IASDR07
INTERNATIONAL ASSOCIATION OF SOCIETIES OF DESIGN RESEARCH THE HONG KONG POLYTECHNIC UNIVERSITY 12TH TO 15TH NOVEMBER 2007

NATIONAL DESIGN INFRASTRUCTURES: THE KEY TO DESIGN-DRIVEN SOCIO-ECONOMIC OUTCOMES AND INNOVATIVE KNOWLEDGE ECONOMIES

Dr. Terence Love[1]

[1]**Curtin University of Technology, Western Australia; Lancaster University, UK; IADE/UNIDCOM, Portugal, t.love@curtin.edu.au)**

ABSTRACT

This paper describes partial findings from a 3-year design research project exploring the role and dynamics of national design infrastructures. The long-term aim is a fully-functional quantitative system dynamic model of the effects of design infrastructure on national innovation and socio-economic development outcomes. The analyses are ongoing. The integrated system dynamic model from this research will, when completed, provide a foresight tool for local and national government policymakers to identify preferred areas of investment in design infrastructure to maximise socio-economic and technological developmental benefits, particularly in the transition to innovative, knowledge-based economies.

Multiple separate subprojects address aspects of the overall modelling problem. This paper describes the outcomes of one of theses sub-projects involving the development of preliminary qualitative causal loop models in preparation for identifying counter-intuitive system

behaviours and prior to creating quantitative predictive system dynamics models and calibrating them.

Design infrastructure, system dynamics, causal loop models

1. Background

Design activity is central to national social, economic and technical development. Design activity is the means by which knowledge about the world is transformed into real world phenomena - products, systems, services, organisations, images, government policies, education programs etc - that provide social, economic and technology development benefits. Most of the environment of individuals in developed and developing countries has been designed in some way - including natural systems. Design activity provides the link between knowledge generation and acquisition by research and the physical creation of the elements of our real world environment (see Fig 1).

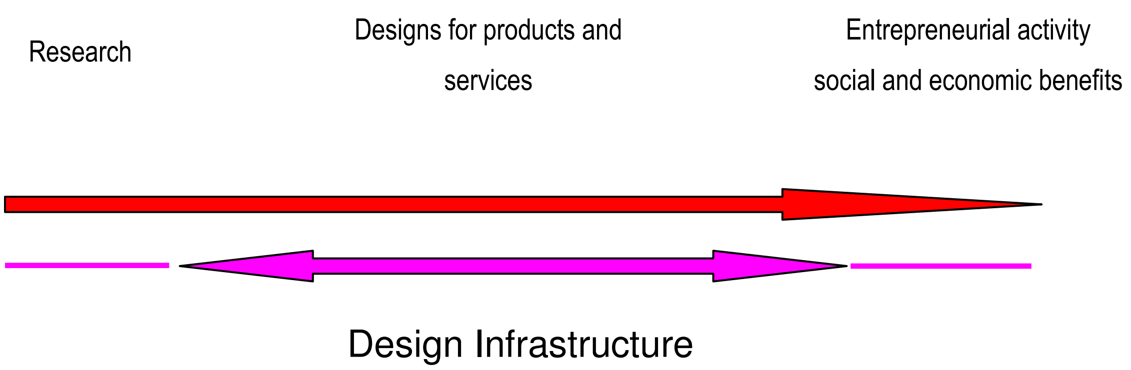

Fig 1: Role of design infrastructure

For creating real world innovative output, design infrastructure is typically more critical than intellectual property (IP) from cutting-edge research. There are two reasons. Cutting-edge research itself depends on appropriate design infrastructure to create the designs for real world outcomes that use the findings of that innovative research. Without the design and actualisation processes, research findings remain stillborn. Second, design activity results in the production of designs for multiple different types of outcomes from *any* given elements of knowledge, and this knowledge does not have to be cutting-edge. For example, much of the design work for the space program is developed using relatively old Newtonian mathematics and related physical laws rather than cutting edge research into (say) relativity or quantum physics. Another example is the way that relatively conventional knowledge about feedback loops, small electrical devices and mechanisms has been converted by designers into millions of different highly innovative mechatronically-based products from thermostats to nuclear power plant controllers – all using the same small body of knowledge, situated a long way back from the cutting-edge of research.

Design activity depends on national infrastructures. Weakness in design infrastructure compromises economic and technological development agendas by reducing innovative output. The utility of design infrastructures depend on their match with the needs and trajectories of development. Some countries have and appropriate rich design infrastructure, however, in other countries, key elements of design infrastructure may be inappropriate, missing or hidden. Australia is an example of a country in which key components of design infrastructure are missing (T Love, 2005) and others are hidden. A project for a small city in Western Australia, (government report not publicly available) revealed many elements of design infrastructure are hidden either by being recoined as something else or because they happen below the 'normal' radar of economic, social and census data collection.

This paper reports a sub-set of unpublished findings and insights gained from research funded by Curtin University of Technology into design infrastructure developments in Australia, Finland, Korea, Norway and the UK against a backdrop of their national socio-economic and technological development trajectories. Two important reasons for modelling design infrastructure dynamics are the significant influence design activity has on innovation and economic development, and the identification of the most effective targets for investment and intervention in a particular national or local development context.

