# System Dynamics Modelling of National Design Infrastructure Development

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I would like to acknowledge the three years of financial assistance for this project provided by the Office of Research and Development and the Faculty of Built Environment, Art and Design of Curtin University of Technology. In addition, I would like to thank the national design experts from governments, universities and businesses in the UK, Norway, Finland, and Australia that kindly contributed their time, expertise and knowledge to the research.

## Abstract

This paper describes system dynamic modelling of national design infrastructure following three-year research (approx AU$200,000) developing a conceptual framework and gathering field data about five national design infrastructures: UK, Norway, Finland, Korea and Australia. The effects of design infrastructure are complex and located within multiple interrelated systems with high levels of complexity. Dynamic modelling is non trivial with a relatively large number of environmental variables different in each country and varying over time.

The paper outlines the extended role of design in social, economic and cultural development, and discusses systemic aspects of national design infrastructure. It then describes preliminary modelling of: design knowledge, design education and the role of design in social and economic development, and identifies outcomes some of which are counter-intuitive. The research offers the basis for guiding the investment

into the design infrastructure needed for innovation and the building of local and national knowledge-based economies.

# Introduction

All developed and developing countries aim to improve their social and economic status. They do this through human instituted changes. Design activity is the foundation of all intentional human instituted change.

A commonly accepted definition of design as an activity was coined by Nobel Laureate Herbert Simon (1969). He defined design as to "[devise] courses of action aimed at changing existing situations into preferred ones". When used as a noun, typically ‘design’ is regarded as a specification for making something or doing something. This is a subtle but important point. The design is the *specification*, not the thing.

Much of the design activity that goes into changing human environments and, hopefully, improving societies’ social and economic lot is relatively hidden regardless of our dependence on it. Any human, looking around themselves would find that the majority of their environment has been designed – even the most apparently nature-laden aspects. Most design work goes on behind the scenes, regardless of the illusion otherwise, that is implied by the tiny amount of objects in which the fact that they have been designed is a prominent part of their sales promotion. Mostly design activity is extensive, embedded systemically and out of the public view.

Take for example, the case of a simple set of IKEA wooden shelves

A practical and simple example first proposed on the PhD-Design discussion list on Jiscmail (T Love, 2001). I am sat in my office looking at some IKEA timber bookshelves originally intended for use in garages and outhouses and visually acceptable for use in office settings The shelves consist of four different sorts of timber elements, one kind of coach bolt, some special twisted plated mushroom headed nails, a zinc plated cross brace, and four small zinc plated screws. The pack of shelves when supplied by IKEA is fastened together for transport by a glassfibre reinforced plastic strap whose ends are crimped with a zinc-plated steel sleeve. The shelving pack has a small black and white label with assembly instructions and

several small barcode labels all attached using a pressure sensitive non-setting adhesive.

Many different sorts of designers were involved (see Table 1.):

Table 1: Different fields of design involved in making a simple wooden bookshelf

| | | |
|---|---|---|
| designing the overall configuration | designing the coach bolts | designing the fancy nails |
| designing the cross cutting machine for the timber | designing the four head cutters for shaping the timber | designing the drilling machine for the holes for the bolts |
| designing the nailing machine and its jigs (a different designers job) | designing the steel smelting machines | designing the wiredrawing machines from which the nail blanks and the coach bolt blanks are cut |
| designing the labels | designing the plastic strap | designing the printing machinery |
| designing the nail making machine | designing the barcode system | design the policy standards for grading the wood |
| designing the cross brace (and the machines for making and plating it) | designing the die cutting machinery for cutting the labels | designing the software used to create the print instructions for labels |
| designing the hardware systems from computer to printer for the labels | designing the material content and properties of the steel | designing the plating machine for the fancy nails |
| designing the chainsaws to cut down the timber | designing the debarking machine for preparing the logs | designing the machines that make the glassfibre and the plastics for the strap |
| designing the paper making machinery | | designing the saw mills for planking the logs (this includes a plethora of building designers/safety designers/ road designers etc/environmental designers/economic policy designers) |

Now each of the machines/ buildings mentioned in the above table is also made of components that were designed and these designers and design fields should also be added as must the designers and design fields involved in transportation, logistics, business processes, information systems, computer systems, software, timber harvesting, environmental policy design, the design of the different training programs for the wide variety of individuals involved in the accounting etc, etc. Taken together, the design resources needed for specifying the activities, machines and other objects and processes needed for the creation and use of these IKEA shelves comprise the specific *design infrastructure* needed for the shelves to exist and provide social and economic benefits.

