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FAST INNOVATION OF CONSTRUCTION TECHNOLOGIES WITH COMPUTER AIDED INNOVATION TOOLS

Wen-der Yu
Professor,
Institute of Const. Mgmt.,
Chung Hua Univ., Taiwan
wenderyu@chu.edu.tw

Chih-Ming Wu
Ph.D. Student,
Institute of Tech. Mgmt.,
Chung Hua Univ., Taiwan
d09603004@chu.edu.tw

Wei-Chih Lien
Master Student,
Institute of Const. Mgmt.,
Chung Hua Univ., Taiwan
M09516016@chu.edu.tw

ABSTRACT

Innovation of construction technologies have been slow compared with other industries due to lack of fast innovation tools and systematic approach. This paper presents the preliminary result of a recent work on development of fast innovation method for construction technologies, namely Systematic Technology Innovation Procedure (STIP), in Chung Hua University, Taiwan. The proposed STIP method founds its background on three building blocks: patent analysis, Theory of Inventive Problem Solving (TRIZ), and a computer aided innovation tool. A systematic procedure that integrates the building blocks is proposed to implement fast innovation of construction technologies. A case study on building pipeline leakage repairing technology is conducted to demonstrate the applicability of the proposed STIP method. It is found from the case study that the proposed STIP method provide a powerful tool for fast innovation of construction technologies.

KEYWORDS

Construction technology, innovation, TRIZ, patent analysis

1. INTRODUCTION

Construction technology has been defined as "the combination of construction methods, construction resources, work tasks, and project influences that define the manner of performing a construction operations" [1] to "accomplish a desired aim necessary for human sustenance and comfort" [2]. It was conceived by Robert Harris that "…there is more to the construction process than just management…there is more to the construction process than just structural design or geotechnical evaluation…we need to create better methods for construction…"[3]. Technology innovation can result in revolution advancement in construction practice that traditional management techniques and other skills are not be able to achieve.

Unfortunately, innovation of construction technologies has been slow compared with other areas in Civil Engineering and other industries, e.g., Information and Communication Technology (ICT), Bio Genetic Technology, Nano Materials, etc. One of the key reasons and maybe the most important one is the lack of a systematic approach for fast innovation. As pointed out by Daniel Halpin in his speech of the Seventh Peurifoy Construction Research Award: "…we need a common framework—a common language" [4].

The research aims at responding the appeals posed by previous researchers to develop a common framework for fast innovation of construction technologies based on computer aided innovation tools. The preliminary result has proposed a Systematic Technology Innovation Procedure (STIP). A case study that applies STIP to innovate the building maintenance technology for RC embedded watering pipelines is conducted to demonstrate the applicability of the proposed STIP method.

The rest of the paper is presented in the following manner: the previous researches on construction technology innovation are reviewed in the second section with comments on pros and cons; the Computer Aided Innovation (CAI) tools and their applications in the other industries are introduced in the third section; in the forth section, the proposed systematic technology innovation procedure (STIP) for fast innovation is developed and described in details; a case study on the application of STIP approach for selected building embedded piping maintenance technology is described in the fifth section; finally, conclusions are drawn and future works are suggested for future researchers.

2. CONSTRUCTION TECHNOLOGY INNOVATION

Innovation of construction technologies has resulted in dramatic revolutions in construction practice. For example, the introduction of Portland cement in 1824 has brought up thousands of new construction technologies and equipment that completely change the way of construction engineering; furthermore, in the first quarter of the 20th century, the steel structural technology was invented and introduced to construction industry, which triggered the other revolution of construction technologies. During the late 1970's, construction industry has suffered in low productivity, hence inspired the next generation of construction innovation. Issues such as constructability [5], prefabrication, modulization [6], and automation [7] have drawn numerous researchers to devote in the innovation of construction and management processes.