The project focuses on the application of System Dynamics as the primary tool for modelling the behaviour of design infrastructures, supported by other approaches to understanding complex systems such as morphological analysis. An important advantage of using a system dynamics approach to investigating design infrastructure is that it provides a dynamic overview of the interactions between the dynamics of design infrastructure and socio-economic development. The research indicated that without an overview of the role and functioning of design infrastructure typical of the system dynamics approach, weaknesses in design activity are commonly identified as unconnected problems and this in turn leads to an over simplistic understanding in which the complex of feedback relationships associated with design infrastructure and necessary to remedying or improving the overall situation are ignored in favour of trying to 'fix' individual problems. This historically, is associated with repeated attempts to go back over the same ground, and a repeated 're-discovering' of the need for design activity in the hope that that will resolve the issues. The over simplistic approach results in an unmanaged feedback loop in which government policymakers are poorly informed about where to best invest national resources to facilitate innovation through design. Australia and Norway are good current examples of this process, as is the UK from around 40 years ago to the present. It is in trying to get a better understanding of the complexity of the inter-relationships between elements of design -infrastructure and socio-economic development that is the focus of the larger research project of which the material reported here is a part.

System Dynamic (SD) modelling offers several significant benefits in design research in relation to modelling design infrastructure development and the effects of investment in it. Systems Dynamics can deal with high complexity, high numbers of feedback loops and partial information. It can be used both qualitatively to identify directions of change and patterns of change, and quantitatively to identify specific levels and dynamics of change. More complex models can be built from smaller simpler model components or system dynamic modelling 'molecules', and perhaps most importantly, System Dynamics provides a strong foundation for identifying counter-intuitive outcomes in design research.

The research project on which this paper is based gathered empirical data from experts in design along with desk data to provide a foundation for modelling design infrastructure dynamics. In the secondary modelling phases the focus has so far been at the 'molecule' level, identifying particular characteristic or archetypical sub-processes and feedback loops that can later be brought together in combinations to build a larger model.

The partial models reported here were developed using Vensim system dynamics software. Vensim was chosen because of its long history, because it is free for academic use, because most other packages will import Vensim models and because it is not clear at this stage which of the more expensive industrial-scale SD modelling packages will offer the best benefits when it comes time to integrate the sub-models.

2. Sub-system elements of design infrastructure

Sub-system elements of design infrastructure were identified both in the larger research project and in the modelling phases. Sub-system elements often occur in multiple forms associated with specific benefits and needs, and interrelated with other elements of national socio-economic, technological and political infrastructure. Typical design infrastructure elements are shown in Table 1.

Table 1: Typical design infrastructure elements

Businesses that use design	Communication systems	Design associations
Design businesses	Design centres	Design education services
Design promotion organizations	Design research investment	Design researchers
Design support technologies	Design support technology suppliers	Design teams (often crossing business, discipline and national boundaries)
Designers	Design-focused investment	Distribution services
Drive to improvement in society	Government policy organisations to support design and	Manufacturing

	design research	
Marketplace for designed ideas and services	Organisations commissioning and funding design research	Organisations educating design researchers
Organisations representing design research	Organisations undertaking design research	Prototyping services
Research in other fields	Design certification	Cultural support for innovation

Each of these has multiple roles in the evolving socio-economic structures in which design activity contributes to improving individuals' lives, fulfilling national agendas for innovation and change, and creating real world social and economic benefits. The role and functioning of elements of design infrastructure are self-evidently different depending on contextual factors such as discipline area, stage in maturity of particular areas of design infrastructure, balance of national economic activity, and type and stage of national social and economic development trajectory.

The research indicated that design infrastructure of a resource-based economy with low levels of manufacturing and high dependency on imported consumer goods is typified by the characteristics shown in Table 2.

Table 2: Typical design infrastructure characteristics of resource-based economies

High levels of design activity focused on improving resource extraction and value add.	Low levels of design activity in product design arenas	High levels of design activity in marketing and advertising (selling imported goods)
High levels of design activity in secondary investment-related project areas (e.g. new office blocks, residential	Moderate to high levels of design activity in developing retail centres	Design associations primarily focused on providing services to designers in the

accommodation and interior design refurbishment from reinvestment of pension funds and asset gains from resource sector).		resource sector
Low general awareness of the role of design in social and economic development	Low levels of institutional support for design activity outside resource sector.	Low levels of awareness of the role of design activity in creating a knowledge economy

3. Morphological analysis

Understanding the complexity of roles of different design infrastructure elements is facilitated by development of characteristic or archetypical sub-types of design infrastructure elements. The 'broad brush' element categories of Table 1 may each contain a very wide range of sub-types. In design teams, for example, there are enormous differences in practice, form, resource needs and business networks between say a 200 designer engineering design team and a 2-person fashion design team. In parallel, the dynamic characteristics of design infrastructures can change quickly. For example, the last 50 years in Korea and Finland have seen dramatic changes in design infrastructure forms.

The high level of change of organisational form and purpose of design infrastructure elements presents a problem for design researchers in getting a big picture to make models of the situation.

3.1 Example: design in organisations

A survey of design activity in a fast-growing peri-urban region of Australia in 2005 categorised businesses in terms of their *use* of design activity (Table 3).

Table 3: Businesses use of design

Businesses whose primary function	Businesses that provide design

is to provide design services	services as part of their portfolio of services (e.g. ‘design and build’ civil construction consortia)
Businesses that provide design services incidentally and tacitly as part of providing something else (e.g. landscape gardeners, lawyers, doctors, managers – professionals who se services require internalised diagnosis and design of solutions)	Businesses that are primarily only users of design services (e.g. petrol stations – using advertising , stationery, building design etc)

Differentiating between the roles of design activity in this way helped local economic development planners have a better picture of the dynamics of change as this peri-urban region transitioned towards becoming a knowledge-economy rather than a primarily horticultural/fringe agriculture region. This knowledge-economy transition is seen as one of the few potential options for socio-economic improvement in peri-urban development.