## National Design Infrastructures

Viewed more broadly, *design infrastructure* is necessary for all change. At a national level, each country has an extensive design infrastructure, much of which is hidden and integrated into a wide variety of national and local systems. Elements of national design infrastructure include:

| | |
|---|---|
| design professionals | design centres |
| businesses undertaking design | government agencies to promote design |
| departments undertaking design within organisations | design-focused associations representing those undertaking design |
| national design policies | government agencies to develop design-focused policies |
| hardware and software tools available to support design | organisations commissioning and funding design research |
| organisations educating designers | organisations educating design researchers |
| design researchers | organisations undertaking design research |
| organisations commissioning design activity | organisations representing design research |

*Design infrastructure* provides the bridge between new knowledge generated by *research* and the actualisation of designed products, systems, services, processes and organisations by governments, institutions and individuals. The role of design infrastructure in this process in relation to commercial products is shown in Fig 1.

[Figure 1 about here]

In each country there is a different distribution of design infrastructure elements in relation to their quantity, quality and distribution. The elements of design infrastructure comprise a system shaped by the relationships between design infrastructure elements and with other national systems and subsystems and the users.

A key question to ask is how well a country's design infrastructure system matches the country's development trajectory and its social, economic and technological developmental agendas.

Obviously, if a country's design infrastructure is primarily focused on designing new bio-technology, it suggests that there will be a certain innovation weakness if government focus is on economic development via shipbuilding. Similarly, if a country's design infrastructure is primarily dedicated towards craft and art, then it will not provide strong support for national aspirations to develop advanced computer system production. In fact, the situation is much more subtle for countries with a sharp awareness of the details of their design infrastructure systems. For example, Taiwan chooses to only manufacture certain *types* of computer chips and hardware – in line with their design infrastructure system and its planned evolution. Finland, a country that has committed its national development to expertise in design, has recently proposed a rejigging of its university elements of design infrastructure by combining the University of Art and Design with the Helsinki University of Economics and the University of Technology.

Systemically, at the largest scale, the behaviour of design infrastructure systems can be envisaged as relatively simple: does the country have expertise to design particular things. Analytically, the problem comes in exploring how well a country has the capacity to support radical competitive innovation and the novelty and destabilising social and economic changes that accompany the economic potential of disruptive designed outcomes.

Even at the largest scales of national design infrastructure systems, examples of the management cultural blindness cautioned against by Forrester and others (Jay W Forrester, 1975; Jay W. Forrester, 1998; Sterman, 2002) can occasionally be evident. An example is the case of Australia. Recent research by the author demonstrated an almost complete lack of awareness of the role of design infrastructure and design activity in innovation in Australian government, universities, research funding bodies

and industry (T Love, 2005; T. Love, 2006). Instead, there had developed a bi-polar view of innovation in which research gets magically transformed into commercial outcomes as in Fig 2.

[Figure 2 about here]

This almost complete lack of awareness of the systemic role of design activity and in innovation and fulfilling national social and economic agendas did not mean that no design activity occurs. In fact, engineering design companies, particularly in the oil and gas and resources sectors are producing world-class designs for plant and equipment and there is increasing awareness of the work of some Australian art and craft designers. Systemically, in terms of Australia as a viable system (Beer, 1988, 1989), it means that management attention in levels, 2, 3, 4 and 5 fully commits its resources for innovative development on one hand to a limited subset of research for knowledge production that does not include design activity and its essential roles in innovation, and on the other hand to commercial activities that presume that the design work is done elsewhere. In essence, this is a system failure caused by management blindness.

The idea of development trajectory informs the why and wherefore of this problem. Australia's history is primarily as a colony of the UK on which it depended for value added or manufactured products, technical expertise and its professional services (for which again design has a primary role – e.g. lawyers design strategies for the courtroom, doctors primary role is in designing medical treatment programs). For most of this time, Britain discouraged the development of Australian design and innovation systems whilst at the same time committing heavily to the development of design infrastructure and research in UK innovation system. An example is the way that research into wool was divided between the UK and Australia where the UK undertook all the research into design-based development of value added outcomes, and Australian research was limited to finding ways of producing more wool (Boardman, 2001). In spite of this, Australian design activity has increased – without government and institutional support.

