CONSTRUCTION INNOVATION USING TRIZ

Conall Ó Catháin[1] and Darrell Mann[2]

1 Queen's University, Belfast, N. Ireland.

2 IFR Consultants Ltd., United Kingdom.

TRIZ, the Theory of Inventive Problem Solving, is the most comprehensive systematic innovation and creativity methodology available. Guided by a strategic philosophy, the method works by restating the specific design task in a more universal way and then selecting generic solutions: from identified principles, from previously-codified evolutionary patterns, and from databases of designs and patents gathered from a wide range of technologies. Initially developed for engineering design, TRIZ has been applied to a wide range of problems. The work reported here shows that the method can generate innovative Construction solutions while reducing risk. The authors applied the method retrospectively to the design of a complex part of the façade of a recently-completed building, showing how use of TRIZ could lead to a simpler and more robust solution. The method was introduced on an ad-hoc basis to a number of postgraduate architecture students, with a limited amount of tutoring. In most cases TRIZ produced great enthusiasm and creative output on the part of the students, who applied TRIZ to a variety of tasks, including planning, detailed design and façade design. One of the most powerful notions in TRIZ is the concept of Ideality. Imagining designs which gives us all of the "good stuff" we need, without producing any of the "bad stuff" is a strong starting place for design. TRIZ produces solutions that are often highly sustainable. It is a completely open approach that amplifies individual creativity, rather than limiting exploration to a narrow solution space in the way that traditional methods do. Furthermore, it is not necessary to be highly experienced in the use of TRIZ in order to generate creative results.

Keywords: TRIZ, Ideality, Innovation, Design, Architecture.

BACKGROUND

Architects have come in for a lot of criticism from disappointed clients. Ó Catháin (2003) has suggested that the studio-based type of training peculiar to architecture is a major cause of this, leading to an unsystematic, intuitive approach to design.
"It seems that architects rarely use information which is not totally essential for the basic completion of their tasks. Architectural education does not seem to have inculcated a systematic and analytical structure for the use of distinctively architectural information. Thus it is difficult to construct any notion of generic information ..." (Ó Catháin & Howrie, 1994).

Architects generally do not use systematic or formal design methods. They have preferred to sketch and 'worry' the problem until inspiration strikes. This somewhat haphazard approach seems to have several undesirable consequences:
1. It can take a long time to find a solution. Criteria are vague and there is no stopping rule. Continual design changes also cause problems for others in the supply chain.

2. It tends to produce concentration on style or visual imagery. With no formal method the designer often studies 'precedents' for inspiration, for opening up possibilities.
3. It is a move away from the client's requirements. Since the designer cannot proceed in a logical manner from the requirements to a design (Ó Catháin, 1984), there is less incentive to keep them uppermost in his mind. Some experienced clients have have advocated keeping the architect away from the drawing board for the first month in order to learn about their business! (RIBA Strategic Study, Phase 2, 1992-4).
4. It is tending to lead to the loss of the brief development function. Astute clients now employ people to develop briefs that focus on what functions are required to be accommodated rather than using a schedule of accommodation as a surrogate brief.
5. It treats technology and process matters superficially. The mainly visual way of working dates from the time when the salient aspects of a design could be adequately covered by drawings alone. For a long time now architects have relied on others to complete the non-visual, complex or technical aspects of their designs.

The last point is corroborated by Taleb (2008) who argues that we tend to make up stories to make facts fit, so that the 'story' makes sense. Empirical research has identified two modes of thinking, the experiential and the cogitative. He says, "most of our mistakes in reasoning come from using System 1 [experiential] when we are in fact thinking that we are using System 2 [cogitative]. … Since we react without thinking and introspection, the main property of System 1 is our lack of awareness of using it! … Much of the trouble with human nature resides in our inability to use much of System 2, or to use it in a prolonged way … we often just forget to use it."
This starts to explain why designers may feel overloaded and may oversimplify the problem in an attempt to make headway, why they may reject information because it is too difficult or time-consuming to gather or incorporate. It explains the sometimes rather slack connection between external reality – particularly the client's – and their design intentions. Architectural designs typically have very large numbers of variables and it is simply more congenial to stay inside the architect's 'comfort zone' pursuing lofty architectural objectives rather than try to keep all those variables in one's head.

