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Rehabilitation of Existing Building Stock: A System Dynamics Model to Support Policy Development

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Abstract

The development of policies to support an agenda of urban rehabilitation as a part of a city's approach to engender sustainability is a difficult process owing to the need to consider a large number of stakeholder needs and demands. For example, Hong Kong has accumulated a considerable amount of building stock due to its rapid economic development over the last 50 years. However, despite Hong Kong's economic growth, it has overlooked the need to rehabilitate its existing building stock (i.e. to restore the condition, operation and capacity of buildings) As such, a significant proportion of Hong Kong's aging building stock is in need of rehabilitation. Further, the absence of a systemic maintenance policy, has stymied the Hong Kong's government's ability to ensure that its private building stock are resilient and adaptable for the future. Responding to the resulting need to develop urban rehabilitation policies for Hong Kong, this paper develops a system dynamics (SD) model to: (1) understand the future trend of the aged private buildings, particularly their sizes and age distribution; and (2) examine the complex relationships between allocated resources such as building professionals, number of aged private buildings and the strength of rehabilitation policies. The SD model developed can be used as a planning tool to simulate the effects of regulatory changes on aged private building stock management in consideration of available resources. The model development relies on a real-life database that can be applied to any city that faces the need to rehabilitate its ageing building stock as a part of an urban rehabilitation strategy.

Keywords: Aged buildings, policy analysis, system dynamics, rehabilitation.

1.0 Introduction

"By far the greatest and most admirable form of wisdom is that needed to plan and beautify cities and human communities." — Socrates

Urban renewal is a long-term strategy that is being embraced by many towns and cities worldwide to preserve their environment, without compromising the ability of future generations to meet their own needs (Rees and Roseland 1998; Newton et al. 2012). Such strategies are integral to ensuring a city's sustainable development, as they proactively engender improved public health and a better quality of life for all their citizens by limiting waste and consumption (Azapagic et al. 2004; Cooper 2013). In pursuance of a sustainable development goal, new and green technologies focusing on reducing energy consumption and improving the environmental impact of buildings have been widely proposed (Yiu 2007; Ascione et al. 2013). However, increasingly, the emphasis has been placed on ensuring that new building technologies are able to positively contribute to a city's sustainable development, with limited consideration being given to adapting its existing stock (Bullen and Love 2010; Tam et al. 2016).

A complex array of interrelated variables and factors need to be considered to preserve a city's existing building stock so that it conforms to regulatory (e.g., codes and standards) and environmental requirements (Bullen and Love 2011). Equally importantly, there must be an adequate supply of people who have the requisite skills and knowledge to repair and maintain the city's building stock. Notwithstanding such concerns, there has been a tendency for governments to overlook this critical issue, particularly in Hong Kong. If Hong Kong strives to champion its efforts toward sustainable development, without a strategy to ensure that it has adequate resources to meet this aim, its efforts will be futile. This paper seeks to address this void by providing a systematic analysis of Hong Kong's existing building stock and developing a system dynamics (SD) model that can be used by policy-makers to evaluate scenarios for formulating effective urban rehabilitation policies on private building stock.

2.0 Literature Review

2.1 What is Urban Renewal and Rehabilitation?

Urban renewal is a program of land redevelopment in cities that seek to redress decay and deterioration that may prevail (Egan et al. 2013). Its goal is to create livable cities through carefully planned transformation projects and well-thought-out construction assets that preserve the old and mix with the new to achieve quality living standards for its citizens while contributing to the nation's social and economic development (Boon and Sunikka 2017).

Urban renewal is generally used interchangeably with 'urban redevelopment', and 'urban rehabilitation', which are akin in nature but have dissimilar meanings. Urban redevelopment generally includes works that are relatively large scale focusing on slum clearance and the subsequent physical regeneration (e.g., heritage preservation) (Couch et al. 2011). It aims to comprehensively resolve a series of multi-faceted problems that make urban areas deprivable, by improving economic, physical, social, and environmental conditions (Ercan 2011). However, it also aims to restore the condition, operation and capacity of buildings. The redevelopment of urban assets may require demolition, restoration (Kleinhans 2004; Bernt 2009), refurbishment or retrofitting (Zavadskas et al. 2008; Eames et al. 2013). The research presented in this paper addresses a problem facing many cities worldwide, namely, how to rehabilitate their ageing building stocks as part of an urban renewal strategy.

2.2 Previous Modelling Studies

Previous urban rehabilitation modelling studies have tended to focus on energy efficiency options or technologies and related emission reduction strategies rather than the development of long-term government policies to manage ageing building stock. A range of parameters that have been employed as part of the process of modelling include (Jones et al., 2001; Sanatamouris et al., 2007: Kavgic et al. 2010; Eames et al. 2013) (1) building age; (2) type of building; (3) energy source; (4) construction; and (5) refurbishment. Using such parameters (Santamouris et al. 2007) applied a fuzzy clustering technique to identify groups of ageing buildings' energy consumption. Similarly, Kavgic et al. (2010) developed building stock models where the ageing buildings were categorized according to their characteristics and required comparable rehabilitation.

Many buildings owned by the private-sector in Hong Kong have been poorly maintained and, therefore, need retrofitting to be in compliance with building codes and regulations (Sing et al., 2015). Under Hong Kong's prevailing urban rehabilitation policy, the government serves statutory notices to the owners of private buildings ("target buildings") requiring them to carry out the inspection and repair works (Sing *et al.*, 2015). Unfortunately, there remains an absence of studies that have adequately considered the complex array of the interrelated variables (e.g. professional workforce, duration of the maintenance works, building age, and rate of demolition) that need to be considered to initiate and implement rehabilitation policies. In view of the dearth of research in this regard, this paper develops a dynamic framework to develop medium-to-long-term rehabilitation policies to address the ageing of building stock problem in Hong Kong.

3.0 Research Approach

The methodology of System Dynamics (SD) is used to determine how government policy and available resources can be used to examine the aged building problem confronts Hong Kong. SD is an objected-oriented methodology where cause and effect variables are arranged into a causal loop diagram (CLD) to represent the structure and interaction of the principal feedback mechanisms within the system under examination (Sterman 2001). Unlike traditional statistical analysis techniques such as regression modeling, a system's structural behaviour is simulated using an SD model over a specific period (Morecroft 2015). The methodology of SD also provides an effective simulation environment for exploring the environment of complex social systems and addressing long-term policy issues exhibiting dynamic complexities. This modeling approach has been widely applied to a number of problems and contexts such as policy research in health care (Homer and Hirsch 2006), environmental management (Rehan et al. 2011); and political decision making (Saleh et al. 2010; Mutingi and Mbohwa 2012). Applications of SD to urban sustainability within the extant literature have tended to focus on the following areas: (1) sustainable land use; (2) greening existing building stock (Fong et al. 2009; Onat et al. 2014); and (3) environmental quality (Guo et al. 2001).