There is some evidence that the situation is changing in Australia as State governments have begun to realise the potential benefits of supporting design activity. Victoria for instance has now set up a small government department to oversee

development of design-based industries. In general, however, the Australian culture remains one of hiding design infrastructure as in for example the 2007 Festival of Ideas in South Australia which ignores design activity except in terms of high profile aesthetically focused 'creative design', and instead substitutes the concept of 'magical discovery of fully formed ideas' . Similarly, but form a different tack, the Federal Australia-wide Festival of Innovation also ignores design activity and instead tries to cover the same ground with the magically discovered scientific 'inventions'. The role of design infrastructure as a production system for designs for new innovative and better products, systems, services, processes and organisations that is the common understanding in many other developed countries is ignored by both.

## System Dynamics Model of National Design Infrastructure

Why is a systems dynamic model of national design infrastructure needed? There are five main reasons:

- To provide a basis for government policymakers to explore which strategies of investment in design infrastructure/innovation are likely to have the best effects
- To address the high level of complexity in interactions between the large numbers of causal factors, intermediate processes and outcomes
- To provide dynamic modelling that includes and illustrates changes over time
- To identify counter-intuitive outcomes that are hidden to conventional research and lead to e.g. the errors of 'blindness' to aspects of design infrastructure found in Australia
- For the dynamic modelling to be capable of refinement in scale and scope without needing to re-create the models and sub-models from scratch. System dynamics offers the means to develop sub models in a piecemeal fashion that can be integrated into a larger scale model.

This paper reports preliminary System Dynamic modelling of three aspects of design infrastructure: design knowledge, design education and design in business. The modelling is referenced against case studies of national design infrastructures in Australia, UK, Norway, Finland and South Korea involving desk-based review of design infrastructure and historic national development trajectory supported by semi-

structured interviews with design experts from government, business and academia in each of the countries with the exception of South Korea. The primary focus of the research funding was to improve Australia's innovation processes. Preliminary desk research on Korea indicated that the significant differences in culture and development trajectories between South Korea and Australia meant that it would be difficult to successfully relate Korean developments to the Australian context.

The main focus at this time in developing System Dynamic models is to identify stocks and flows of key factors and positive and negative causal feedback loops.

## Modelling Design-Related Knowledge

The quality of explicit design-related knowledge available is a key aspect of design infrastructure and is a major foundation for effective and efficient innovation and national development because it enables the use of rationalist/scientific approaches to developing and managing complex products, systems, services and organisations. Although it many 'intuitive/creative' designers from the craft traditions (graphic design, advertising, fashion etc) claim to eschew explicit, research-derived, design knowledge, there is increasing evidence of its use. Examples include readability heuristics of line length and font type, colour forecasts, marketing information, useability studies etc.

Explicit design-related knowledge can both grow and become accessible, and become lost or inaccessible. For example, in a separate research project investigating design processes in the global outdoor clothing sector (findings to be published Oct 07), the author and colleagues discovered that the dynamics of design-related knowledge in that sector was dominated by persistent loss of knowledge due to the detail of the structure of design and manufacturing processes used in the sector. This understanding offers great potential competitive advantage.

Review of design infrastructure across the six countries showed a variety of factors shaped the dynamics of growth and loss of design-related knowledge. One way of representing this in systems terms is shown below in Fig 3.

[Figure 3 about here]

The model is primarily symmetrical in that to the left there are a number of positive loops tending to increase design-related knowledge, and to the right there are positive

loops tending to increase loss of design knowledge. Automated design has a dual role depending on whether explicit design knowledge is deliberately derived from it or not. One way increases design knowledge and the other leads to a potential loss of design-related knowledge. In policy-making terms, the system diagram suggests that gains can be made by amplifying the effect of the factors to the left and attenuating the effects of the factors to the right.

## Modelling Design Education

Design education has a single intention: of creating a pool of highly skilled designers. The research focused on investigating this aspect of the role of design education. It has become increasingly apparent, that another significant role of design education is to educate consumers and business managers to be more aware of the benefits of increased quality of design effort. In reality, most graduates of university-based design education become employed in ways that are not directly related to their design education, thus suggesting that a key role of design education is similar to that of classics education and finishing schools in earlier times.