Sustainability has now become a fashion, a style even. Experts agree that it cannot be 'bolted on' but must permeate the whole design approach. Yet architects will add on a 'green' roof, wind turbines (which may never repay their own carbon debt) and photovoltaic panels to conventional plans, with little or no idea of their effect. Passive Solar design – the basis for sustainable design – is ignored because it does not involve visible kit or equipment that can be bolted on, does not come through a meter, and especially because it involves the discomfort of considering many variables at once.

SYSTEMATIC INNOVATION

There are obvious benefits to be gained from a design procedure that could make relevant, external knowledge available easily and quickly. We now introduce Systematic Innovation which has grown out of TRIZ, a system originally developed for engineering design from the analysis of the nearly 3 million successful solutions and more recently extended to other domains. The method is able to open up a design task and bring to bear on it a wide range of human knowledge in the form of generic information, and hence provoke highly creative, and – more importantly from the client's viewpoint, appropriate design solutions. There are many documents available in books and on line, so only the briefest of introductions is given here.

For a number of years, the authors have worked with postgraduate students, devising ways of applying Systematic Innovation to architecture, in the belief that architectural and other knowledge can be systematised and accessed, a standpoint explicitly opposed to the traditional architects' fear that "creativity might be undermined by knowledge," (Martin, 1966). These examples show that a rich range of creative solutions were uncovered by students with no previous experience of the approach[4].
Although there is a wide range of techniques available, it is important point to note that it is not simply a toolkit. It is a philosophy, an approach that causes us to look at problems differently, viewing the task from many directions simultaneously, and one that can bring the whole range of human knowledge to bear. Thus the creativity of the individual or design team is amplified to an extraordinary extent. Very often an appropriate solution or near solution already exists, but needs to be found.

FIVE PILLARS

There are five "pillars" of the method. It is important to note that one or more - or even all five - may be applied simultaneously, to generate breakthrough designs.
The first "pillar" is Function. It goes far beyond the FAST diagrams of Value Analysis. There are sophisticated methods for analysing functions and their interactions. Once functions have been identified a database is available online that gives numerous examples that may either be directly adopted or modified.

The second "pillar" is Contradictions. Pairs of design variables that are mutually "contradictory" are sought out. These pairs are fed into a table of Contradictions that yields a small number of "Inventive Principles." This "Contradiction Matrix" as it is known is based on the analysis of patents, as well as examples from Nature, and the insight that just 39 "Inventive Principles" can describe them all. The identified inventive principles are a short-cut to an enormous range of design ideas.

The third "pillar" is Resources. Any part of the design that is not fulfilling a required function is targeted as a resource that could be put to use. So the designer looks for trade-offs in order to eliminate them. This is quite subtle: the elimination of "contradictions" and "harmful" functions frees resources. Harmful functions may even be put to beneficial use (Lemons into Lemonade).

The fourth "pillar" is Ideality. This principle says that we want the function without any harm, extra material, energy use or increased cost: the "Ideal Final Result." There are many actual examples, but should such a result not emerge, it is possible to work backwards from there to a solution. It does not introduce new disadvantages. This is a powerful way of freeing blocked thinking. "Self-serving" systems exhibit Ideality, for example, self-cleaning glass. Systems evolve in the direction of increased Ideality.
The fifth "pillar" is Interfaces. The designer is guided to look at the task at different points in time, especially immediately before and after the point when a problem is

[4] Examples 1 to 3 below, have previously been reported elsewhere, but have been included here in order to give a fuller picture of the range of applications to date.

encountered. Similarly, the designer's imagination can be stimulated by zooming in and out in space and also in other categories or classifications. The Interfaces principle forces the designer to think "outside the box."

