The Evolution of Construction Accident Causation Models

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Abstract

Construction accident rates have remained unacceptably high in Hong Kong. Despite huge sum of money in implementing safety tools by contractors and developers, the total compensation remains high. Likewise construction academics have developed many accident causation models in an attempt to finding out causes of accidents. This paper aims at reviewing the evolution of construction accident causation models in tandem with development in technology and procurement methods.

Keywords: evolution, construction accidents, accident causation model

1. Introduction

High accident rate in construction is a universal problem which needs to be tackled by all those concerned (Poon et al., 2008). Although in the last decade there is a downward trend in construction accidents in many places such as Hong Kong (Figure 1) due to implementation of numerous safety schemes (Figure 2), improvement in construction accidents record is still necessary. A previous research in Hong Kong has shown that an accident imposes huge cost to the society (Li and Poon, 2009a) and over $10 million of compensation was paid for non-fatal accidents each year during 2004-2008 (Table 1). The direct financial costs of accidents is only the tip of the iceberg when compared to the indirect ones. The injured employees and their families suffer from loss of earning and grief. Accidents on sites also lower staff morale, induce negative corporate image and lead to extension of time in project because of work re-arrangements (Li, 2006). This paper aims at studying and analyzing the evolution in accident causation models.

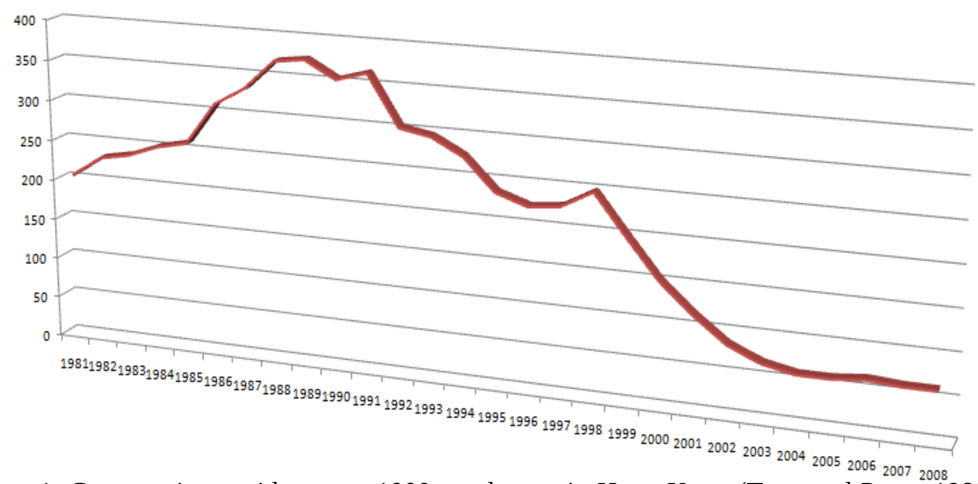

Figure 1: Construction accidents per 1000 employees in Hong Kong (Tang and Poon, 1988, Poon et al., 2008, Lee, 1996, Hong Kong Labour Department, 2009).

Figure 2: Construction Accident Rates and Safety Scheme (Rowlinson et al., 2009)

Table 1 Construction accident compensation in Hong Kong (Li and Poon, 2009b).

Year	*Total number of non-fatal accidents*	*Total PSLA ('000)*	*Total loss of earning ('000)*	*Total loss of earning capacity ('000)*	*Total Special damages ('000)*	*Total Future treatment ('000)*	*Total Deductions from ECC and victims' faults ('000)*	*Total sum of compensation ('000)*
2008	*29*	*6,779*	*26,964*	*267*	*610*	*584*	*4,005*	*32,443*
2007	*16*	*3,400*	*13,980*	*950*	*530*	*279*	*890*	*15,937*
2006	*19*	*7,260*	*20,234*	*875*	*1,378*	*2,669*	*7,640*	*39,643*
2005	*23*	*6,085*	*24,645*	*2,404*	*506*	*382*	*7,771*	*25,725*
2004	*14*	*2,940*	*11,283*	*431*	*211*	*116*	*5,174*	*10,998*

2. Changes in construction industry 1960 – present

2.1 From low-rise building to tower of Babylon

In early 20th century, structural members were designed to carry primarily the gravity loads. Advances in structural design and building materials reduce building weight; taller building construction which can house more people has gained its popularity. Among the fifty tallest buildings in the World, only one was constructed in 60's and the majority were constructed in 80's and afterwards (Graven, 2009). Nevertheless, building slenderness increases also implies that lateral loads consideration becomes more important (Gunel and Ilgin, 2007).