There is currently a radical transformation of design professions. The three driving factors are: a transition from a traditional craft-based/art-based education to a more scientific university education as the basis for designers professional formation; increased dependence on tacit knowledge being made explicit and embodied in technological decision support for designers; and a vary high rate of change in the range and quality of design skills required by the market.

These overarching factors result in two very different pictures emerging from the design infrastructure research. Fig. 4 below shows a systemic view as perhaps perceived from traditional design fields. In this, the impacts of technological and disciplinary change are primarily on the rate at which designers stop being employed as professional designers.

[Figure 4 about here]

In contrast, Fig.5 below, shows a systemic view of the same factors as being perceived perhaps by a member of the newer sectors of design professionals who are used to high levels of change of design skills and disciplines; high technology use; and low interest in the benefits of traditional modes of skill evolution as the basis for

improving design quality. In addition, for younger designers there appears to be, at the same time, respect for older designers and enthusiasm for older designers to leave the professional stage to make more room.

[Figure 5 about here]

In essence, the difference between the two views is whether radical changes in design skills and technology skills are seen as positive or negative.

The implications for design education, in design infrastructure terms, are complex. Current developed countries design infrastructures and design and innovation outputs are depending on a mix of design professionals from both positions. Both positions contribute to and support design output quality. In reality, at this point control of design activity appears to be held by those with more traditional design backgrounds and it is unclear whether a full transition to the new more technology based approach will offer the maximum benefits. At this stage, the main benefits of the above systems diagrams are to make explicit the factors impacting on the situation and the difference in perceptions between the two groups.

## Modelling Design in Business

Design infrastructure has multiple roles in business. It impacts on the design of products, systems, services, organisation structures, business strategies, business processes, and tools, personnel behaviours, marketing and sales activities as well as the external environment in which businesses operate. Figure 6 below shows a simple model of effects of design activity on asset levels that illustrates some of the multiple reinforcing loops by which assets accrue as a result of design activity, and assets are lost as products become obsolete, primarily as a result of new products and cultural change resulting form designed outputs.

[Figure 6 about here]

The increase in assets at firm and national levels results in economic prosperity and cultural change that in turn affects the number of successful designs in a further set of positive feedback loops as shown below in Fig 7.

[Figure 7 about here]

Significantly, economic and cultural change increases levels of critical awareness of designed solutions and also increases the strength and frequency of cycles of ‘fashion’

– in effect increasing the hunger for change via novel and better designed outcomes. This emerges as an increase in the rate at which designed outcomes become obsolete as represented in the right hand loops of Fig 7.

Taken together, the different feedback loops of Fig 7 illustrate the potential for several different scenarios in socio-economic development that is driven by design and innovation:

- Slow balanced scenario: Number of successful designs remains relatively stable and rates of design production and obsolescence are low. Often regarded as a 'sluggish' economy as it results in low asset increase
- Fast balanced scenario: Number of successful designs remains relatively stable and rates of design production and obsolescence are high. This is often regarded as a high change 'booming' economy
- Design hungry scenario: Rate of obsolescent (or potentially obsolescent) designs is high – usually due to poor performance rather than fashion. Number of successful designs is low. Rate of generation of successful new designs is low. Economy is sluggish. Offers high potential for change.
- Innovation driven scenario: Rate of new design production is high. Levels of successful designs are increasing. Designs become obsolescent as they are replaced by ones that provide socio-economic advantage.
- Effete society scenario: Rate of new design production is high. Levels of 'successful' designs are increasing. Designs become obsolescent as they are replaced by ones that are more fashionable. Society is driven by marketing/sales techniques and manipulation of desires. Design success is defined in terms of ability to create emotions of 'desire' rather than socio-economic benefit.

## Future Research

This paper describes one aspect of a larger project. It focuses on the preliminary modelling of: design knowledge, design education and the role of design in social and economic development, and identifies outcomes some of which are counter-intuitive. Other findings will be reported later. The aim is to develop a functional system dynamic model of national design infrastructures that incorporates delays and increased levels

of modelling of interactions between subsystems. The next steps are to complete the range of system dynamics sub-system models that can be inferred from the data and literature reviews, and calibrate them. Future research as the analyses of existing data evolve will focus on identifying dominant feedback loops and key leverage points for interventions.

## Summary

This paper has reported on preliminary outcomes from a three year research project investigating national design infrastructure systems in five countries.