EXAMPLE 1:

Use of the 40 Inventive Principles

The first example shows the use of the method to generate a large number of creative design ideas for a public library. "The first step of analysing the problem was always done in 4 stages. I would map the problem under the headings Contradiction (between uses), Ideality (ideal system), Functionality (positive and negative functions), and Use of Resources (making full use of something). I would often find that, by the time I had written these out, I would have almost 10 solutions in mind (hence 10 principles). Testing these solutions was all that was left to do." Aherne (2004).

Principle 16: Partial or Excessive Actions.

"Move all circulation outside the building? This would give space for the ramp to be sure. Another idea here was a mechanical lift that moved on exterior structural framework, allowing the user to go wherever he or she wanted. The alternative was to concentrate the ramp circulation to the main atrium area. … what I did in the end."

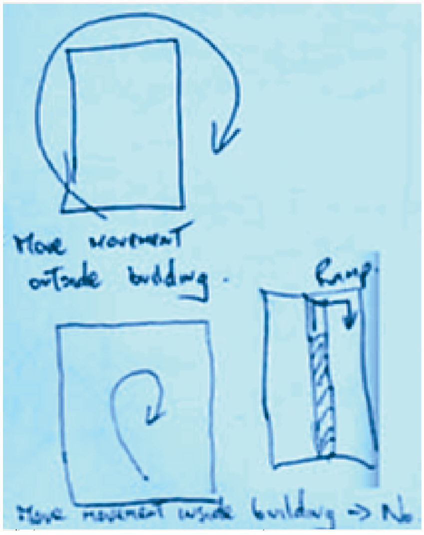


Figure 1. Illustration of Inventive Principle 16: Partial or Excessive Actions (after Aherne)

This is one of many examples showing how simple analysis generated many creative design ideas. As a by-product, the author classified each under one of the 40 Inventive Principles. "I found at many stages that the same proposed solution could be reached by means of several different principles." This repetition indicates strong solutions, and a possible basis for structuring the relation between such design concepts and the Principles in such a way that they could readily be retrieved by others later.

EXAMPLE 2:

Contradiction Elimination and Ideality

Turley (2005) focuses on sensor applications in buildings. The 'intelligent façade' design of an office building was seen as the "solution to many of the problems of an energy-efficient office in an urban site" (Loughran, 2003). Inner-city areas with poor air quality dramatically limit the use of natural cross ventilation. The building's façade consists of a ventilated double skin with electrically controlled shading devices. The building envelope is highly glazed to maximize natural daylight use. Solar screens double as light shelves preventing excessive heat gain while reflecting daylight deep into the building. A mixed-mode ventilation and air-conditioning strategy, controlled by sensors, determines when natural cross ventilation can be used. As a result of misuse and damage to sensors, the building was not operating as designed and shading control devices above the main entrance had stopped working, resulting in unintended extra cooling load. Therefore the facade was using energy rather than saving it. The student also went on to use the knowledge database part of the TRIZ toolkit to identify pre-existing technological solutions to the conflicts and trade-offs identified. He was able to make a significant number of useful suggestions to show how the building's problems were readily tackled using off-the-shelf solutions available in other sectors. Thanks to the student's grasp of the "Ideality" evolution driver – they offer the desired function without complicating the overall structure.

One particularly elegant combination of Contradiction Elimination and Ideality thinking came when he saw a need for 'large numbers of sensors and NO sensors', and then set about using the TRIZ knowledge base to see how it might be possible to have sensors everywhere without having the expense of installation and control complexity. This was achieved by placing a single sensor in a tamper-proof location within the glazed façade, remotely sensing the colour of temperature-sensitive paint.

EXAMPLE 3:

The Trends of Evolution: Improving a façade detail

The authors themselves investigated whether a construction detail which had been arrived at with much. Use of the Trends pointed the way to an elegant improvement. Figure 2 illustrates one of the 37 Trends. Like all of the trends, each of the stages represents a discontinuous "jump" from one design paradigm ("s-curve" in TRIZ terms) to another. As a system evolves from left to right, it becomes 'more ideal,' either because more benefits are delivered, or because cost and other negative aspects are reduced.