2.2 From traditional procurement to integrated procurement

Before 80's, building firms enjoyed post-war expansion due to rebuilding, capital investment catch-up and increasing levels of immigration, which provided economic buoyancy. Clients were led by their design team -- they were not encouraged to be involved in a significant degree during decision making in design and construction, design and construction were separated (Smith et al., 2000). Between 1980 and 1999, traditional procurement method was losing ground (Franks, 1998), design and build gained popularity. The time, cost and quality became part of the construction service ethos. Since 1999 practitioners in Australia and UK, Latham stressed more on construction productivity and efficiency and multi-skilling of the trades to reduce disputes between unions and trades (Smith et al., 2000). Clients seek solutions rather than pure construction services (Rowland, 2001). Concept from manufacturing such as best practice, quality assurance benchmarking and re-engineering have influenced the construction industry, pre-qualification criteria for consultants, contractors and sub-contractors adopted. Integrated forms of procurement based on the principles of concurrent engineering (CE) which promotes cooperation and collaboration between project participants from the outset of a project have been advocated. Moreover, with the assistance of the client's and project advisor's involvement during design development, the project team can jointly develop the project's goals and objectives (Smith et al., 2000).

2.3 From conventional construction method to complicated ever changing digital and prefabricated construction

Construction industry has long been regarded as a labor intensive industry. Construction of bridges, buildings, dams etc are built by a great number of workers. International Alliance of Interoperability (IAI) founded in the USA in 1995 turned on the engine of digital construction, system-independent exchange of information between all stakeholders was developed (Moum et al., 2009).

In this ten years' time since mid 90's, information technology has changed the world of construction industry. CAD drawing has replaced handmade drawing, Video conferencing has replaced frequent freight face-to-face meeting, digital take-off has replaced traditional black and white take-off, and dynamic building information modeling has replaced static building design. Within this decade, man-made construction and design methods have been replaced by "n" kinds of software for quantity surveyors, architects, engineers, form workers and architects. If we view each of these from the system point of view, there are many new born subsystems each day in different parts of the globe. The World Wide Web even helps us to share the new building knowledge in a blink of an eye. All these technologies help us build faster but complicate the whole construction process at the same time – what the best method today does not mean it is the best for tomorrow. We are all trying to catch up with the latest technology.

Moreover, all the building services installations are carried out on site before 1980, with the help of modern technology, off-site fabrication of some building services components become possible (Hui and Or, 2005). Design of tall, asymmetric and specially shaped buildings has gained popularity (Steenbergen and Blaauwendraad, 2007). Building technical complexity has also increased (Joint Cooperative Committee AIA-AGC-CEC-VSPE, 2009), profound understanding of the force flow in these types of structures is not easy as the building plan is not constant along the height of the building (Steenbergen and Blaauwendraad, 2007).

3. Evolution theory

According to Darwin, "... each new variety, and ultimately each new species, is produced and maintained by having some advantage over those with which it comes into competition; and the consequent extinction of less favored forms almost inevitably follows" (Darwin, 1859). The evolution theory of Darwin and Wallance is based on the mechanism of natural selection where such process stresses that organisms better adapted survive and breed (Toole and Toole, 1999), evolution of human is one of the very good example (Advanced Theological Systems, 2009). Lamarckian Evolution states that a change in environment may lead to changed pattern of behavior which can necessitate new use of structures (Taylor et al., 1999). Academic researchers developed construction accident causation models as early as 1960 (Figure 3). Since then, many different accident causation models appear in journals and books. Changing in building complexity due to increase in building height, construction procurement and technology has led to a change in construction accident causation models over time.