The paper first introduces a larger view of design activity as a primary component of national social and economic systems than is usual, in which design has a more extensive role than is commonly perceived. An example was provided, a simple timber IKEA bookcase, in which the extent of the different roles of design activity was made more transparent.

This was followed by a description of the role of design infrastructures in national social, economic and cultural development and the importance of understanding the dynamics of design infrastructure development in terms of countries' histories and development trajectories. The importance of system dynamics as a potential tool for modelling the dynamics of design infrastructures was discussed.

Against this backdrop, the paper then provides preliminary systems models (using Vensim) based on selected findings of the design infrastructure research. These systems models illustrate some of complex behaviours found in the different dimensions of design infrastructure. This paper focuses particularly on three generic overarching issues: the dynamics of design knowledge, design education and the roles of design in business. Directions for future research are identified.

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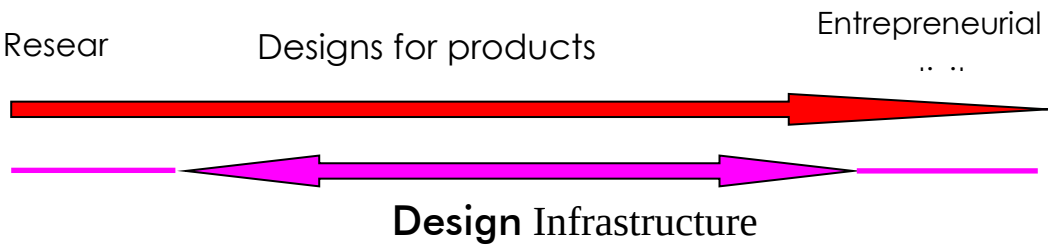