4. Causal loops and counter-intuitive analyses

The process of modelling design infrastructure dynamics must be undertaken in a way that can address a high level of complexity because of the high number of different system elements each with a high variability, the large number of feedback and feed forward loops; and the significant level of expected counter-intuitive findings. This means that in system dynamic terms, it is necessary to build models of smaller chunks of individual sub-systems.

The development of a system dynamics model has several steps including:

- Use empirical data to map out the relationships between elements in sub-systems in terms of qualitative causal loop diagrams
- Identify typical behaviour patterns and potential counter-intuitive behaviours
- Develop and calibrate quantitative sub-system dynamic models

- Integrate the sub-system models together

The following sections describe several causal loop models of subsystems. These were derived from the data gathered about design infrastructures in the five countries that were investigated. These causal loop models form the basis for identifying typical feedback driven behaviour patterns and counter-intuitive system behaviours in these sub-systems. This latter is important.

Internationally, a half-century of experience in modelling complex phenomena have indicated the importance of identifying counter-intuitive aspects of complex systems (Sterman, 2002). Characteristically, human intuition interprets system functioning wrongly in complex feedback situations and thus results in management strategies that, over time, have the opposite effect to what was intended (Forrester, 1975). This is believed to be because human intuitive skills developed evolutionarily for making decisions about relatively simple situations, and the systems involving multiple feedback loops are not only beyond the capability of intuitive human behaviour but feedback loops that are not perceived often result in system behaviours opposite to those inferred. This problematic phenomenon is expected to apply in the case of design infrastructure analyses because of the relatively large number of feedback loops (see the following figures).

4.1 Example:

A simple example of counter-intuitive system behaviours and faulty intuitive thinking is intuiting that a simple and quick fix to improve national innovation outcomes in resource-based countries such as Australia is by investing in current design education programs. The underling faulty model of reasoning is:

‘More design’ = ‘More innovative Australian products’

Most of the current design activity, however, focuses on improving the sales of *imported* products and services. There are a relatively small number of innovative Australian companies competing against the massive Australian infrastructure for selling imported goods and services – all marvellously marketed via the skills of Australian designers. Counter-intuitively, investing in design schools has the potential to worsen the situation for innovative Australian companies because, mostly, Australian designers will be acting on the other side of the market.

Investing to improve design-related outcomes in specific sectors requires careful dynamic modelling of the systems and sub-systems shaping the outcomes. The field of System Dynamics offers well-tested tools for this type of modelling. One of the first major modelling projects using system dynamics was that which led to the report 'Limits to Growth' in 1972 (Meadows, Meadows, Randers, & Behrens III, 1972). This internationally-funded economic research project and report identified bounds on human development on Earth in terms of resource use, population, pollution, affects on the environment etc. More recently, there has been increasing interest in using System Dynamics to model product development processes to improve innovation flows, improve sustainability and reduce time to market amongst other things (See, for example, Cho & Eppinger, 2001; Helo, Hilmola, & Maunuksela, 2000).

5. Causal loop models of sub-systems

Causal loop models offer the basis for 'setting out on paper' simple flow models that describe which things connect with or cause what. In particular, they help identify feedback and feed forward loops, identify and differentiate between generators and attenuators of outcomes, and, perhaps most important, they offer designers and analysts the starting point for identifying counter-intuitive system outcomes as discussed earlier.

5.1 Model: design knowledge

Figure 2 below shows a simplified design knowledge development model with two loops.

Loop 1: (improvement through formal design education)

Design education draws on design knowledge to educate designers who produce designs that are actualised via design businesses into designed outcomes in the real world from which we perceive additional knowledge of use in design (which again contributes to design education.

Loop 2: (improvement through designers' self-education)

Designers draw on knowledge about designs acting in the real world to produce designs that become actualised via design businesses into designed outcomes in the real world from which we perceive additional knowledge of use in design (which again contributes to designers' production of new designs.

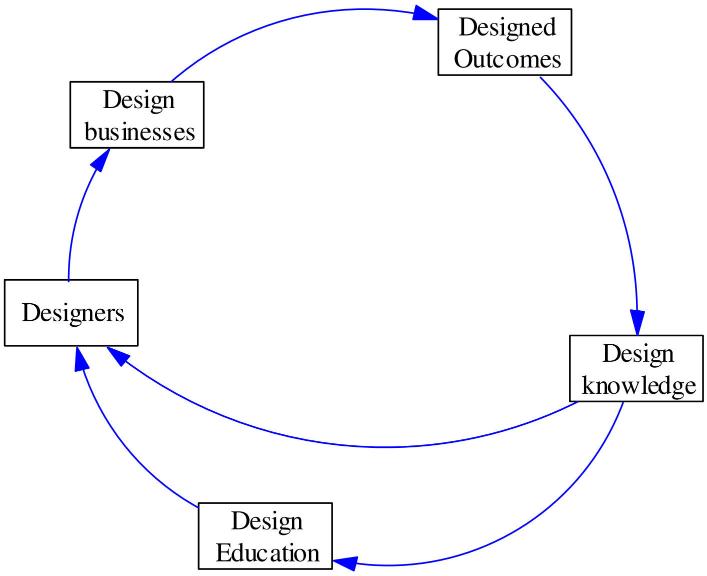

Fig 2: Design knowledge model

This model presents as a closed system and shows the circulation and development of knowledge only within the system. This is only a starting point of model development. In real life, there are more actors, more sources of knowledge, and more processes. A more complex version in Fig 3 below includes some of these additional factors as they relate to education and training.