The process to develop a SD model comprises (1) problem identification; (2) formulation of dynamic hypothesis and assumptions; (3) formulation of a simulation model; (4) model validation; and (5) policy design and simulation (Sterman 2010). The diagramming tools used to construct an

SD model are CLDs and stock and flow diagrams. A CLD consists of cause and effect variables that are connected by arrows denoting their causal influence. Each causal link is assigned a polarity, either positive (+) or negative (-) to indicate the relationship between the dependent and independent variables. In addition, the feedback process within the loop can be simulated to provide a delayed response. This delay creates inertia and oscillation within the system. For example, significant delays arise when identifying the problem of excessive building dilapidation and/ or when changing government policy to support the voluntary repair and maintenance works of ageing building stock.

Simulation is developed in the form of stock and flow variables. A 'stock' describes the system's state (such as the existing number of ageing buildings and those to be demolished) and the 'flow' represents the rate of system changes. An example of a flow is the demolition rate for ageing buildings. The pool of aged buildings can be modelled as:

$$Stock(t)=\int_{t_0}^{t}[inflow(s)\text{-}outflow(s)]ds + stock(t_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..$$
Eq.[1]

where: t_0 is the initial time; t is the current time; stock(t_0) is the initial value of building stock. Inflow(s) and outflow(s) rates represent the stock of new building completion and the pool of existing buildings, which are either 'aged', 'demolished' or 'repaired'. Inflow(s) and outflow(s) have the units of *stock (t)* divided by time. The benefits and features of SD include:

- the capacity to predict the behaviour of the non-linear system (Wong et al. 2012);
- the ability to develop a framework that examines controversial issues and enables a deep understanding of them in the context of a larger system (Heijkoop and Cunningham 2007); and
- The capacity to compare and contrast different scenarios to understand the consequences of employing various resource requirements and their impact (Heijkoop and Cunningham 2007).

An SD model is developed below to acquire an understanding of the issues that need to be considered when formulating policies to address the ageing of building stock and to support a strategy for urban rehabilitation.

4.0 Case Study

Hong Kong has a total land area of 1,104km^{2}. In 2016, it was identified as being one of the world's top five most densely populated urban areas (Planning Department 2015). In 2014, the population of Hong Kong was 7,234,800, more than a double of that in 1961 (!!! INVALID CITATION !!!). The number of domestic buildings constructed between 1961 and 1990 was fueled by a rapid increase in population and immigration from mainland China. To satisfy the demand and need for providing accommodation to its citizens, the government focused on meeting the immediate requirements. However, in doing so, the quality of buildings constructed was sacrificed (Sing et al. 2015). Moreover, many residential properties were built without any long-term government strategy to regulate and govern their management and maintenance. For example, in 2015, there were 23,800 private buildings over three storeys in height. In addition, there were 16,479 private buildings that were 30 years old or above (Table 1).

Table 1. The age profile of private building stock in Hong Kong (as at 31st December 2015)

Age	**Number of Private Buildings**	**Percentage**
<10	385	2%
10-19	2298	10%
20-29	4635	19%
30-39	5087	21%
40-49	5095	22%
>=50	6297	26%
Total number of buildings over 30 years	16,479	--

Source: Sing *et al.* (2015); Leung *et al.* (2015)

Once private buildings got occupied in Hong Kong, they were seldom subjected to maintenance (Sing et al. 2015). Ineffective regulations not only contributed to building dilapidation but also raised safety and environmental concerns. For example, during the period 1990 to 2001, a total of 143 accidents occurred due to unsafe and dilapidated building structures, which caused 101 deaths and 435 injuries (CIRC 2001). According to the (Task Force on Building Safety and Preventive Maintenance 2014), the number of accidents related to dilapidated buildings increased significantly between 2002 and 2012 (n=4,859), which resulted in 63 deaths and 602 injuries. From 2008 to 2010, the Development Bureau of the Hong Kong Government conducted an extensive condition survey of buildings aged 30 years or above, which revealed that more than 20% of them were in a dilapidated state (Development Bureau 2011).

The distribution and density of aged private buildings varies throughout different regions of Hong King. These regions are: (1) Hong Kong Island; (2) Kowloon; and (3) New Territories (see Figure 1). Sing et al.'s (2015) database of ageing building stock, which covers these regions, is used to formulate the SD model presented in this paper. In addition, the software package Vensim® Version 7.0 is used to construct the SD model.

The core of the proposed SD model is akin to the concept of the ageing chain summarised by (Lyneis and Ford 2007). According to this model, after the completion of the product ("building"), the performance of the product ("building condition") will gradually deteriorate from original status to old age until its disposal ("building demolition") or refurbishment ("building maintenance works") and leaves the whole system. This paper applies the same principle when considering stock variables "aged private buildings". The stock variable of aged buildings can be affected by both external and internal factors.

Drawing on the ageing chain concept, internal factors that influence the stock of aged building are the numbers (a) becoming aged (i.e. growth rate); and (b) of those being repaired and subject to demolition. Conversely, external factors relate to the (a) anticipated workload (i.e. the number of the buildings to be repaired per year); and (b) resources to support the inspection and maintenance works of the buildings. Anticipated workload relates to government policies for aged private buildings, for example, the number of statutory notices served to the owners for carrying inspection and maintenance works. In Hong Kong, there is a statutory requirement that building owners must employ a professional ("Registered Inspectors) to carry out inspection works for their private aged assets (Hong Kong Buildings Department 2012). For purposes of this research, the difference between the demand and available supply of building professional to inspect aged buildings is referred to as the "workforce gap".

A CLD for the ageing private building stock problem is presented in Figure 2. It can be seen that the system consists of several balancing (*B*) and reinforcing (*R*) causal loops: (1) workforce supply and demand (*B1*); (2) urban sustainability and government policy (*R1* and *R2*); and (3) government policy and owners to repair their buildings on an individual basis (*R3*). A balancing loop (*B*) indicates that it maintains the system's stability. For example, in balancing loop *B1*, if the number of buildings to be repaired increases, then workload increases, which will lead to an increase in workforce demand. This can lead to a reduction in the workforce gap (i.e. the difference between the supply and demand) and therefore reduce the number of the buildings needing to be repaired. A reinforcing loop (*R*) is one in which an action produces a result that influences more of the same action, thus resulting in growth or decline. This CLD is then validated by the experienced and chartered surveyors in the final stage of the model formulation.