In spite of tremendous efforts spent, innovation in construction industry is relatively slow [8]. Lack of a common framework, as pointed out by Halpin, may contribute significantly to this lag. Previous researchers have developed models for organization process innovation [1], technology evaluation [9], and advanced technology repositories [10]. However, few of these efforts target directly to design of new technologies. Halpin proposed a CYCLONE model for analysis of construction processes [11]. Many efforts on construction process simulation followed him, eg., COOPS [12] and STROBOSCOPE [13]. Most of functionalities of process simulation techniques are still limited to the modelling the existing processes, rather than the invention of new technologies.

Just recently, a new area of construction innovation has been developed based patent analysis [14] 15] and the Theory of Innovative Problem Solving (TRIZ) [16–19]. The former approach innovate the target technology based on existing technologies of other area, which are stored in the patent databases; the latter apply a systematic procedure to identify engineering potentially improvable attributes with tools provided with TRIZ.

3. COMPUTER AIDED INNOVATION

Computer aided innovation (CAI) is an emerging area of research for technology innovation. As indicated by the name, CAI employs computer programs to assist the innovator or inventor in creating innovative ideas and developing the physical product models. There are two groups of CAI software available: (1) Patent analysis (PA)/Patent map (PM) tools—assisting the users in searching, collecting, analyzing, and visualizing the patent data; (2) Innovative Solution Generation (ISG) tools—helping user in creating the innovative problem-solving models [20] [21]. Popular members in the former group include Derwent Analytics®, Delphion®, Aureka®, etc.; while examples of the latter group consist of Knowledgist™ , Pro/Innovator®, and Goldfire Innovator™. In addition to the patent searching and analysis functions of PA/PM tools, the ISG tools are usually equipped with innovative problem-solving methodology such as TRIZ [22].

In spite of the successful applications in other industries with the abovementioned powerful tools, computer aided construction technology innovation has yet found in literature. The CAI tools adopted in the paper consists of a commercial PA tool and an ISG tool (called Goldfire Innovator™), both provided by Invention Machine®.

4. PROPOSED SYSTEMATIC TECHNOLOGY INNOVATION PROCEDURE (STIP)

4.1. Basic Model

The basic model of STIP was derived from the systematic product development procedure of the International R&D Project Management Body of Knowledge (R&D IPMBOK) published by the Taiwan Project Management Association (TPMA) [23], a member association of the International Project Management Association (IPMA) with headquarters in Netherlands.

The basic model of STIP consists of three elements: (1) a problem description scheme; (2) a systematic procedure of technology innovation; (3) a set of criteria for technology evaluation.

In description of problem, Root Cause Analysis (RCA) Model and Function Model (FM) are adopted. The STIP procedure is described in the following section. The criteria for technology evaluation are predefined as functionality, constructability, and cost effectiveness of the innovative technology.

4.2. STIP Procedure

The proposed STIP procedure is depicted in Fig. 1.

The STIP procedure starts with targeting a problem to be tackled; then the problem is defined with key factors resulting in the problem in the Root Cause Analysis (RCA) model; in the third step, the RCA model is analyzed using PA/PM technique and the Functional Model (FM) of the problem is established with the aid of ISG tool; in the fourth step, innovative scenarios are generated based on TRIZ or other inventive principles; in the fifth step, solutions are suggested for the generated scenarios using ISG tool; finally, the suggested solutions are evaluated with predefined criteria set up in problem definition; the candidate solution that passes evaluation is recommended as the innovative technology for further implementation as the innovative technology, while those does not pass are diverted back to problem definition and the innovation process starts again in a recursive manner.