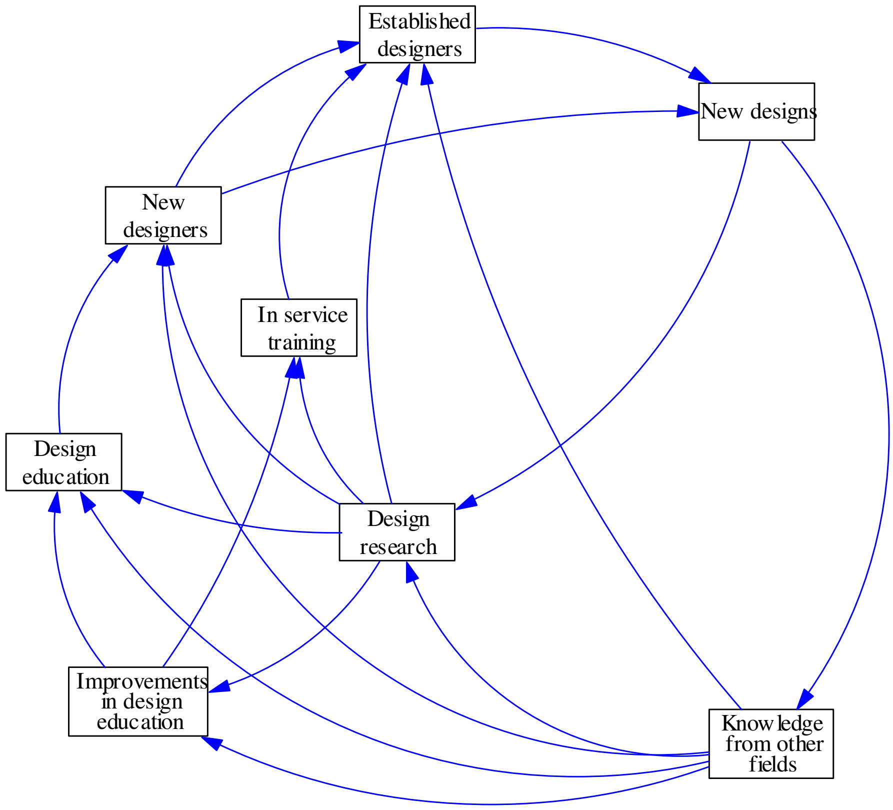

Fig 3: Model of design knowledge flows relating to design education

Complexity increased rapidly as additional elements are added. Segmenting designers into newly qualified and experienced designers is important for understanding both the maturity of a local design infrastructure and its likely conservatism. Including design research and research-based knowledge from other fields is necessary to provide increased understanding of improvements in the knowledge base of design activity. Similarly, increased differentiation of the education process into basic education, in service training (for continuing professional development) and improvement of design education is necessary because all impact differently in quality and quantity and with different levels of delay on the improvement of the skill base available for undertaking design activity.

5.2 MODEL: DESIGN ACTIVITY AND BUSINESS

In this model of the role of design activity in business, design activity acts as an intermediary. Businesses commission design work so that products can be made and sold and profit taken. This is represented in the right hand loop of Fig 4 below.