Using the concept of CLD, a stock-flow model is created and presented in Figure 3, which is used to predict the influence of aged private buildings and evaluate a number of urban revitalisation policies for Hong Kong's Islands over the next ten years. The equations used to generate the SD model are presented in Appendix A, which can be amended and used to develop urban rehabilitation policies for other cities.

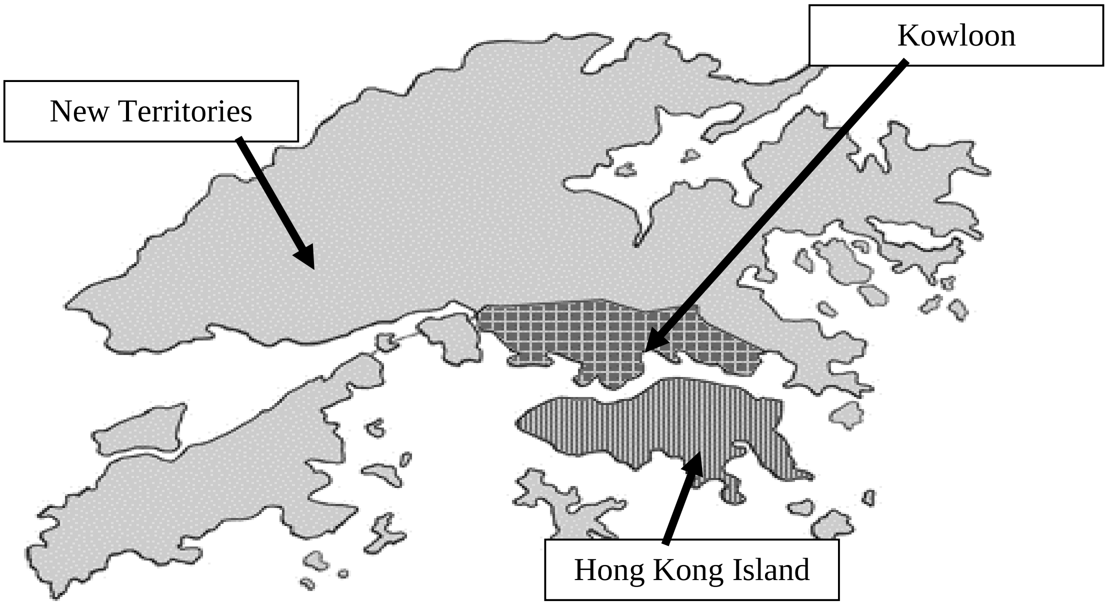

Figure 1. Three major districts in Hong Kong

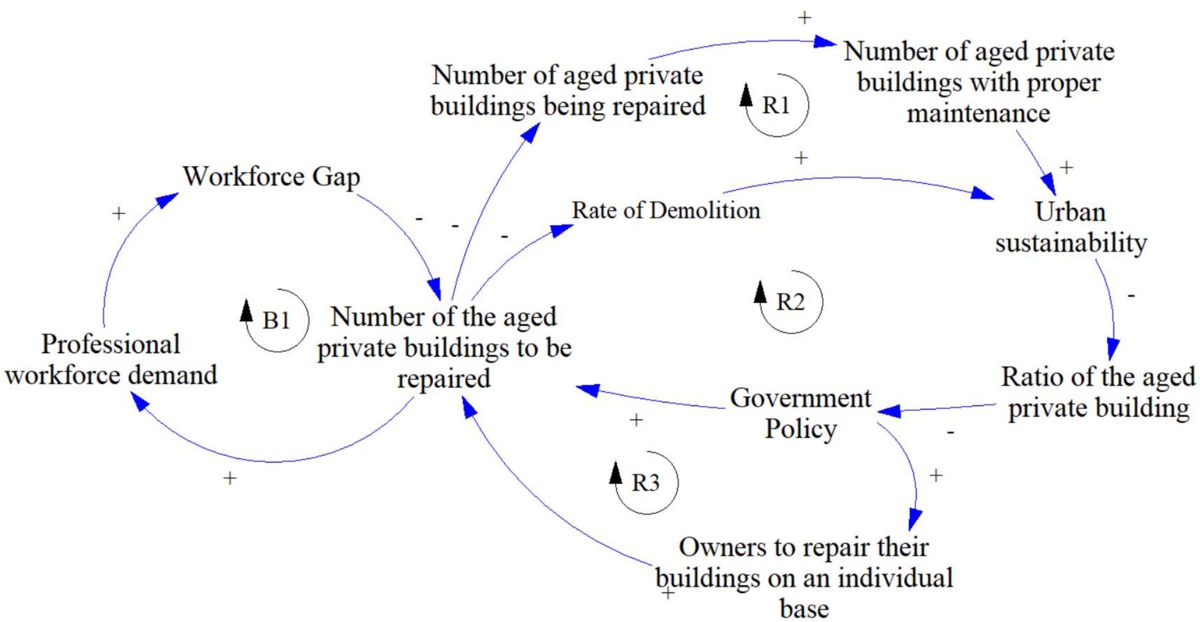

Figure 2**.** Causal loop diagram of the urban rehabilitation on aged private buildings