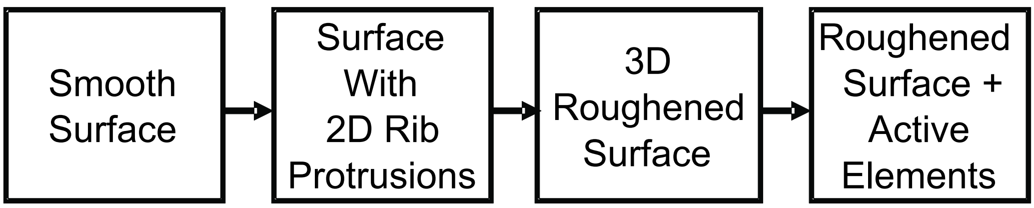


Figure 2. 'Surface Segmentation' Technological Evolution Trend

It is not immediately obvious why a system would benefit from shifting to a stage farther to the right. Based on what others have determined to be a successful direction, somewhere there is a good reason for doing so. The basic aim of this and of the other 36 Trends is to act as a signpost to help designers to create more 'ideal' solutions.
Details of all of the trends may be found in Mann (2002), which also introduces the concept of 'evolution potential.' This systematic resource identification tool works by

forcing comparisons with each of the trends, starting from the basic idea of comparing a system with each of the trends and asking how far along the trend has the system currently evolved. Figure 3 plots the resulting evolution potential analysis for the aluminium skin illustrated in Figure 4. Each of the spokes on the plot describes one of the trends of evolution (not all 37 are included in every diagram because, as is often the case, not all 37 will be relevant to any individual case).

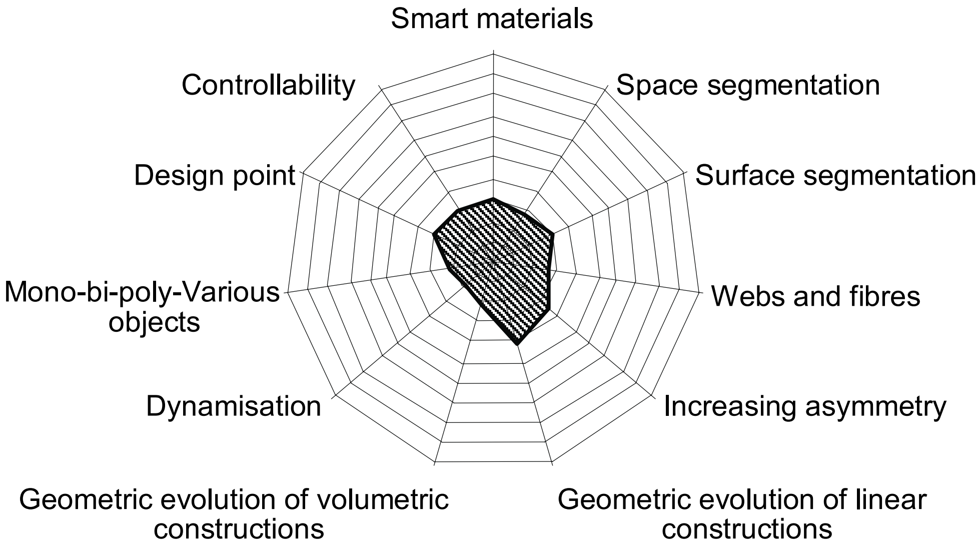


Figure 3. Evolution potential plot for the aluminium skin of the built design

There is clearly a high degree of untapped potential for improvement in the built design – in common to most systems in the building industry. The aluminium skin is still at the first stage of the Surface Segmentation Trend illustrated in Figure 2. There is likely to be an advantage in moving to the right, by adding '2D rib protrusions' to the structure. Such protrusions could strengthen the structure, and also provide a means of mounting the stone veneer onto the aluminium – without piercing the skin. Furthermore if the strengthening is aluminium and not steel it can be on the OUTSIDE so to speak; therefore the strengthening 2D protrusion could double as the stone support, eliminating several components, as well as the risk of electrolytic corrosion due to the juxtaposition of dissimilar metals in a potentially wet environment.