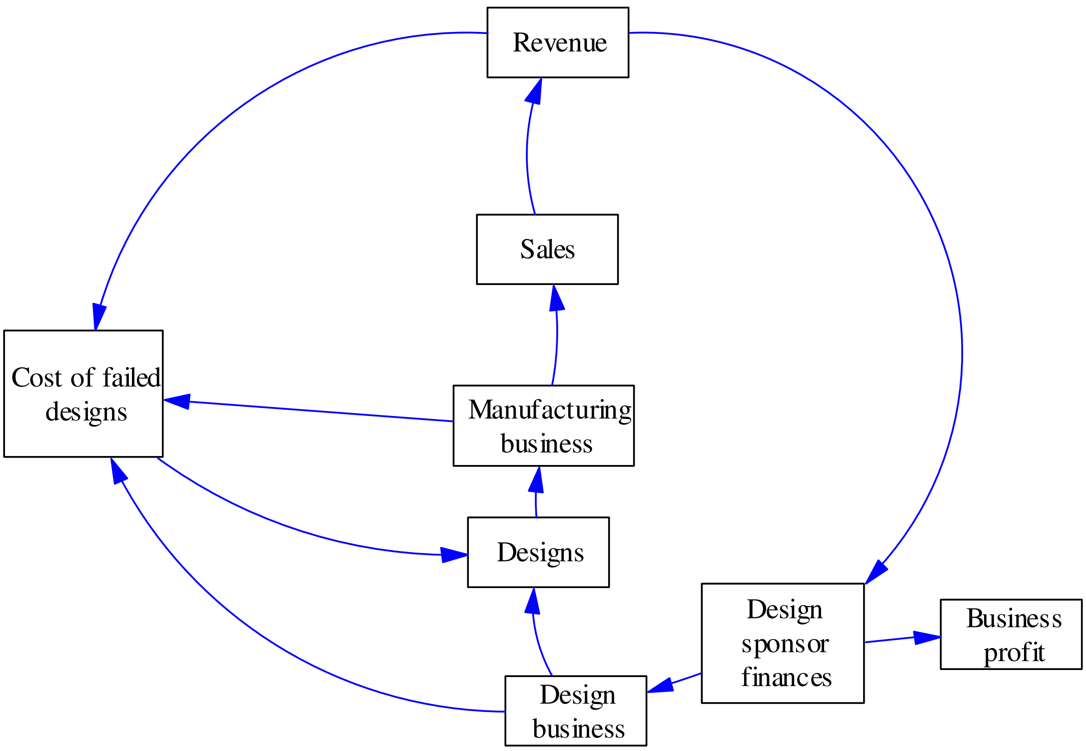

Fig 4: Model of business process for product design

The perhaps more interesting loops are to the left of the figure. Producing 'faulty ' or low performing designs result in direct costs for the design and manufacturing businesses and if the flow through the system poor designs result in reduced revenue and profits for manufacturers, design businesses and business investors(sponsors). This, classically - in systems analysis terms, suggest that efforts should be made to reduce the introduction of 'faulty' or low performing designs into the system at the design stage. I.e., in systems terms, follow the path of minimising root defect production.

In design research terms, this suggests additional effort and resources is needed in pre-design processes for identifying and qualifying the optimal regions of solution sets. This latter design activity of analysing solution set space has to date been only weakly developed in many sectors of design, in particular in those areas where the traditional focus is on satisfying design briefs or developing designs according to an integrating concept.

5.3 Model: Second-stage model of design activity and business

In Fig 5 below, the model of design activity outlined in Fig 3 has been expanded to include additional stocks, flows and auxiliary variables relating to the costs and profit taking.

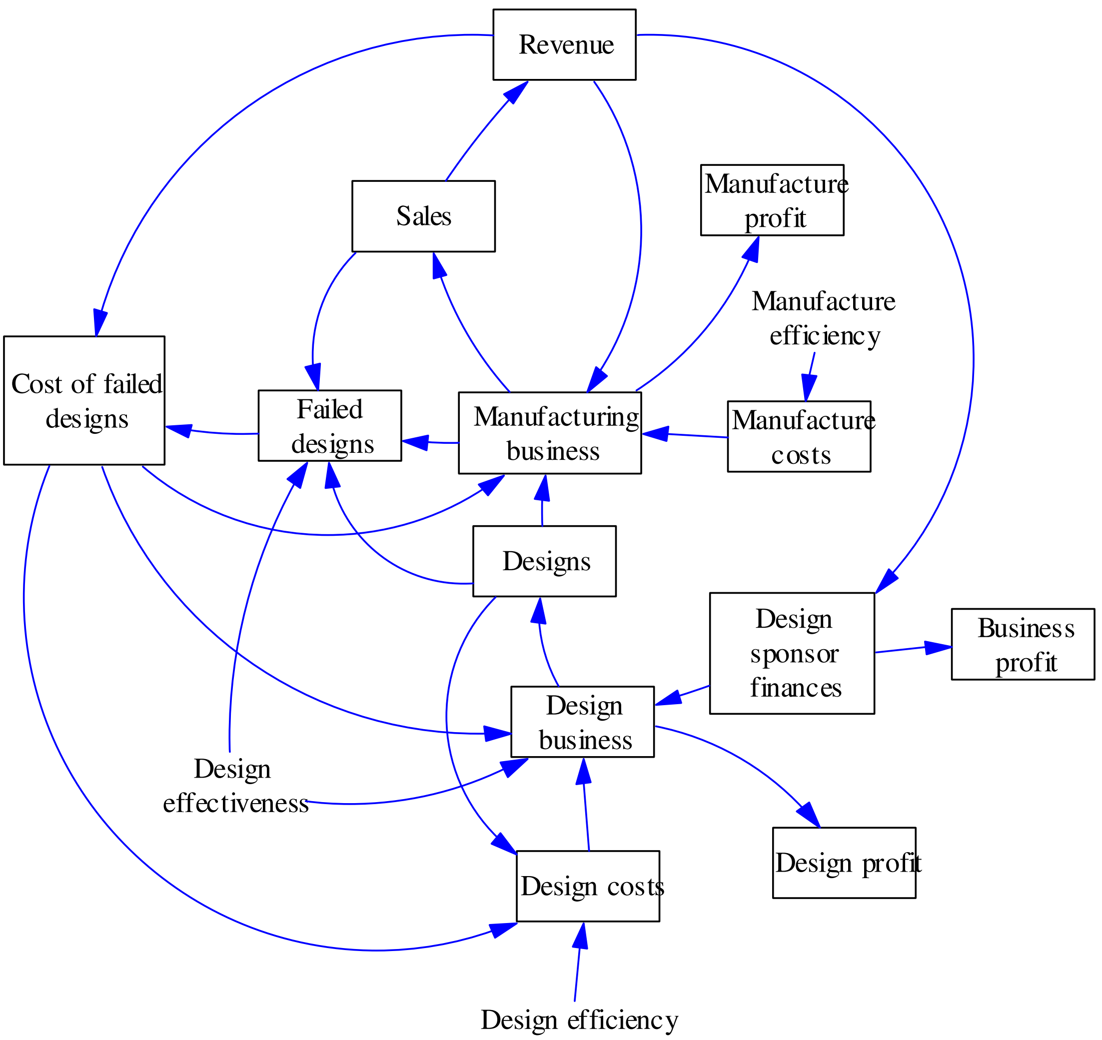

Fig 5: Second-level model of financial flows of commercial product design activity

As additional elements are added to the model, the model starts to echo a conventional business process model. This is of advantage because conventional business process data can then be used to develop the modelling equations and calibrate the model. Establishing the values of auxiliary constants such as ‘design effectiveness’. With the addition of time delays, not yet included on this model, this enables the modelling of the dynamic behavior of the system.

