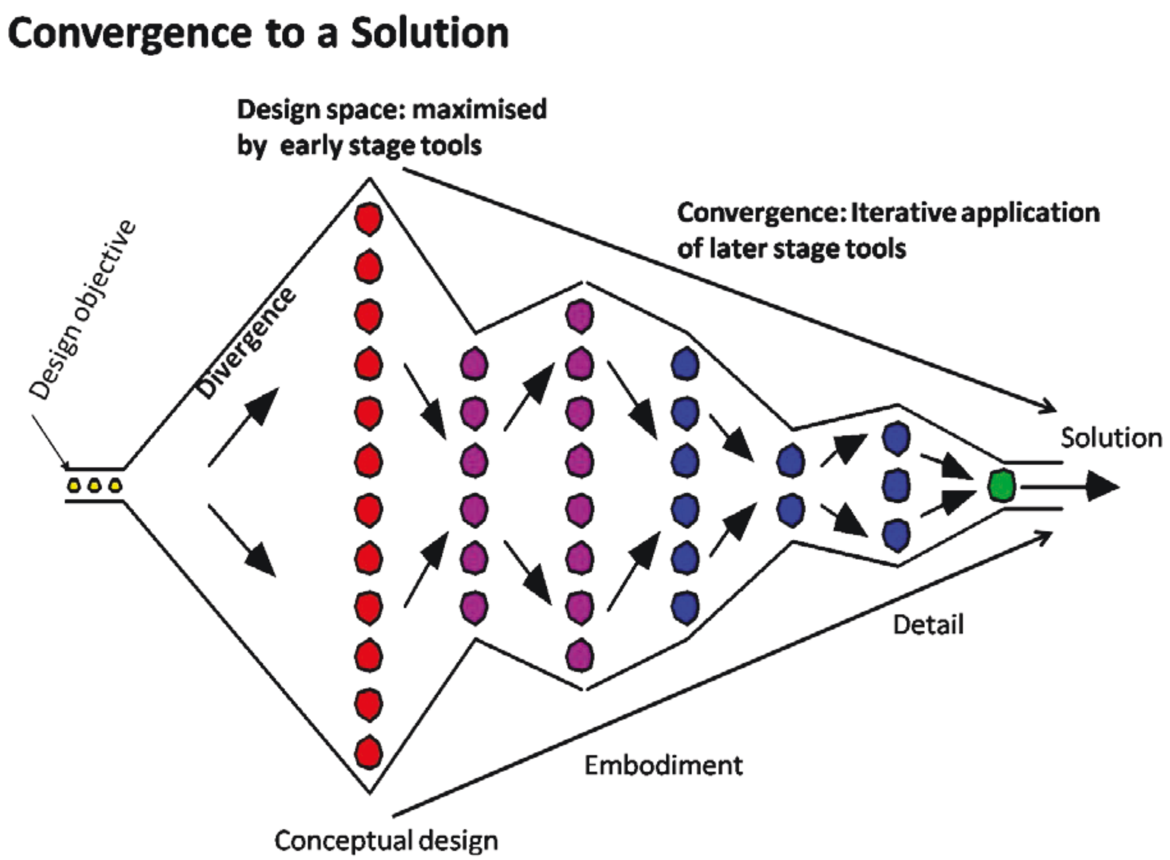

Figure 2: A schematic to show the three main phases of the design process and relate to early and later design tools referred to in Table 2 (Derived from Ulrich and Eppinger, 2008).