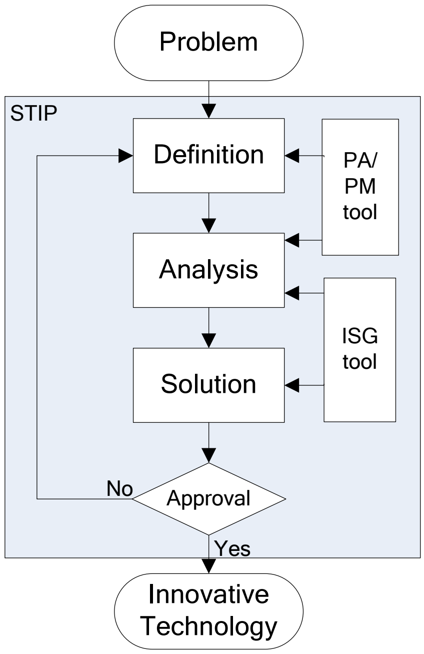

Figure 1. STIP Procedure

5. DEMONSTRATION OF STIP APPLICATION

5.1. Problem Description

Most of the Taiwan's residential buildings are built with reinforcement concrete (RC) structures. The current construction method embeds watering pipelines in the RC structure. The embedded pipelines tend to be damaged by stress due to various causes such as earthquakes. Leaking of water often causes secondary damages to the structure and interior finishing. Moreover, the unequal lifetimes of RC structure and watering pipeline also cause leaking of embedded pipelines.

As a result, pipeline leakage is omnipresent and becomes one of the major items of facility repairs.

5.2. RCA Modelling

The objective of case study is to develop an innovative technology for leakage repairing of the pipeline in the built structure. The Root Cause Analysis (RCA) model is constructed, as shown in Fig. 2, to identify the essential factors causing pipeline leakage. It is noted that the root causes for pipeline leaking are "concrete crack" or "broken pipe". The reasons (e.g., earthquake, erosion, temperature, etc.) trigger these two roots are shown below. The RCA model shows that the leakage will be remedied if the two root causes are removed.

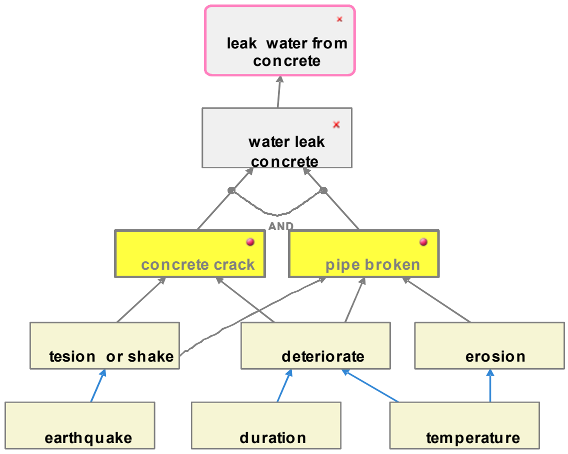

Figure 2. RCA model for pipeline leakage

5.3. Patent Analysis and Function Modelling

Based on the RCA model, candidate remedy solutions can be "sealing the concrete crack" and "fixing broken pipe". Before building the Function Model (FM), the state-of-the-art is searched from existing patents. The related patents are listed in Table 1.

After reviewing the patent documents, it is found that US4758295 (Method of stopping leakage of water in concrete structure) employing vesicant as repairing material can be a candidate solution for innovation. The device model (DM) is then built as shown in Fig. 3. The DM is one of the two forms of FM, i.e., DM and process model (PM).

The DM of Fig. 3 serves as a prototype solution to the pipeline leakage problem. In the next section, the design scenarios are generated based this prototype DM.

Table 1. Related patents from USPTO

Patent Number	Patent Title	Pub. Date
US20070249779 A1	COMPOSITION FOR, AND METHOD OF, SEALING CRACKS IN CONCRETE	2007
US6948716B2	Waterstop having improved water and moisture sealing features	2005
US6478561 B2	Kit of parts for filling cracks with foamable polyurethane prepolymer	2002
US20010054474 A1	User friendly crack-filling system and method for filling cracks with foamable polyurethane prepolymer	2001
US6309493 B1	Method for filling cracks in a concrete structure with foamable polyurethane prepolymer	2001
US5226279	Sealing method for the treatment of portland cement concrete	1993
US4758295	Method of stopping leakage of water in concrete structure	1988
US4744193	Method of sealing water leakage in concrete structures	1988
US4360994	Concrete crack sealing system	1982