5.4 Model: University Education of Designers

The university education of designers is a dynamic process in which what is taught and learned evolves and changes over time to reflect changes in knowledge. In many domains of design, the reference point is the current state of the art of professional practice in that domain. This reflects the guild-like historical traditions of the craft roots of some parts of the design sector. This focus on current state of the art of professional practice as a reference for qualification can be seen in membership processes of the Institution of Mechanical Engineers, which requires new members to be assessed by current Chartered Engineers; the Design Institute of Australia, which requires new members to be assessed by experienced members; and the Design Research Society, which requires its Fellows to be assessed by existing Fellows.

Most university-level institutions providing design education follow the same pattern and have reference to professional practice as a reference point for their course development. Typically, the evolution and development of new curricula in design education follows a simple feedback loop as in Fig 6 below.

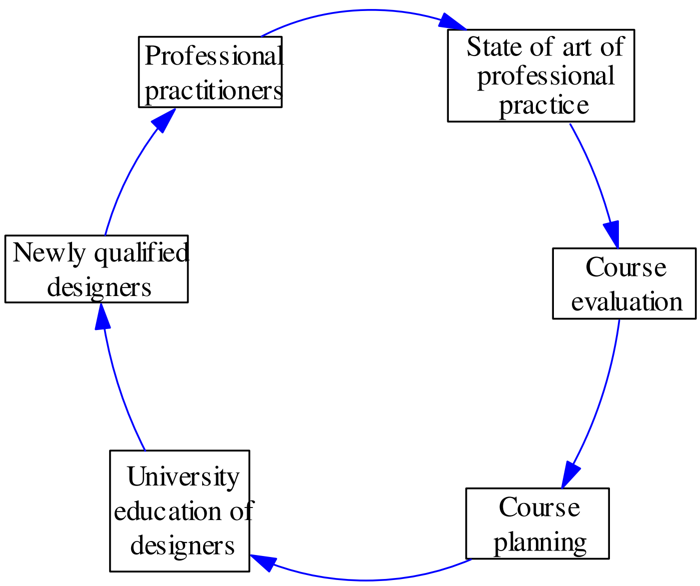

Fig 6: Feedback loop model of development of a design education course

The logic of the model looks sensible, which is why many organisations use it. A system dynamics model, however, tells a different story. Similar to any simple loop-like model of relations between entities, Fig 5 represents the situation independently of time.

If we add time delays as shown in Fig 7, it makes obvious that this conventional and tradition process of education development is slow to respond to changes in the real world.

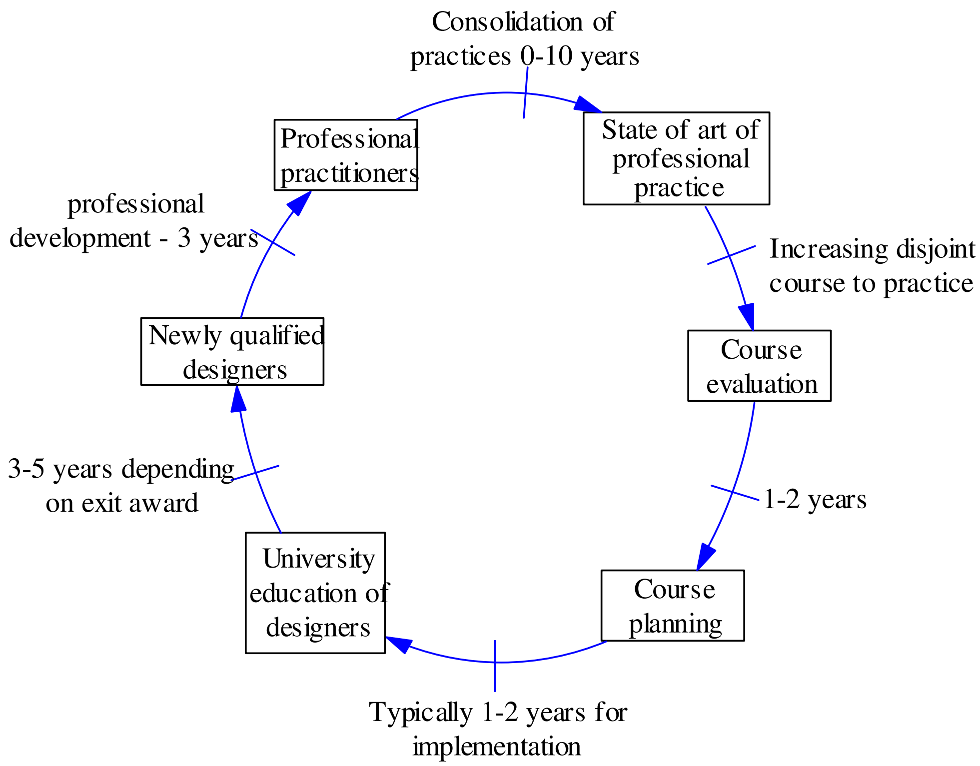

Fig 7: Feedback loop model of development of design course with time delays **added**

The delays in the process act as a brake on course development that guarantees that design education will always be out of date with what is needed. In fact, if design course development actually was developed according to the process implied by universities written descriptions, it might be expected that designers were educated with skill sets about ten years out of date for the time that they become fully-developed design professionals.