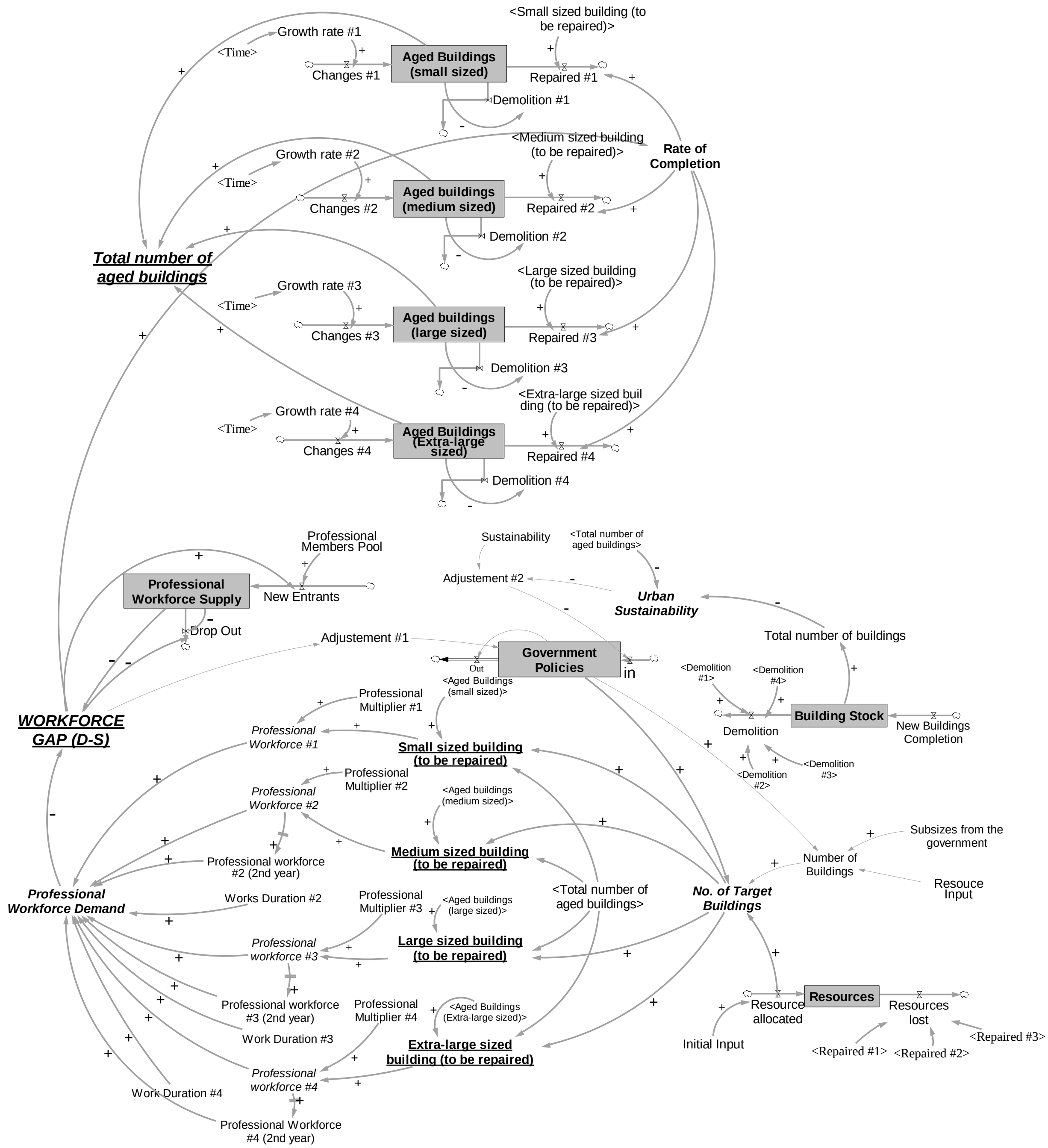

Figure 3. Model for predicting the influence of aged private building stock

4.1 Data Collection

Before introducing the key parameters used in this research, the process used to acquire data to construct and simulate the developed SD model is presented. The data items that needed to be collected from numerous sources are listed in Table 3. Initially, data were collated from technical manuals, documents and reports published by the government departments. Next, questionnaire surveys were used to obtain data about the cost and duration of maintenance works and the nature of the workforce. Finally, interviews were used to validate the developed model.

Table 3 Data collection process and corresponding key variables in the SD model

Methods	Descriptions	Key Variables
Primary data sources	Government publications and reports	4.2(a), (b), (c), (e)
Questionnaire Survey #1	Average duration, contract sum of the maintenance works. 156 questionnaires (or project records) were collected.	4.2(d)
Questionnaire Survey #2	Professional workforce for inspecting and supervising maintenance works	4.2(f)
Interview	Interviews with five chartered building surveyors who have extensive experience in maintenance works	Model validation in s.4.3

4.2 Key Variables in the SD Model

(a) Size of Building Stock

According to the local Buildings Ordinance, mandatory inspection and maintenance should be undertaken for the private buildings more than 30 years old (Buildings Department 2016). All buildings considered in the developed model adhere to this requirement. The (HKIS 2012) conducted a study of professional fee scales for building maintenance work and subsequently recommended that they should vary according to the number of units within a building. Existing building stock is therefore divided into the following categories for the purposes of the SD modelling:

- <=50 (‘small-sized’);
- 51-200 (‘medium-sized’);
- 201-400 (‘large-sized’);
- 401-800 (‘extra-large-sized’); and

- >800 (‘jumbo-sized’).

Since there were only 39 buildings with a total number of units >800 (0.2% of the total building stock), this group was excluded from the modelling process.

(b) Aged Building Stock

Reinforced concrete is the primary material used in Hong Kong to construct buildings in view of its accessibility and low cost (Tsang 2009). The typical service life of concrete is approximately 40 to 50 years, subject to climatic conditions. According to the (Buildings Department 2016), owners of buildings older than 30 years are required to undertake a building inspection once every ten years so as to maintain the condition of their building. These buildings are therefore categorised as ‘aged building’ in the SD model (Table 4).

Table 4. Aged building stock

Categories	**Hong Kong Islands**	**Kowloon**	**New Territories**	**Total**
No. of Buildings (>3 storeys)	7,965	9,274	6558	23,797
No. of Buildings, N_i (Aged >30 years and >3 storeys)	5,829 (73%)	7286 (78%)	2,466 (37%)	15,584

To deal with this aged building stock, the Hong Kong government has introduced two different approaches to deal with its dilapidated buildings (Chan et al. 2014): (1) demolish existing decaying stock and redevelop with new contemporary buildings; and (2) extend their life by renovating them. The aforementioned parameters are described hereinafter.

(1) Redevelopment of the Existing Buildings

In Hong Kong, buildings are typically designed to have a life of approximately 50 years. It is therefore expected at the end of their life that they are redeveloped as this is deemed to best economical option (Leung et al. 2015) However, within densely populated cities such as Hong

Kong, local governments may consider alternative options in light of prevailing safety and environmental issues. In Hong Kong, a majority of buildings have been financed by multi-ownership/investors, and therefore their consent is required to undertake any form of redevelopment (HKSAR 2010). Naturally, disagreements arise between owners as each has his/her vested interest at heart (Kent et al. 2002). The corollary, in this instance, is that the process associated with enacting a redevelopment program requires complex negotiations with stakeholders and thus is considered to be a long-term initiative of an urban renewal strategy.

(2) Repair and Maintenance of Ageing Buildings

Regular maintenance work can preserve a building's condition and prevent its deterioration. Such works are relatively straightforward to undertake, but the management and initiation of maintenance schedules of private property in Hong Kong pose many challenges considering the sheer number of owners that need to be consulted (Ho and Gao 2013). To assist property owners in their building management, the following three principles have been established in Hong Kong:

1. it is the owner's responsibility to maintain their building in good condition;
2. the government should ensure the safety of buildings through its statutory regulations; and
3. the government should collaborate with other partner organisations (such as the Hong Kong Housing Society) to repair and maintain the buildings owned by private parties (Urban Renewal Strategy Review 2015).