Our building and construction environment has become more complicated, so as our accident causation models.

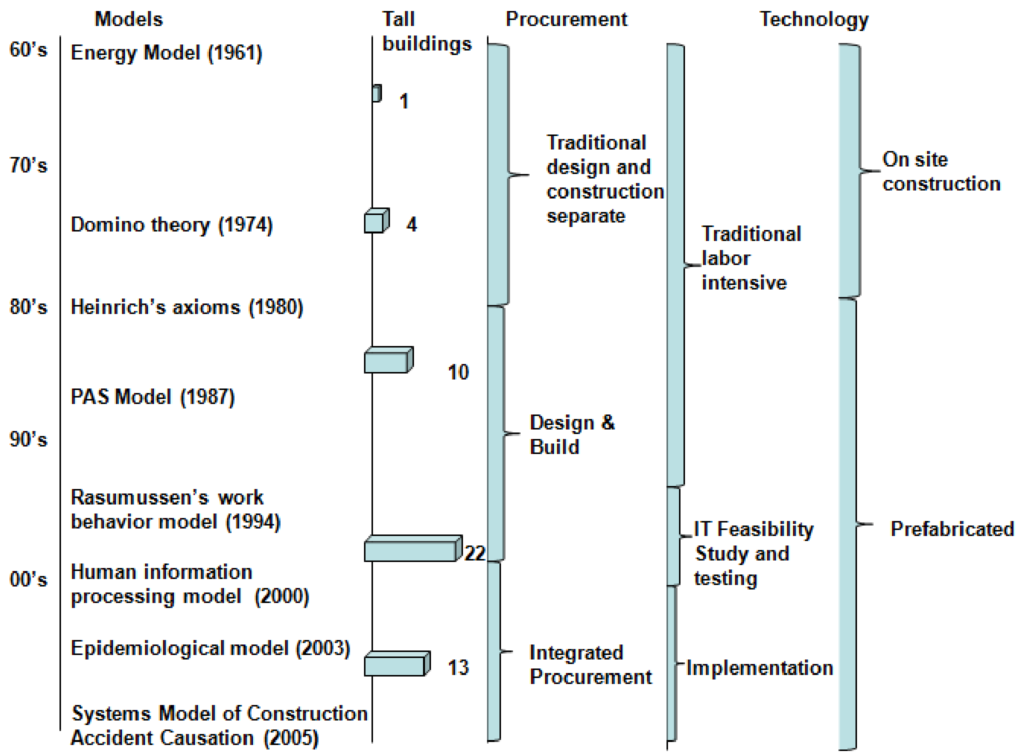

Figure 3: Accident Causation Models, distribution of year of construction for the fifty tallest buildings in the world, procurement method and technology Timeline (Graven, 2009, Smith et al., 2000, Steenbergen and Blaauwendraad, 2007, Franks, 1998)

4. Accident causation model

4.1 Energy model (1961)

Haddon suggested that accident happens when there is an excess energy transfer (Gibson, 1961). Accident causing agent such as electrical, mechanical and thermal, energy can lead to accidents. This model suggests that the occurrence of an accident basically follow the laws in Physics: it happens after there is an excess amount of uncontrolled energy and consequences depend on the amount of energy (Kjellen, 2000).

Yet this model has received some complaints from Lingard and Rowlinson (2005) who pinpoint that the abstract nature of this model fails to lay down a good foundation in identifying hazard in routine work. It also fails to suggest the appropriate safety measures under different circumstances (Kjellen, 2000).

4.2 Bird' domino model (1974)

In 1974 Bird (1974) suggested that the accident can be viewed as the last domino in the 'domino sequence' where accident is the results of a sequence of events. The first domino falls on the second one and the second one's fall lead to the fall of the third domino, so on and so forth. Bird suggested that workers will be safe so long as the first domino, i.e. site management does not fall (figure 4) (Kjellen, 2000). However, other researchers point out that there are many factors which lead to accidents. It is inappropriate to regard accidents as the last event in a sequence (Li, 2006). It can be the case like the last straw being placed on the camel.