In reality, design education professionals and students uses a variety of educational kludges that reduce the problems of this delayed feedback.

5.5 Model: Design Education with forecastin

To demonstrate some of the value that the systems approach adds to understanding and improving design infrastructure processes. Fig 8 below shows an alternative that uses forecasting to enable design education to educate designers in ways that avoid them being out of date at graduation.

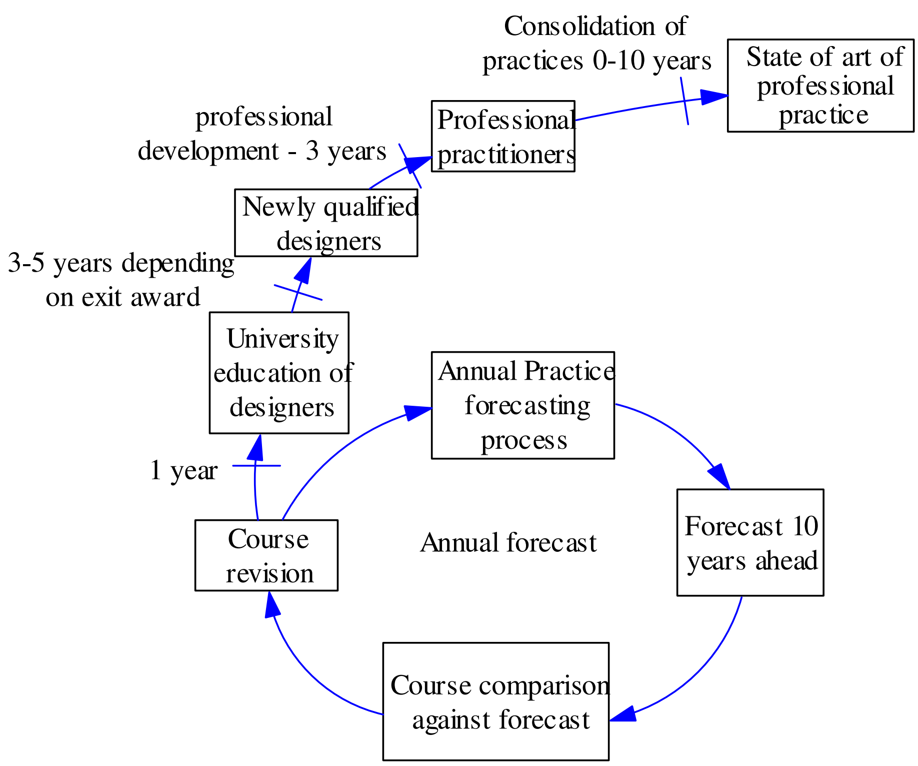

Fig 8: Development of design education using forecasting

A more successful 'real world' system would also contain some assessment over time of whether the forecasting process was producing sound forecasts at the forecasting horizon and within it.

5.6 Model: Design centres

An archetypical sub-type that emerged in research was that of design centres (Love, 2006). Morphological review of existing design centres suggested a four-part taxonomy of along a spectrum from the promotion of design activity to design research (see, Table 4).

Table 4: Design centre archetypes

Promotional Design Centre Located in prime public retail space; open and welcoming appearance; present aesthetically pleasing displays of designed products, storyboards, graphically enhanced drawings, photos and 3D displays of design representations. This type of design centre has two important roles. The first is to explain to business how other businesses have benefited from using designers in terms of: improved competitiveness; improved profitability and growth; environmental and social responsibility; and improved sustainability. The second is to promote government support programs for using design services and improving design activity.	*Design Services Centre* Provides advanced facilities and expertise for the designing, prototyping and testing of a wide range of products and services. This would be expected to be located in a mixed office and technology environment such as in a technology park. The services provided might include: rapid prototyping services; access to in -house product designers; access to useability testing facilities and evaluation and measuring facilities; access to 3D development software, CADCAM software; extensive access to information needed for designing; focused access to expertise in wide range of discipline areas, e.g. first class industry specialists and academic researchers.
Design Advice Centre	*Design Research Centre*

Provides straightforward advice about design and about access to design resources. Operates from an easy-to-access office environment. This type of design centre would be expected to offer access to expertise in general product design; design processes: innovation processes; patents, copyright, and design rights; and business development.	Provides two services. The first is as a contact point for arranging design-focused research to be undertaken, typically under contract, perhaps subsidised by a government funding support. The second is to make available, and facilitate access to, an extensive body of up-to-date design-focused research findings.

Design centres typically act as a cornerstone of mature approaches to developing national design economies. In many ways, the presence or absence of design centres and government design policy units act as an indicator to differentiate between mature first-tier design-focused knowledge economies and second-tier developing design economies.

Like many of design infrastructure elements discussed above, the roles of design centres are systemically complex when viewed in detail. Causal loop diagrams, however, offer a way to understand their relationships with other elements in a design ecology in ways that can flow naturally from the simple to the complex, and from the qualitative to the quantitative.