**Figure 1: Role of design infrastructure in relation to research and entrepreneurship.**

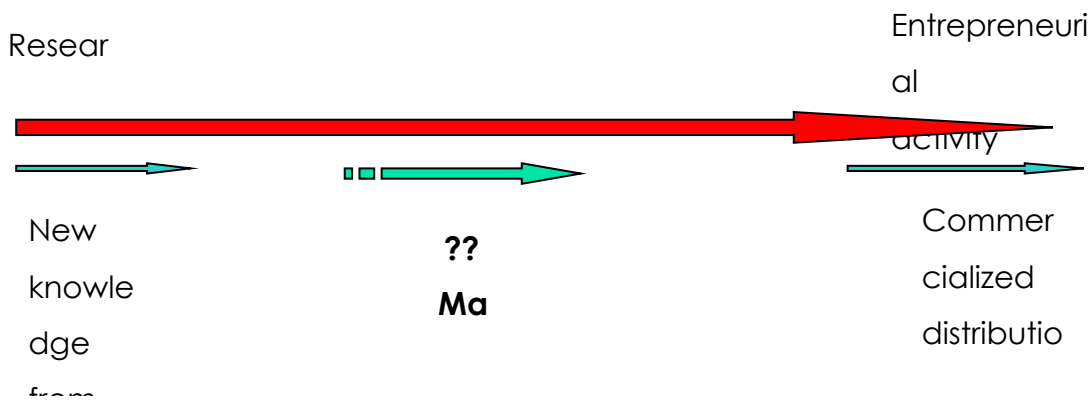


**Figure 2: 'Hollow' model of innovation (e.g. Australian government policy and research funding circa 2005)**

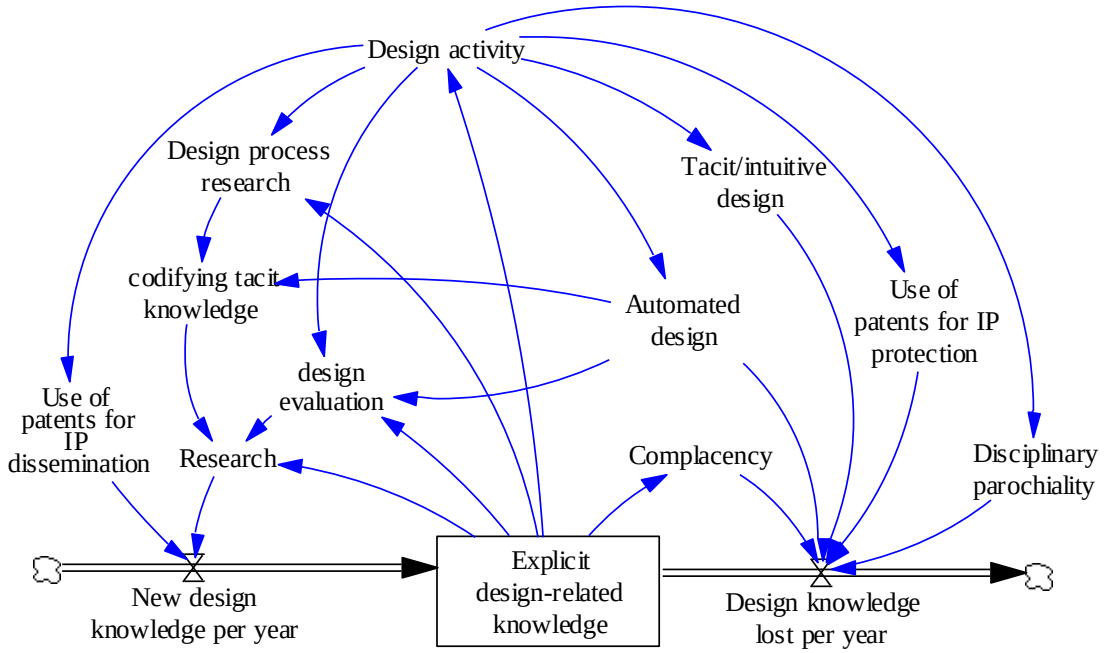


**Figure 3: Factors acting on development of explicit design-related knowledge.**

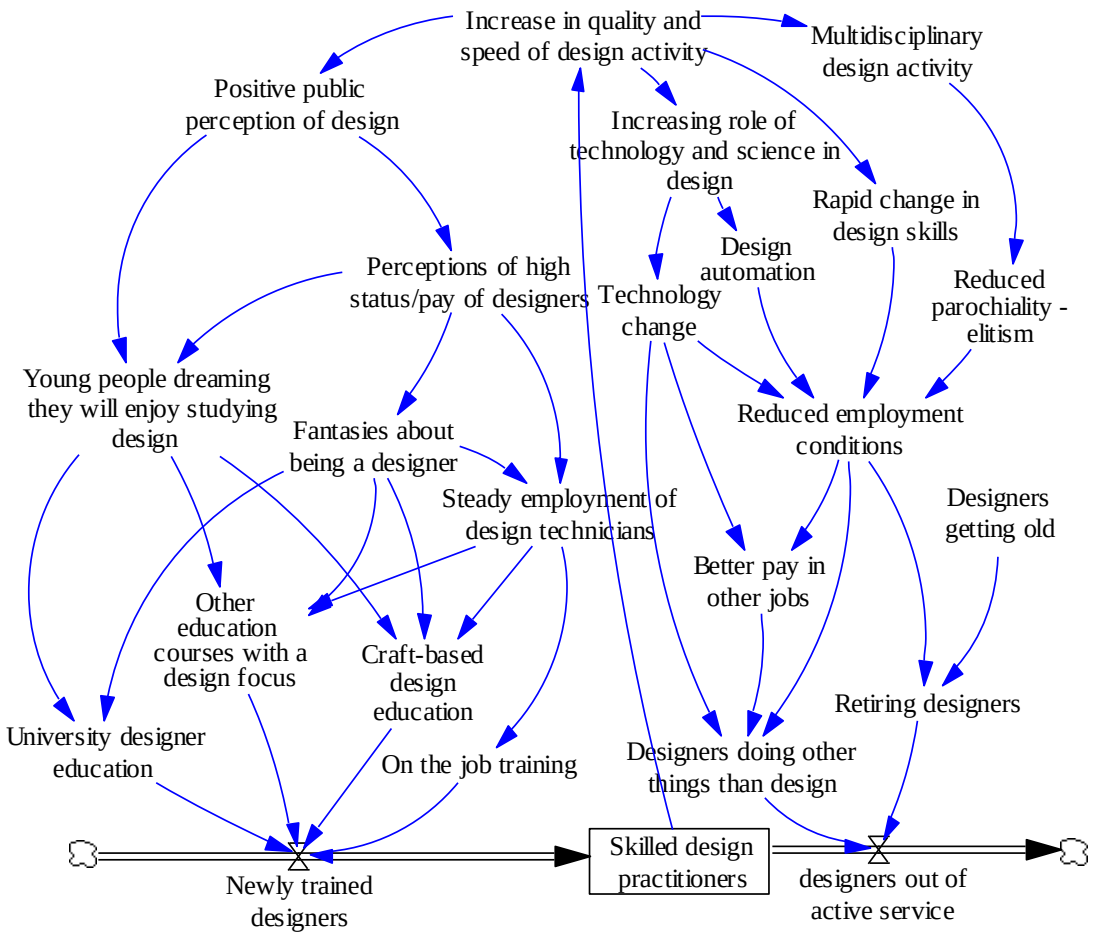