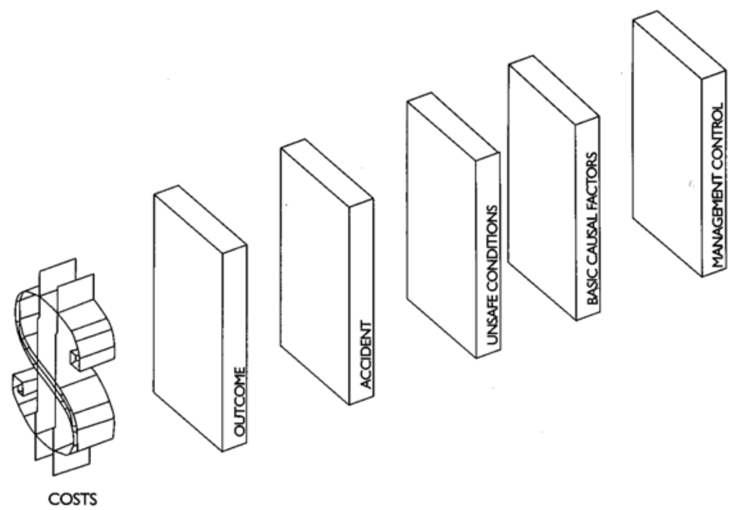

Figure 4: The Domino Sequence (Rowlinson, 1997)

Bird's contention was that these unsafe conditions were symptoms of management oversight and mismanagement in planning, organizing, commanding, coordinating and control (Fayol, 1949). Nevertheless, such model has failed to make a clear relationship between various relations between personal and organizational factors. Readers of domino sequence may misunderstand that personal factors and mental stress play the same role in accidents. Hence, such theory often leads to a false interpretation on the underlying accident causation factors. This is particularly true for those high rank officers who usually do not have really work on site and lack of safety knowledge in depth (Kjellen, 2000).

4.3 Heinrich's axioms (1980)

Heinrich et al. (1980) proposed that more than one-fifth of accidents are caused by a series of unsafe acts which finally lead to accidents occurs. He further elaborates that the degree of injury is a matter of probability. Not in the camp of Henrich, Hopkins (1995) thinks that such model is too simple and cannot reflect the real life situation where accidents are caused by interaction between a handful of causes. Moreover, Cooke (2003) points out that this model fails to show the effect of feedback in construction industry.

4.4 Potential accident subject model (1987)

Leather (1987) proposes that both endogenic and exogenic factors might affect the potential accident subject's acts and thoughts which might lead to accidents in Potential Accident Subject (PAS) model. The PAS stresses the dynamic relationship between various stakeholders on accidents, e.g. workers, managers within the construction companies or even those people who work outside the construction companies. Under PAS model, any people even the victim himself can be PAS. Furthermore, people's behaviors and attitudes are affected by reward, management systems, punishment, training, instructions given by seniors and so on. Some rewards for finishing task quickly may induce workers to take short cut and ignore the possible source of risks (Li, 2006).

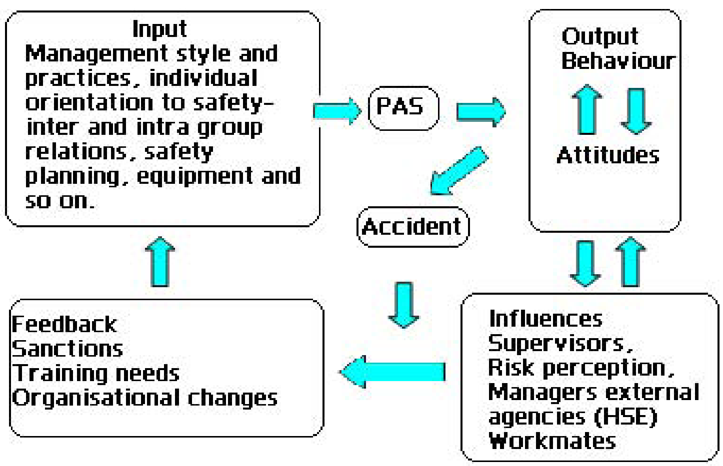

Figure 5: PAS model (Booth 2004)