In the case of the simple system diagram of relationships for a 'Promotional Design Centre (PDC)' as described below (see Fig. 9), the role of the PDC is typically catalytic at the locus of several positive feedback loops. Of special interest are the multiple loops involving the design centre, socio-economic benefits and government design incentives. A primary driver of governments' behaviours is election. Satisficing of socio-economic benefit gains can lead to governments' redirection of the resources for design incentives into other programs, as happened at various times in the UK over the last three decades.

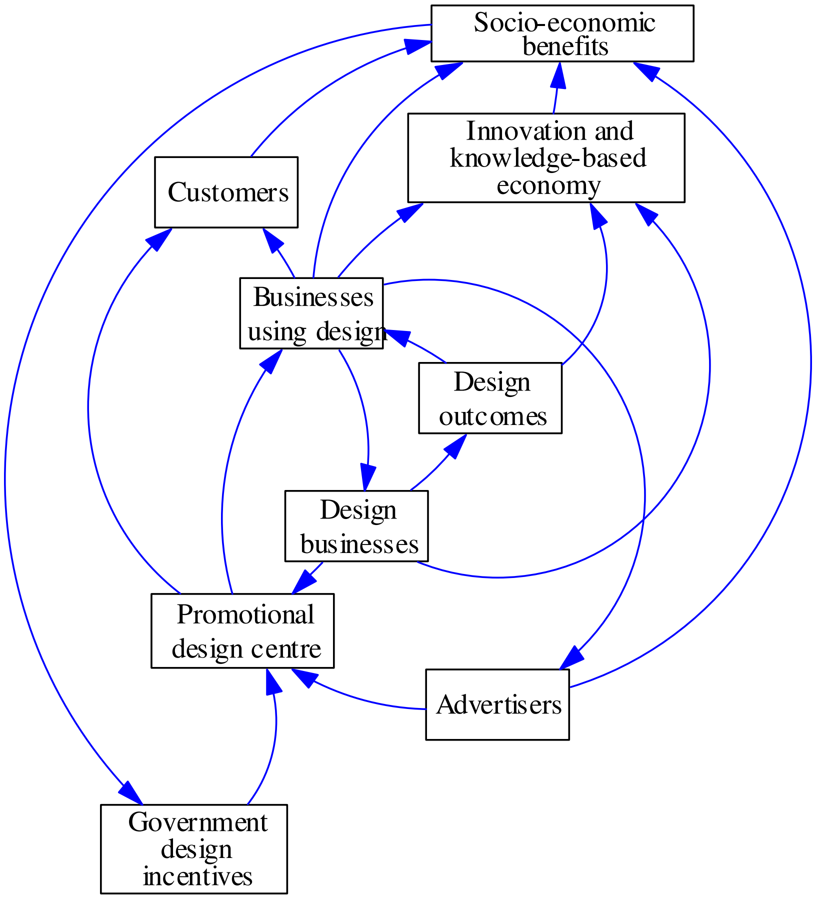

Fig 9: Model of relationships involving a 'Promotional Design Centre'

A further advantage of using this system dynamics approach to modelling the roles and relationships of design centres emerges when it is applied to all four design centre types (for brevity only one has been included here). The technique provides a clear and very visible means of means of differentiating the roles, purposes, activities and relationships of the four different types of design centre.

6. Conclusion

This paper has outlined some aspects, findings and analytical techniques using data from research funded by Curtin University of Technology exploring the development dynamics of national design infrastructures in Australia, Finland, Korea, Norway and the UK.

System Dynamics modelling emerged as an effective tool for mapping and analysing relationships and causal behaviours of national design infrastructures. Its use provided the basis for identifying useful sub-system archetypes that are transferable between national and local case studies. The system dynamic software-modelling framework also provides the means by which sub-system models can be seamlessly aggregated into larger models and preliminary qualitative causal models can be calibrated and quantified into predictive models based on empirical data. The approach was found to be useful in identifying counter-intuitive relationships and outcomes. Further, the modelling method produced visually useful representations helpful to discussing complex interrelated situations and causally related behaviours and outcomes in studying design infrastructures and their behaviours.

7. References

Cho, S. H., & Eppinger, S. D. (2001). *Product Development Process Modeling using Advanced Simulation*. Retrieved 30 May 2007, 2007, from http://function.basiceng.umr.edu:16080/asmedtm/misc/2005/best_papers/(2001)%20DTM-21691.pdf

Forrester, J. W. (1975). Counterintuitive Behavior of Social Systems, 1970. In J. W. Forrester (Ed.), *Collected papers of Jay W. Forrester*. Cambridge Massachusetts: Wright-Allen Press Inc.

Helo, P., Hilmola, O.-P., & Maunuksela, A. (2000). *Modelling Product Development Productivity with System Dynamics.* Paper presented at the Sustainability in the Third Millenium, Bergen, Norway.

Love, T. (2005). Design Infrastructure: Australian Developments. In *2005IDC New Design Paradigms Proceedings* (pp. N00000808ATLIP00000972.pdf [CDROM]). Douliou, Taiwan: National Yunlin University of Science and Technology, Taiwan.

Love, T. (2006). Design Centres as Elements of Design Infrastructure. *SEEDesign Bulletin (Design Wales)*(2), 3-5.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). *The Limits to Growth* (2nd ed.). G.B.: Pan Books.

Sterman, J. D. (2002). All Models are Wrong: reflections on Becoming a Systems Scientist. *System Dynamics Review, 18*(4), 501-531.