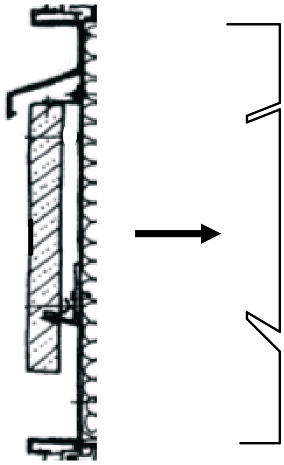


Figure 4. Evolution from complex, as-built design to a simpler conceptual aluminium skin with ribbed protrusions, based on the Surface Segmentation Evolution Trend.

EXAMPLE 4:

Applying the Trends of Evolution to Architecture

In this example, the student was first tasked with making the Trends more accessible to architects, by developing architecturally relevant 'reasons for jumps' and examples, which could "be 'tapped' into as required." At the end of this process she observed,
" … They allow other industries' ideas and thinking to be grasped easily such as aerospace and automotive industries. These particular industries are streaks [sic] ahead of the building industry. … their ideas can be easily adapted to architecture. This can spark creative and innovative ideas, which have the strong advantage that they have evolved from the trends – a proven system, and so the ideas have a much higher possibility of success. The mind is opened to a huge number of possibilities and released from the preconceived thoughts which restrain us from generating creative ideas and solutions. ... " (McLaughlin, 2008).
"Throughout the investigation, majority of the trends proved successful in generating further examples and reasons for progressions in an architectural context. This tool, in the author's opinion, would be the best tool to use for newcomers to TRIZ. The 'reasons for jumps' along with clear examples provide the designer with a logical indication of how to apply the trends with ease." (ibid).

Applying the Trends of Evolution to the "Shadow Box" problem

She used the Trends on the problem of condensation and staining inside the "shadow box" on elevations, a topic that has exercised curtain walling suppliers of late.
"A shadow box is a glass curtain wall design methodology and feature to create an expression of depth and light penetration into glass façade spandrels, column covers and other "opaque " areas where visual depth from the exterior is desired but actual vision through the glass to the interior is either not required or desired." (Boswell & Walker, 2005).

In such a small volume of air, high diurnal temperature swings and hence pressure differences can occur due to solar gain, putting strain on the components and joints.

Entry of external air introduces pollutants which stain the inside of the glazing following condensation. The following are selected from the possibilities generated by the student, with the corresponding innovation trigger named.

Current Technology

- "Apply a corrosion coating to the interior surface of the glazing so if condensation occurs staining won't." (Trend of Evolution: Macro to Nano).
- "Create vacuum within shadow box. If no air flow occurs within the box, condensation cannot occur." (Inventive Principle: parameter changes
- "Introduce a desiccant such as silica gel into the shadow box to absorb any moisture within the shadow box." (trigger not identified).

Needs further design

- "Place fine wires within the glass which will heat up … This technology is used within rear car windows and is very effective at preventing condensation". (Inventive Principle: Preliminary Anti-action).
- "Fins within panel – will break up glass facade, reduce drag and can also allow ventilation into shadow box." (Trend of Evolution: Surface Segmentation).
- "Cavity Pressurised with individual compressors which prevent condensation … . Pressurised air is fed through valves in the lower frame profile and led out at the top of the glazing system." (Inventive principle: Local Quality)
- "Glass panels are openable and can automatically open at night to allow air flow and prevent condensation. As temperature drops externally, sensors within facade open panels to allow air flow into shadow box. Hence conditions externally match conditions internally." (Trend of Evolution: Controllability)
- "Use triple glazing … to improve insulation … , hence avoiding any large temperature differentials." (Trend of Evolution: Space Segmentation)
- "Use of Insulating Glass Units, which consist of two or more panes of glass that are joined … , creating a sealed air space between them. This air space behaves like a buffer and can be filled with dehydrated air or inert gas in order to improve its performance." (Trend of Evolution: Space Segmentation)

Pie in the Sky Technology

- "Facade which behaves like the human skin. Porous glazing technology applied to a glazing system to allow air movement … without letting rain in. The pores would not be visible ..." (Trend of Evolution: Surface Segmentation/Macro to Nano).