4.5 Rasumussen's work behavior model (1994)

Rasmussen suggested that construction laborers' work is shaped by economic, functional, safety related objectives and constraints. The model identifies three zones: safe zone, (where the workers' behaviors are complied with safety rules) hazard zone and loss of control zone. Most of the construction managers on sites work along the cost gradient and the worker searches for the least effort gradient. All these end up with a systematic migration toward the boundary of acceptable performance only. In view of this, safety plan on sites are often designed to act against the pressures outlined in the model. Nevertheless, the pressures that push workers toward the safe zone require a continuous effort. Rasmussen therefore proposes that accident prevention should focus on error tolerant work systems development which make the boundary of loss of control reversible and visible (Mitropoulos et al., 2005).

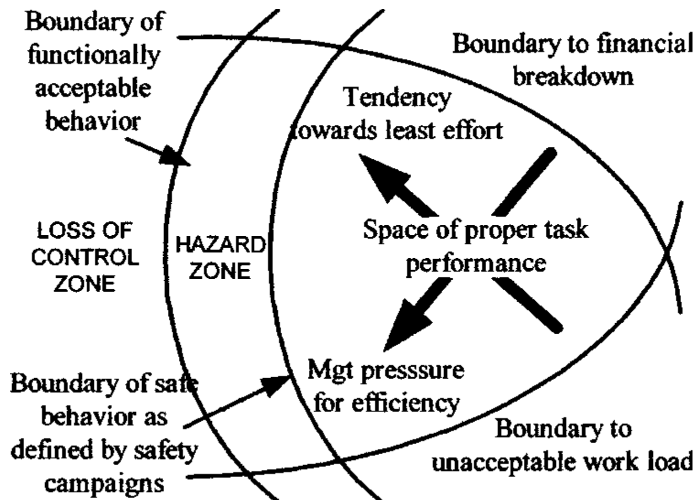

Figure 6: Rasmussen's work behavior model (Mitropoulos 2005 et. al.)

4.6 Human information processing model (2000)

Kjellen (2000) sheds light on human and environment interaction from an operator's point of view. Under this model, people are viewed as an information processor who makes their own judgment in response to environment risks, hazards or deviations. Accidents happen when people are unable to handle information under complicated circumstances. Accident analysis is one of the very good practice to identify and evaluate the safety risks on sites and provide suitable safety measures in turn.

Yet, this model suffers from two very major drawbacks. Firstly, the model only sheds light on 'cold' variables with regard to human's cognitive processes which does not conform well with real life situation. In reality, emotional variables such as threat do affect people's capability in problem solving and accident prevention. Secondly, internal information processes are absent. Interpretations by actual behavior observations and interviews become necessary which requires expertise. Because of the two aforementioned problems, application of this model is limited to in-depth investigation with experts participation (Li, 2006).

4.7 Epidemiological model (2003)

Conventional safety theorists put the lens on finding out accidents and injuries. There is, however, a trend in encompassing environmental factors which may be possible to cause an accident. Based on this idea, the Epidemiological model views accidents as a disease entity and arise as a product of interaction between the agent, environment and the host (Goetsch, 2003). Nevertheless, whether the agent in accidents can be meaningfully separated or not from its environment is in doubt (Hacker & Suchman 1963).

4.8 Systems Model of Construction Accident Causation (2005)

Building on Rasmussen's model and various construction accident causation models in the past, this model identifies various variables which influence the probability of accidents during a construction activity. While the arrows in the figure indicate cause-effect relationships, the signs show the direction of the relationship between these factors. A positive sign indicates that when there are changes in factor X, the effect Y changes in the same direction. A negative sign signifies the effect of changes in an opposite way. This model proposes that unpredictable task and environment increase the likelihood of accidents as it increases the likelihood of errors hazardous situations and the production pressures (Mitropoulos et al., 2005).