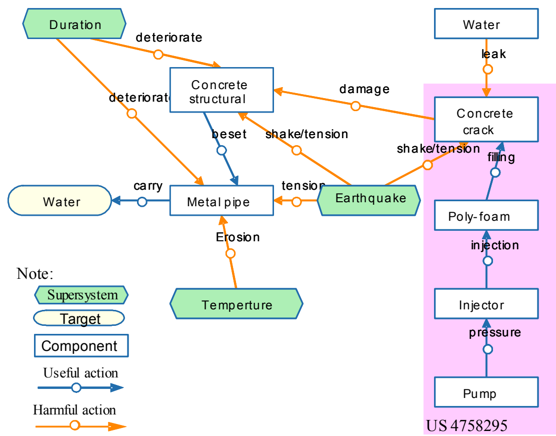

Figure 3. The device model adapted from US4758295

5.4. Design Scenarios

With the assistance of ISG tool, a modified DM is shown in Fig. 4. The new design scenario is generated by: (1) replacing the original poly-foam (a type of vesicant) with a seal material; and (2) replacing the pump injector with compressed air.

Although the new design scenario is generated, a feasible solution needs to be developed by defining the components to provide the required functions.

5.5. Solution Generation

The TRIZ method is adopted in developing candidate solution. At first, the contradiction matrix is applied to find the direction for conceptual solution. Secondary, the conceptual solution is realized with the aid of the Knowledge Base and Science Effects provided by the Goldfire Innovator™.

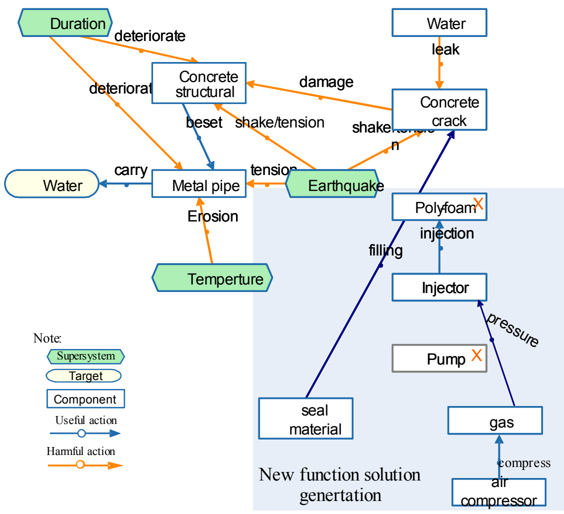

Figure 4. Modified device model

TRIZ application

The TRIZ contradiction matrix suggests that Engineering Parameter (EP) 5 (area of moving object) needs to be improved with the worsening EP 21. The referred contradiction matrix is shown in Table 2.

The conceptual solutions suggested by Goldfire Innovator™ ISG tool include three inventive principles (IPs): (1) IP19: “Periodic action”; (2) IP10: “Preliminary action”; (3) IP32: “Optical property changes”; and (4) IP18: “Mechanical vibration”.

Table 2. Referred contradiction matrix

Problem	Contradiction	Conceptual Solution
To achieve high permeability with liquid seal material; resulting in insufficient power.	Improving: EP 05 “area of moving object”	IP19: “Periodic action” IP10: “Preliminary action”
	Worsening: EP 21 “Power”	IP32: “Optical property changes” IP18: “Mechanical vibration”

Knowledge Search

Goldfire Innovator™ provides two built-in databases (Science Effect and Patent Database) for solution generation. By entering the following requests:

1. How to stop/repair leaking water in concrete?
2. How to improve liquid/ fluid mobility/ permeability?

The Science Effect database suggests four solutions as shown in Fig. 5: (a) Increasing the pressure difference increases the force on the moving fluid molecules; (b) The capillaries water droplets from a gas-water mixture; (c) Sound increases the diameter of air bubbles in water; and (d) The air bubble absorbs the air dissolved in the water.