These examples show the range of ideas that can be generated. With technical knowledge and teamwork brought to bear, many more could be generated.
For example the idea of heating the glass suggests using night cooling to heat the inner face ("Resources"). Phase change materials in the box soak up solar heat in the daytime and release it at night ("Ideality"). There is a battery of Passive Solar design techniques that might possibly be applied here in miniature. Consideration of vacuum technology suggests a different way of providing insulation avoiding its normal bulk. The TV vacuum tube industry may offer answers here – and gain a new lease of life?

URBAN SPRAWL

Problem Exploration

To find out if the approach could be applied to broader design problems, that include social and psychological issues, another student tackled 'suburban sprawl.' She started out with the 'Problem Explorer' technique which is designed to guide the user from a specific problem to a generic problem and consists of 'Benefit Analysis,' 'Problem Hierarchy' and 'Identification of Resources.'

The main problems associated with the suburban crisis had been identified as lack of housing, affordability, location, transport, sprawl, poor design, privacy, space and lack of individuality. She went on to concentrate on the privacy/space related elements. The 'Benefit Analysis' element proved unsuccessful when applied to space/privacy, so she began with the 'ProblemHierarchy' diagrams for privacy and space.

"The results from the 'problem hierarchy' can be summarised as;

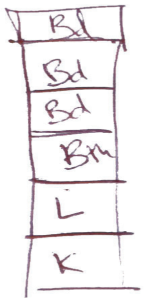
- Broader problem for privacy - Find a way of providing privacy architecturally.
- Narrower problem for privacy - Discover a means of making the space between dwellings useful.
- Broader problem for space - Investigate a new approach to urban living.
- Narrower problem for space - Provide different means of allowing growth/expansion other than sprawl.

"These problems helped me to identify the areas I should focus attention on within the larger general problem of privacy and space."
Unable to make use of the Contradiction Matrix, she "opted" to use the Forty Inventive Principles. These yielded quite a number of useful ideas, too many to discuss in detail here. The following gives a flavour:

1 Segmentation

c) Increase amount of segmentation.

She proposed that living quarters be segmented into 'social' e.g. Kitchen and Living Rooms, and 'private' e.g. Bedrooms. Here the student rediscovered a planning principle widely used in non-western cultures, where houses are segregated by sex. Next came a novel suggestion illustrated:



"Three metres wide, six stories high. Stacked with kitchen on ground floor, then living room, bathroom and bedrooms. … most public space on ground floor up to the most private spaces. Individual rooms could be stacked - buildings would become taller but individual houses would still touch the ground. The basic human territorial urge for ground space would thus be satisfied."

Figure 4. Diagram of a three-bedroom house "stretched" vertically.

This diagram – not to be taken literally – is capable of generating novel, flexible configurations, particularly in the context of new thinking about megastructure, tenure and access. There could be considerable economies in placing layers of similar accommodation contiguously.

2 Taking Out – Separation

This yielded a series suggestions dealing with privacy and overlooking. She wants to, "Design a building form that will not be overlooked by neighbours," and rediscovers the traditional English terrace house! But TRIZ thinking reverses this. "In plan the more private areas could be situated to the rear." Then, using the Resources trigger, she says, "Imagine if the 'dead' wall was utilized." … "Front façades would become 'living' green entities" … "Terraces could be redesigned to offer more privacy." This sequence produces a breakthrough: Combining the above she arrives at a new urban form that starts to answer contemporary problems of higher density and privacy, even giving people opportunity of growing some food using new techniques such as grow-bags and hydroponics, with the vertical greenery helping to give privacy.

CONCLUSIONS

This work represents a major new innovation driver for the construction industry. It is a means of generating large number of creative solutions. Sustainability, in particular is built in.

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