**Figure 4: Factors acting on design education and number of skilled design practitioners as perceived from the viewpoint of traditional established designers**

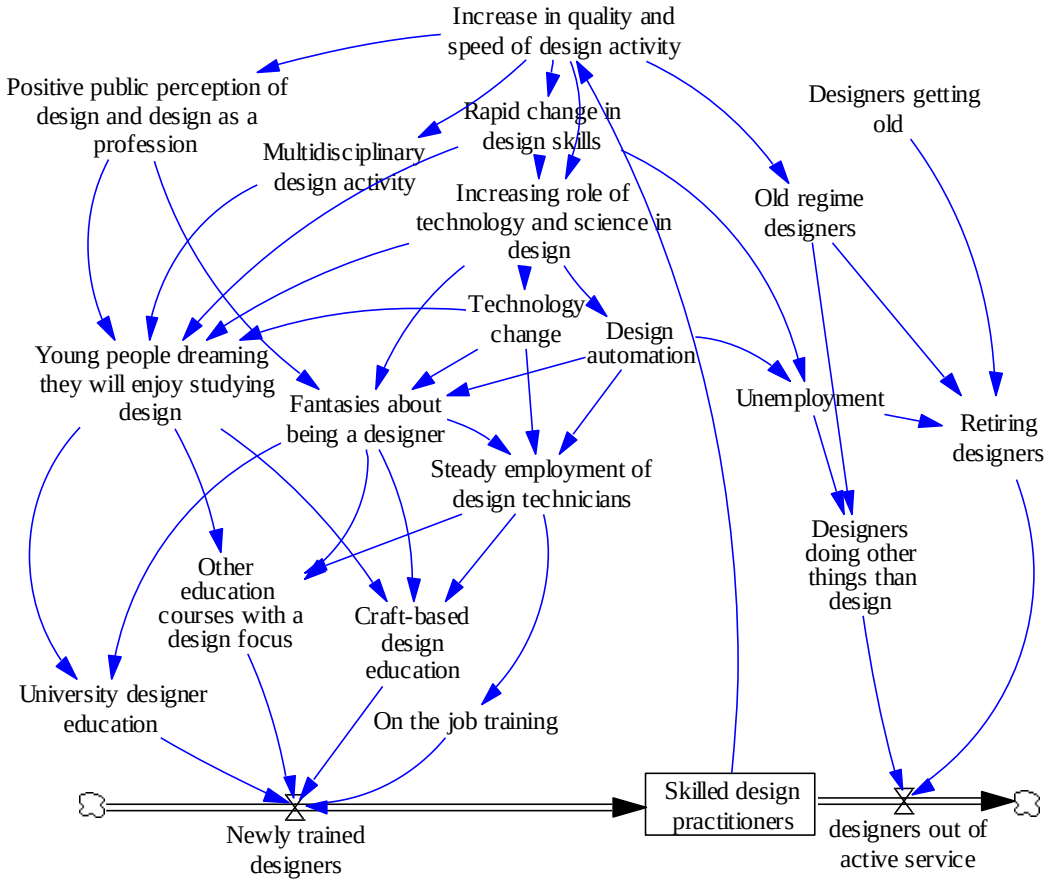


**Figure 5: Factors acting on design education and number of skilled design practitioners as perceived from the viewpoint of designers used to high levels of skill and technology change.**