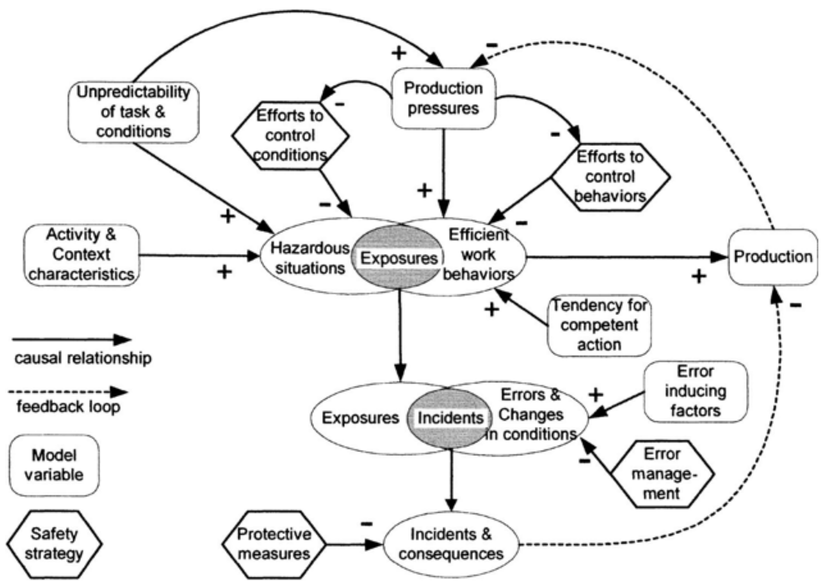

Figure 7: System model of accident causation (Mitropoulos et al., 2005).

5. Conclusions

To conclude, all the seven writers suggest that accidents are not the result of bad luck. Accidents happen because of failure in one or more than one factors. Nevertheless, when we take a closer look at the changes of accident causation model over the years from 1961, we can see an interesting phenomenon: the models are getting more and more complicated. Accident causation models before mid 80's were a lot simpler than model developed later on, i.e. complicated model "survive" in natural selection. It is predicted that future accident causation model will be more complicated when high technological tools are used on sites, construction procurement and height of buildings have changed i.e. Lamarckian Evolution also takes place in causation model.

Table 2 Changes in accident causation models

	Initial Accident Causation Models	*Latest Accident Causation Models*
Direction	*One*	*Multiple*
Categories	*Few*	*Multiple*
Factors	*Few*	*Multiple*

References

ADVANCED THEOLOGICAL SYSTEMS. 2009. *Introduction: Beyond Darwin and Intelligent Design* [Online]. Available: http://www.starlarvae.org/Star_Larvae_Introduction_Beyond_Darwin_and_Intelligent_Design.html [Accessed 16 December 2009].

BIRD, F. E. 1974. *Management Guide to Loss Control,* Atlanta, Georgia Institute Press.

COOKE, D. L. 2003. A System Dynamics analysis of the Westray Mine Disaster. *System Dynamics Review,* 19**,** 139-166.

DARWIN 1859. *The origin of species,* London, Penguin.

FAYOL, H. 1949. *General Industrial Management,* London, Pitman.

FRANKS, J. 1998. *Building Procurement Systems A Client's Guide,* Essex, Longman.

GIBSON, J. 1961. The Contribution of Experimental Psychology to the Formulation of the Problem of Safety. *In:* JACOBS, H. H. (ed.) *Behavioral Approaches to Accident Research.* New York: Association for the Aid of Crippled Children.

GOETSCH, D. L. 2003. *Construction safety and health,* New York, Upper Saddle River, Prentice Hall.

GRAVEN, J. 2009. *World's Tallest Buildings Ranked* [Online]. Available: http://architecture.about.com/library/bltall.htm [Accessed 20 December 2009].

GUNEL, M. H. & ILGIN, H. E. 2007. A Proposal for the Classification of Structural Systems of Tall Buildings. *Building and Environment* 42**,** 2667-2675.