The Hong Kong government has implemented a number of policies based on the above principles (see also Table 5).

Table 5. List of the Government policies to address building dilapidated

Year	Scheme/ Programme	Target Buildings	Compulsory or Voluntary	Government Support
2012-Present	Mandatory Building and Window Inspection Scheme	Buildings aged 30 or above	*Compulsory* Local government authority will select around 2000 private buildings every year and require their owners to carry out inspection and repair works	*No*
2000,2001 and 2002	Coordinated Maintenance of Building Scheme (CMBS)	Buildings with defects in common areas and with a large number of unauthorised building works	*Compulsory* Local government authority will select around 200 private building per year for the CMBS.	*Yes* Government department will assist the building owner(s) in coordinating the required repair and improvement works
2000-2009	Large Scale Operations (1) Clearance operation of unauthorised building works (2) programmed repair of old building scheme	The building owner(s)	To reduce or remove danger and nuisance caused by unauthorised building works (UBW) by issuing removal and repair orders as appropriate and instigating prosecutions if the building owner(s) fail to comply with the orders.	No
2001 – present	Comprehensive Building Safety Improvement Loan Scheme	The building owner(s) (interest-free loan will be provided to owners of low-income category)	To provide an interest-free loan to the individual owner(s) of private buildings who may wish to obtain financial assistance in carrying out works for improving the safety of their buildings	Yes

(c) Demolition of Aged Buildings

The issue of whether old buildings should be demolished and replaced has remained a controversial issue (Bullen and Love 2010). However, demolition is often preferred if an existing building's life expectancy is estimated to be less than the new alternative (Douglas 2006). According to (Kohler and Yang 2007), buildings are demolished when they are perceived to have no value to investors and the society. The rate at which demolition occurs within a city has been identified as performance metric within urban renewal programme (Weber 2002).

To forecast building demolition trends in the next ten years, a data set containing records of demolition over the past 15 years was derived from the *Monthly Digest* as published by Hong Kong Buildings Department (Buildings Department 2005-2015). A time series model was then developed to provide a forecast of the number of buildings to be demolished from 2017 to 2027 (Table 6). The data used in this model included the quarterly time series for the number of buildings demolished from January (Q1) 2005 to December (Q4) 2015. To prevent random short-term fluctuations, a centred four-quarter moving-average technique was applied to smoothen the raw data's trend in the presence of quarterly seasonality.

Table 6. Time series model for the trend of the building demolition

District	**Time Series Model**	**R^2**
Hong Kong Island	$y = 0.089x^2 - 1.12x + 23.23$	0.82
Kowloon	$y = 0.078x^2 - 1.15x + 19.43$	0.85
New Territories	$y = 0.088x^2 - 1.18x + 20.25$	0.75

(d) Duration of the Repair and Maintenance Projects ("Renovation")

In the SD model, the ratio between the number of aged buildings and the total available stock was calculated and used to infer the level of urban rehabilitation at time *t*. The stock of aged buildings at time *t*, could be calculated as

$$B_t^A = B_t \cdot \alpha - B_t^D - B_t^R \quad \text{Eq.[2]}$$

where B_t^A is the aged building stock at time t; α is the ratio of aged buildings within the districts; B_t^D is the number of buildings to be demolished at the time, t; B_t^R is the buildings to be renovated at time t.

A delay was incorporated into the model as the renovation works cannot be immediately completed within a year. To model the renovation works' duration d, the data were collected from a variety of stakeholders (contractors) that were involved in the maintenance projects using a questionnaire survey. As noted in Table 3, a total of 156 questionnaires were collected, and the data obtained from the projects were analysed in terms of their building size, average duration, and average contract sum of the maintenance works (Table 7). Using a two-tailed significance test, all the critical values of project duration were accepted at $p = 0.05$.

Table 7. Project duration of repair and maintenance works

Building block and sizes	**No. of project data**	**Average project duration (years), d_i**	**Average contract sum (HK$M), ps_i**
Small-sized	60	0.8	6.5
Medium-sized	35	1.05	9.5
Large-sized	31	1.6	12
Extra-large-sized	30	2.0	18

(e) Estimated Number of Aged Buildings being Repaired

Besides the enforcement of the mandatory inspection scheme, owners are also required to inspect and maintain their buildings. Since they do not need to seek formal approval from the local government prior to or after the completion of the maintenance work, there is a paucity of information with regard to the number of buildings repaired by the owners each year. Since the majority of buildings in Hong Kong are financed through multi-ownership, the owners' representative seeks advice on technical queries and tender arrangements from various government departments prior to the commencement of the maintenance works. The numbers of such enquiries are then used to infer the number of buildings that will be repaired.

According to the (Home Affairs Department 2013), 132 formal enquiries, on average, were received per year between July 2012 and June 2016. It was assumed that half of these enquiries would have resulted in the self-initiation of building maintenance projects by the building owners. The number of buildings being repaired within the aggregated model was therefore set at 65 per year.

Government policies can also stimulate the owners to conduct the repair and maintenance works with the provision of subsidies or variants thereof, for conducting maintenance works. For example, one-off technical and financial assistance ("Operation Building Bright") was provided to owners of approximately 1,000 aged buildings to conduct repair works was provided between 2012 and 2014. A grant of 80% of the cost of repair of common areas (up to a maximum of $16,000) was provided to owners of each unit within their building. An axillary variable of "subsidised by the government" was used to control the number of the buildings being repaired under the above government policies. Figure 4 denotes the influence of government policies on the number of the buildings to be repaired.

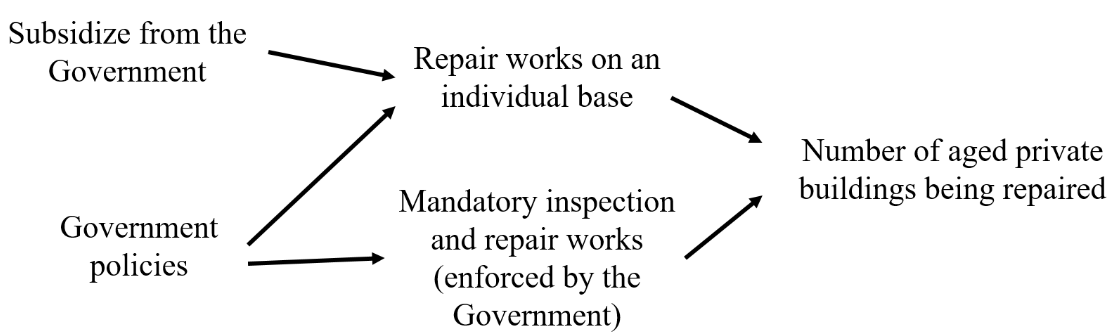

Figure 4. Estimated number of aged private buildings being repaired

(f) Workforce Allocation

The amount of repair and maintenance work ('works') to be completed depends upon the supply pool of professional surveyors that are required to inspect and supervise the maintenance works.