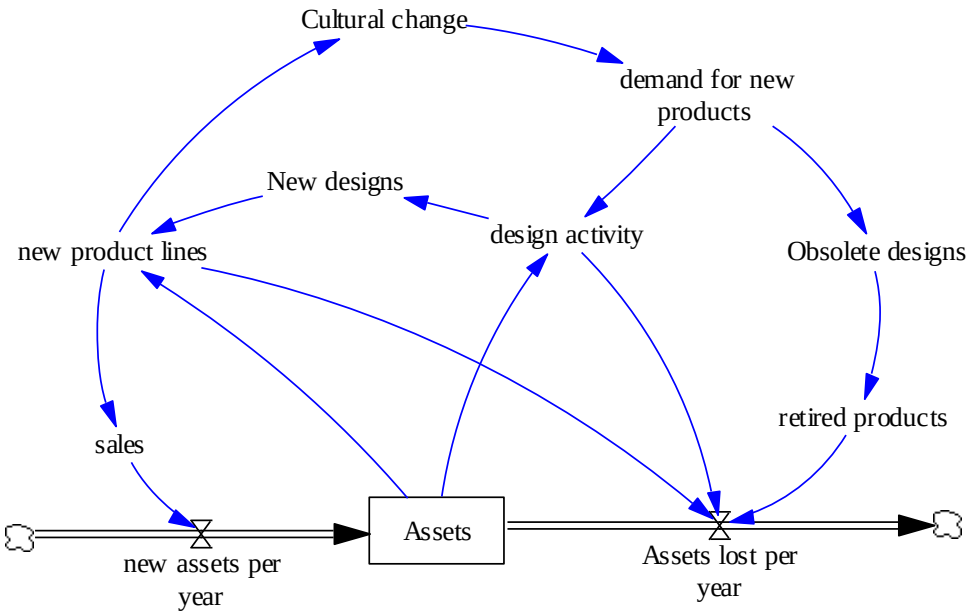


**Figure 6: Effects of design activity on asset levels**

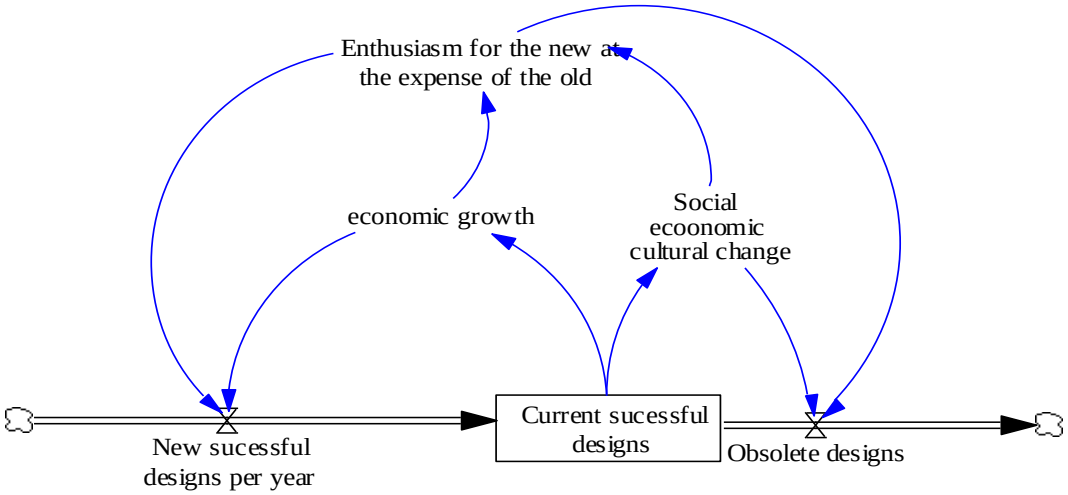


**Figure 7: Effects of economic growth and cultural change on numbers of successful designs,**

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Being a university researcher in Australia is Terence's third career after a long period as the owner manager of a consultant and contractor business in the UK and Europe, and following an earlier period employed as a design engineer.

Terence's main areas of interest are at the intersection of design research and complex systems analysis, with a particular emphasis on emergent systems with inter-related social, technical, political and control issues. Recent projects (with colleagues) include research into planning implications of different systems models of coastal sand movement'; implications for commercial and political control of e-learning systems and learning object architectures of the transfer to RDF-based meta-data; study of the public health failure of control of use of CCA-treated timber; development of five new extensions to Ashby's Law of Variety to extend its use in the political and social control of complex evolving systems; development of organisational intervention strategy to support interagency collaboration to minimise crime and antisocial behaviour in rail environs; design process failures in the UK Outdoor Clothing sector; research into design theory. Terence has with colleagues written over a hundred publications, of which pre-prints are available at http://www.love.com.au/PublicationsTLminisite/Publications.htm