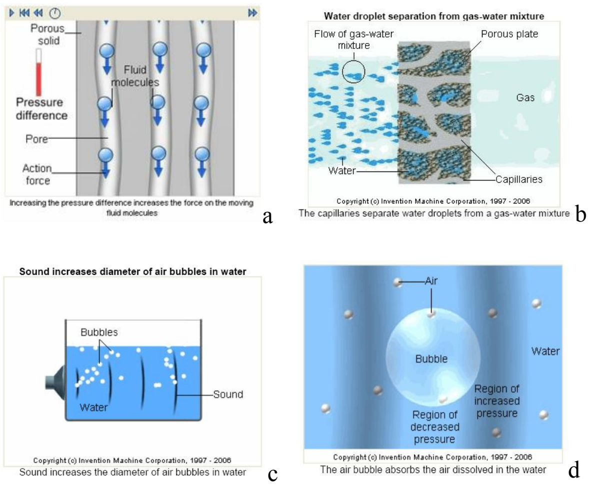

Figure 5. Suggested solutions from Science Effect database

Innovative Technology

The innovative technology is developed based on the conceptual solutions. The final solution is shown in Fig. 6.

The developed innovative technology for repairing embedded leaking pipeline in RC structure consists of four components: (1) a mixer of sealing liquid with air; (2) an air compressor supplying compressed air to the open container; (3) an open container to hold the compressed air; and (4) an ultrasonic generator to provide vibrations. Due to the limited size of the paper, details of the technology are not disclosed here.

5.6.Approval of Innovative Solution

The last step of STIP is to evaluate the developed innovative technology with predefined criteria by the domain experts. Three criteria are set to test the feasibility of a construction technology: (1) functionality; (2) constructability; and (3) cost effectiveness. The domain experts have been selected from the both academia and the industry with expertise and experience in pipeline leakage repairing. The testing results are shown in Table 3.

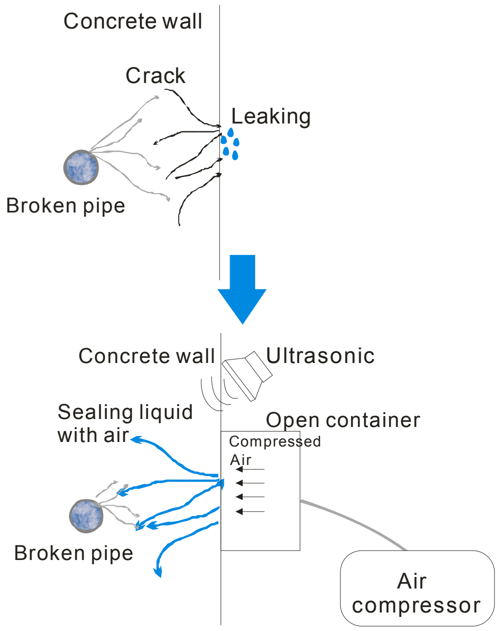

Figure 6. Innovative technology

Table 3. Evaluation of innovative technology

	US 4758295	Innovative technology
Functionality	Good	Good
Constructability	Medium	Good
Cost effectiveness	Poor	Medium

6. CONCLUSION AND FUTURE RESEARCH

6.1. Conclusion

In this paper, a Systematic Technology Innovation Procedure, namely STIP, is proposed. The STIP is equipped with an Innovative Solution generation (ISG) tool called Goldfire Innovator™ to form the first-of-its-kind fast construction technology innovation method. A case study of STIP application to the innovation of RC embedded pipeline leakage repairing technology is conducted to demonstrate the applicability of the proposed STIP. The innovative technology developed by STIP is evaluated with predefined criteria including functionality, constructability, and cost effectiveness. It is concluded that the proposed STIP provides a common framework for fast innovation of construction technologies.

6.2. Future Research

The proposed STIP method has been successfully applied to develop new pipeline leakage repairing technology; more technologies will be considered for innovation in the future including building construction technologies, civil infrastructure construction technologies, engineering professional service processes, etc.

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