The demand and supply of qualified professionals to support the urban rehabilitation process thus becomes a core issue during SD modeling (Figure 3).

Undertaking the maintenance works of aged buildings in Hong Kong requires them to be: (a) inspected and (b) supervised during their repair. This is enforced by the Mandatory Building Inspection Scheme (MBIS), according to which Registered Inspectors (RI) are required to inspect and supervise repair works. The RIs are required to hold professional memberships (e.g., be a registered architect, surveyor or engineer) in accordance with the Cap 123P Building (Inspection and Repair) Regulation and to pass a formal interview.

To determine the capacity of the professional workforce (i.e. the number of the aged building they can inspect and supervise repair works), a web-based questionnaire survey utilising SurveyMonkey®) was used to collect quantitative data from practising architects, surveyors and engineers. In total, 299 questionnaire surveys were completed; 151 (51%) engineers, 129 (43%) surveyors and 19 (6%) architects. The variable of 'workforce multiplier' in Figure 3 is defined as the 'average staff hours allocated to each building' (Table 8).

Table 8. Average staff hours for inspecting and supervising repair and maintenance works

Task	**Categories**	**Registered Inspectors**			**Mean *staff hours* per building**
		Architect	***Engineer***	***Surveyor***	
Inspection	Small-sized	82	91	81	85
	Medium-sized	122	128	114	121
	Large-sized	189	198	172	186
	Extra-large-sized	272	275	243	263
Supervision	Small-sized	329	363	325	339
	Medium-sized	486	512	457	485
	Large-sized	757	790	688	745
	Extra-large-sized	1087	1101	974	1045

Using Table 6, the demand for RIs to conduct mandatory inspection could be written as:

$$\{wd_{t,1}, wd_{t,2}, wd_{t,3}, wd_{t,4}\} = \begin{Bmatrix} 85 & 121 & 186 & 263 \\ 339 & 485 & 745 & 1045 \end{Bmatrix} \cdot \left(\begin{Bmatrix} B_{t,1}^{R} \\ B_{t,2}^{R} \\ B_{t,3}^{R} \\ B_{t,4}^{R} \end{Bmatrix} + \begin{Bmatrix} B_{t,1}^{R} \cdot d_1 \\ B_{t,2}^{R} \cdot d_2 \\ B_{t,3}^{R} \cdot d_3 \\ B_{t,4}^{R} \cdot d_4 \end{Bmatrix} \right)$$

……………………Eq.[3]

subject to

$$B_{t,i}^{R} = B_{t}^{A} \cdot \alpha \cdot \partial + \phi$$

$$d_i = \{0, 0.05, 0.6, 1\}$$

where $B_{t,i}^{A}$ is the stock of aged building by their size, *i* at time *t*; d_i is a delay variable; $B_{t,i}^{R}$ is the number of the buildings being repaired due to: (a) mandatory inspection scheme; and (b) self-initiated by building owners. α is the ratio of aged buildings within each of the districts, ∂ is the target number of buildings under the mandatory inspection scheme, ϕ is the number of the buildings to be repaired. Then, the workforce gap in the SD could be expressed as:

$$WG_t = \sum_{i=1}^{4} wd_{i,t} - WS_t$$

……………………………………………………………………………Eq.[4]

where $wd_{t,i}$ is professional workforce (e.g. RIs) demand for inspecting and supervising the maintenance works of the building size, *i* at the time, *t* and WS_t is the supply at time *t*.

4.3 Model Validation

Model validation is critical to building confidence in the results produced by the simulation. The logical order of validation suggested by (Barlas 2007), which includes testing the validity of its structure and testing the accuracy of its behaviour, is adopted in this paper to test the validity of the model's structure. The individual equations and CLDs are examined using the available knowledge within the extant literature and similar real-life scenarios. In this regard, expert opinions were solicited (Goh and Love 2012). Feedback from five chartered building surveyors with more than 15 years' experience in repair and maintenance sector were collected using face-to-face interviews. They had been randomly selected from the membership list available from the official website of the Hong Kong Institute of Surveyors. They were asked to validate the loop structures (Figures 2 and 3) in the proposed SD model based on their understanding of the urban rehabilitation. For example, there was a consensus that the CLDs for workforce availability and government interventions accurately reflected existing practice. Secondly, the model's behaviour was examined by comparing the estimated values produced with actual historical data using two key indicators: (1) number of buildings being repaired; and (2) the supply of professionals from 2012 to 2016. According to (Barlas 1994), a model's behaviour is accurate when an error rate smaller than 5% can be attained. In the event, using the following equation, an error rate of 0.44% could be achieved:

$$error = \frac{\left|\overline{E} - \overline{A}\right|}{\overline{A}} \quad \text{Eq.[5]}$$

where $\overline{E}$ is the average estimate values, $\overline{A}$ is average historical value. A comparison between the model and two key parameters is presented in Table 9.

Table 9. Comparison between the SD model and key parameters

Year	(a) Professional workforce supply		(b) Number of buildings of aged buildings (over 30 years)*	
	Historical value	Estimated value	Historical value	Estimated value
2013	448	449	14680	14980
2014	456	458	15380	15880
2015	470	467	16479	16900
2016	484	476	17320	17500
	Error	**0.44%**	Error	**2.2%**

*Note: the number of buildings of aged buildings (over 30 years) is the sum of the aged small-sized, medium-sized, large-sized and extra-large sized buildings as shown in the SD model.

5.0 Policy Scenarios

Scenario development is a predictive method where present data is used to develop future policies (Erdmann and Hilty 2010). The SD model developed in this paper can provide policymakers with the ability to manipulate relevant data within each year to produce alternative scenarios for evaluation. Examples are the number of aged buildings that need inspection under the MBIS and its influence on the workload on RI. The application of the SD model is illustrated below using two scenarios: (1) a baseline model to evaluate the raw impact of the current government resources allocated and implement the MBIS policy for the number of aged buildings that are being inspected and repaired; and (2) evaluate various policy options (such as changing the targeted number of buildings to be inspected and repaired and its effects on the professional workforce).

5.1 Baseline Scenario

The baseline model assumes that the government's input into the urban rehabilitation is based upon the existing MBIS policy and that their existing policy remains unchanged during the simulation period. Several key assumptions extracted from existing government policies and supply of the RI are listed in Table 8. For the MBIS policy, it is assumed that the number of 'target buildings (i.e. to be inspected, repaired and maintained)' is 2000 per year. As a result, the local building authority will need to issue a statutory order and require owners to employ RIs to inspect their buildings as well as supervise the required repair works. Figure 5 presents the number of aged buildings that have not been inspected/ repaired.