HEINRICH, H., PETERSON, D. & ROOS, N. 1980. *Industrial Accident Prevention,* New York, McGraw Hill Book Company.

HONG KONG LABOUR DEPARTMENT. 2009. *Occuaptional Safety and Health Statistics* [Online]. Available: http://www.labour.gov.hk/eng/osh/pdf/OSH_Statistics_2008.pdf [Accessed 19 December 2009].

HOPKINS, A. 1995. *Making Safety Work,* Sydney, Allen & Unwin.

HUI, S. C. M. & OR, G. K. C. Year. Study of Prefabricated Building Services Components for Residential Buildings in Hong Kong. *In:* Hubei-Hong Kong Joint Symposium, 2005 Wuhan.

JOINT COOPERATIVE COMMITTEE AIA-AGC-CEC-VSPE. 2009. *Virginia Construction Industry Guidelines* [Online]. Available: http://www.vspe.org/PDFs/VA%20Construction%20Industry%20Guidelines.pdf [Accessed 19 December 2009].

KJELLEN, U. 2000. *Prevention of Accidents through Experience Feedback,* London and New York, Taylor and Francis.

LEE, H. K. 1996. *Construction Safety in Hong Kong,* Hong Kong, Lorrained Concept & Design Project Management Limited.

LI, R. Y. M. 2006. *Effectiveness of various construction safety measures in Hong Kong.* BSc Thesis, The University of Hong Kong.

LI, R. Y. M. & POON, S. W. 2009a. Future motivation in construction safety knowledge sharing by means of Information Technology in Hong Kong. *Journal of Applied Economic Sciences,* 4**,** 457-472.

LI, R. Y. M. & POON, S. W. 2009b. Workers' Compensation for Non-fatal Accidents: Review of Hong Kong Court Cases. *Asian Social Science,* 5**,** 15-24.

LINGARD, H. & ROWLINSON, S. 2005. *Occupational health and safety in construction project management*, New York, Spon Press.

MITROPOULOS, P., ABDELHAMID, T. S. & HOWELL, G. A. 2005. Systems Model of Construction Accident Causation. *Journal of Construction Engineering and Management,* 131**,** 816-825.

MOUM, A., KOCH, C. & HAUGEN, T. I. 2009. What Did You Learn from Practice Today? Exploring Experiences from a Danish R&D Effort in Digital Construction. *Advanced Engineering Informatics* 23**,** 229-242.

POON, S. W., TANG, S. L. & WONG, F. K. W. 2008. *Management and Economics of Construction Safety in Hong Kong,* Hong Kong, Hong Kong University Press.

ROWLAND, M. 2001. *2001 Skills Foresight The Skills for the Future of Construction* [Online]. Available: http://www.constructionskills.net/pdf/research/skillsforesightworkshop.pdf [Accessed 19 December 2009].

ROWLINSON, S. 1997. *Hong Kong Construction* - *Site Safety Management,* Hong Kong, Sweet & Maxwell Asia.

ROWLINSON, S., YIP, B. & POON, S. W. 2009. *Safety Initiative Effectiveness in Hong Kong,* Hong Kong, CII-HK.

SMITH, J., LOVE, P. D. & JACKSON, N. 2000. *Changing Construction Procurement for the Millennium* [Online]. Available: http://www.buildnet.co.za/cdcproc/docs/1st/smith_j.pdf [Accessed 19 December 2009].

STEENBERGEN, R. D. J. M. & BLAAUWENDRAAD, J. 2007. Closed-form Super Element Method for Tall Buildings of Irregular Geometry. *International Journal of Solids and Structures,* 44**,** 5576-5597.

TANG, S. L. & POON, S. W. 1988. *Project Management,* Hong Kong, Hong Kong Polytechnic.

TAYLOR, D. J., GREEN, N. P. O. & STOUT, G. W. 1999. *Biological Science 2: Systems, Maintenance and Change,* Cambridge, Cambridge University Press.

TOOLE, G. & TOOLE, S. 1999. *Understanding Biology For Advanced Level*, London, Stanley Thornes Publishers Limited.