Table 10. Key parameters for the SD model under the baseline scenario

Variables	Statement
Existing supply of the Registered Inspector ('RI')	440
New entrants of the RI	• The number of new entrants will be 2% of the total workforce supply pool
Mandatory Building Inspection Scheme	• The number of 'target buildings' is 2000 per year • The target building is distributed to the three main regions in Hong Kong
Repair and maintenance works conducted by self-initiated building owners	65 (unit: no. of buildings)

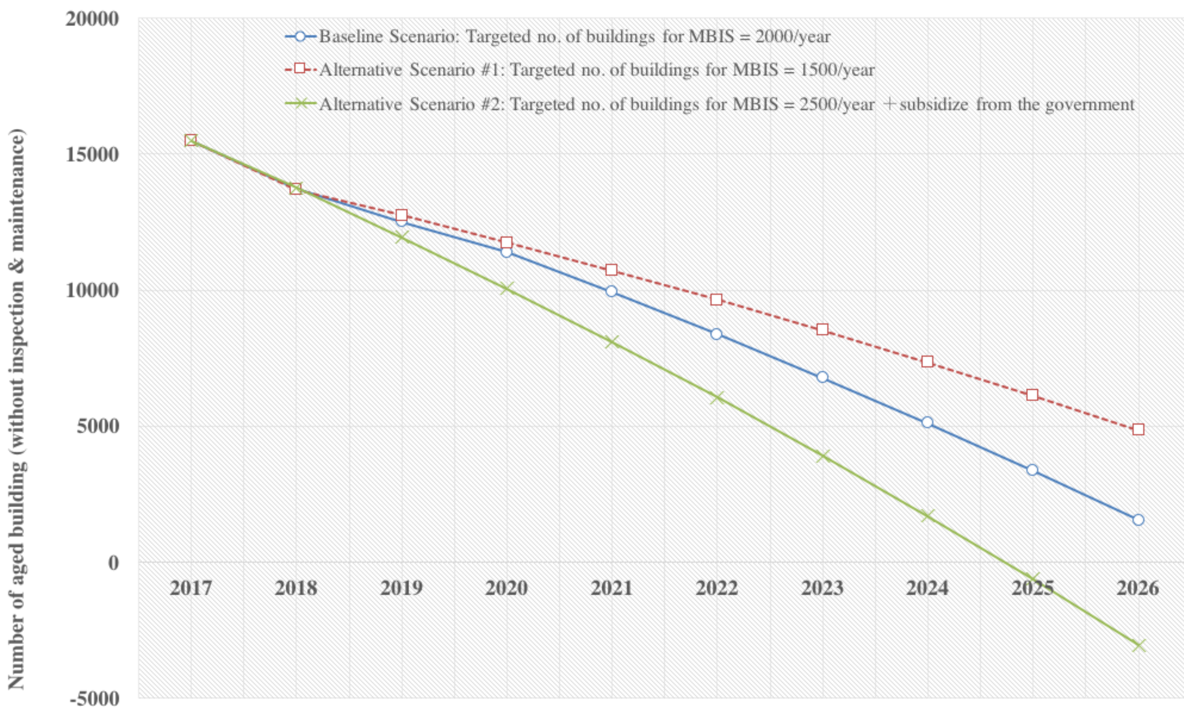

Figure 5. Policy analysis on the number of aged buildings that have not yet been inspected and repaired under different kinds of government policies

5.2 Alternative Scenarios

The SD model developed will be used to test the policy intervention programme on the aged building problem for the period 2017 to 2027. In alternative scenario #1 (Figure 5), if the government reduces the number of target buildings from 2,000 to 1,500 as part of its mandatory inspection process, then urban rehabilitation is expected to decline and the number of aged buildings (without inspection and maintenance) will still remain to be one-fourth of the aged building stock in year 2016. However, in alternative scenario #2, the government and public both aim to: (1) increase the number of target buildings from 2000 per year to 2500; and (2) provide subsidized incentive programmes to encourage building owners to carry out 'voluntary' inspection and repair works. This would result in the number of buildings being repaired, increasing from 65 to 100 under the government incentive policy.

In alternative scenario #2, the expected duration to inspect and maintain the existing aged building stock would take approximately seven years (from 2016). The existing supply of professionals is sufficient to meet this demand. Due to the additional workload that will be generated from the government implementing its MBIS policy, extra RIs will be made available. However, if the government follows the existing policy (i.e. 2000 buildings per year), it would take nine years. In Hong Kong, any changes in government policy require approval from the building safety committee of the Legislative Council; the administrative procedure and resource allocations normally take around one and half years to complete. Therefore, changes to policy in alternative scenario #2 do not take effect on the number of buildings being renovated until 2018 (a year after the implementation of the policy changes, i.e. from 2,000 buildings to 2,500 buildings).

As illustrated in Figure 5, the model represents a useful planning tool to simulate the effect of regulatory changes on how the aged building problem can be solved. However, the SD is only able to provide a reliable forecast when entry parameters (i.e. new entrants of the RI) are realistic. Fortunately, the SD model allows the modification of these parameters, which can provide policy makers with invaluable insights to examine 'what-if' scenarios to enable the equilibrium between the social resources and urban to be achieved.

6.0 Conclusions

This paper has presented a SD model that can be used to examine the dynamics behind the formulation of policies to address issues surrounding urban rehabilitation in Hong Kong. Specifically, the model examines the dynamics influencing the relationship between aged buildings, the rehabilitation policies and resourcing (e.g. professional workforce). It is so formulated that it can facilitate policy scenarios analysis with regard to studying the impact of several key parameters that can improve the policy making related to urban rehabilitation of aged private buildings. However, it relies on a number of the data sources such as rate of demolition of private buildings and duration of the inspection and maintenance works, to support the simulation. A user of the model will need to ensure that data sources are regularly updated so that they reflect the prevailing environment of Hong Kong. The SD model can be readily adapted to other cities from around the world, provided, similar data can be obtained. Future research may focus on the wider policy and feedback relationship contained in the SD model. This requires further refinement and re-calibration. For example, the model can be further extended to include an endogenous variables loop of the factors influencing the incentive of owners to conduct repair and maintenance works on a voluntary basis. Research of this nature would provide policy-makers with much-needed knowledge to further develop policies that will make a significant contribution which can ensure that Hong Kong's building stock is resilient and adaptive to changing demands and needs.

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Appendix A: SD model

```
FINAL TIME  = 2027
        ~       Year
        ~       The final time for the simulation.
        |

INITIAL TIME  = 2017
        ~       Year
        ~       The initial time for the simulation.

SAVEPER  =
    TIME STEP
        ~       Year [0,?]
        ~       The frequency with which output is stored.

TIME STEP  = 1
        ~       Year [0,?]
        ~       The time step for the simulation.

Number of Buildings=
        IF THEN ELSE(Subsizes from the government>0, Resouce Input*Government Policies , 0 )

Resouce Input=A FUNCTION OF(Resouce Input)

Financing Support to the owners=1

Subsizes from the government=0

"No. of Target Buildings"=
        Resource allocated*Government Policies+Number of Buildings
        ~       Dmnl
Government Policies= INTEG (in*"Adjustement #1"-Out,1)
"Adjustement #2"=
        IF THEN ELSE(Urban Sustainability<Sustainability, 1 , 1.2 )

Out=Government Policies

in="Adjustement #2"

Sustainability=0.2

"Adjustement #1"=
        IF THEN ELSE("WORKFORCE GAP (D-S)">0 :AND: "WORKFORCE GAP (D-S)"<0.1, 0.1 , 0 ) + IF
THEN ELSE\
                ("WORKFORCE GAP (D-S)">=0.1 :AND: "WORKFORCE GAP (D-S)"<0.2, 0.2 , 0 ) + IF
THEN ELSE\
                ("WORKFORCE GAP (D-S)">=0.2 :AND: "WORKFORCE GAP (D-S)"<0.3, 0.3 , 0 )++ IF
THEN ELSE\
                ("WORKFORCE GAP (D-S)"<=0, 1, 0 )

"Repaired #4"=
        "Extra-large sized building (to be repaired)"*Rate of Completion
```

```
"Changes #4"=
	"Growth rate #4"

"Growth rate #4"= WITH LOOKUP (
	Time,
		([(0,0)-(3000,10)],(2017,2),(2018,2),(2019,4),(2020,5),(2021,4),(2022,5),(2023,4),(\
		2024,3),(2025,3),(2026,2),(2027,2) ))

"Demolition #4"="Aged Buildings (Extra-large sized)"*0.01

"Aged Buildings (Extra-large sized)"= INTEG ("Changes #4"-"Demolition #4"-"Repaired #4",47)

adjustment required=1

Demolition="Demolition #1"+"Demolition #2"+"Demolition #3"+"Demolition #4"

"Extra-large sized building (to be repaired)"=
	"No. of Target Buildings"*("Aged Buildings (Extra-large sized)"/Total number of aged buildings)

"Small sized building (to be repaired)"=
	"No. of Target Buildings"*("Aged Buildings (small sized)"/Total number of aged buildings)

"Large sized building (to be repaired)"=
	"No. of Target Buildings"*("Aged buildings (large sized)"/Total number of aged buildings)

"Professional Multiplier #4"=0.5

"Medium sized building (to be repaired)"=
	"No. of Target Buildings"*("Aged buildings (medium sized)"/Total number of aged buildings)

"Professional workforce #4"=
	"Extra-large sized building (to be repaired)"*"Professional Multiplier #4"

Total number of aged buildings=
	"Aged Buildings (Extra-large sized)"+"Aged buildings (large sized)"+"Aged buildings (medium sized)"\
		+"Aged Buildings (small sized)"

"Professional Workforce #4 (2nd year)"=DELAY FIXED("Professional workforce #4", 1 , 0 )

"Work Duration #4"=1

Professional Workforce Demand=
	"Professional Workforce #1"+"Professional Workforce #2"+"Professional workforce #3"+\
		"Professional workforce #4"+"Professional workforce #2 (2nd year)"*"Works Duration #2"\
		+"Professional workforce #3 (2nd year)"*"Work Duration #3"+"Professional Workforce #4 (2nd
year)" *"Work Duration #4"

Urban Sustainability=
	Total number of aged buildings/Total number of buildings

"Demolition #3"="Aged buildings (large sized)"*0.01

Resource allocated=
	Initial Input

New Entrants=
```

IF THEN ELSE("WORKFORCE GAP (D-S)">0 , Professional Members Pool*0.002 ,0)

Rate of Completion=
IF THEN ELSE("WORKFORCE GAP (D-S)">0,0, 1)

"Professional workforce #3 (2nd year)"=
DELAY FIXED("Professional workforce #3", 1 , 0)

"Professional workforce #2 (2nd year)"= DELAY FIXED (
"Professional Workforce #2", 1 , 0)

"Work Duration #3"= 0.6

"Works Duration #2"= 0.2

"Growth rate #3"= WITH LOOKUP (
Time,
([(0,0)-(3000,400)],(2017,14),(2018,14),(2019,18),(2020,18),(2021,18),(2022,18),(2023\
,18),(2024,13),(2025,13),(2026,13),(2027,13)))

"Growth rate #2 "= WITH LOOKUP (
Time,
([(0,0)-(3000,2000)],(2017,50),(2018,50),(2019,39),(2020,39),(2021,39),(2022,39),(2023\
,39),(2024,39),(2025,39),(2026,39),(2027,39)))

"Changes #3"= "Growth rate #3"

"Growth rate #1"= WITH LOOKUP (
Time,
([(0,0)-(3000,7000)],(2017,63),(2018,63),(2019,63),(2020,51),(2021,51),(2022,51),(2023\
,51),(2024,51),(2025,43),(2026,43),(2027,43)))

"Repaired #1"=Rate of Completion*"Small sized building (to be repaired)"

"Changes #2"="Growth rate #2 "

"Changes #1"="Growth rate #1"

Resources= INTEG (Resource allocated-Resources lost,50)

Initial Input= 645

Resources lost="Repaired #2"+"Repaired #3"+"Repaired #1"

Building Stock= INTEG (New Buildings Completion-Demolition,42000)

Total number of buildings=Building Stock

New Buildings Completion=180

"Aged buildings (large sized)"= INTEG ("Changes #3"-"Repaired #3"-"Demolition #3",
166)

"Aged buildings (medium sized)"= INTEG ("Changes #2"-"Demolition #2"-"Repaired #2",1441)

Professional Members Pool=8000

"Repaired #2"=Rate of Completion*"Medium sized building (to be repaired)"

"Repaired #3"=
"Large sized building (to be repaired)"*Rate of Completion

"Demolition #1"="Aged Buildings (small sized)"*0.02

"Demolition #2"="Aged buildings (medium sized)"*0.01

Drop Out=IF THEN ELSE("WORKFORCE GAP (D-S)">0 , 0 , 0.1)*Professional Workforce Supply

"Professional workforce #3"=
"Professional Multiplier #3"*"Large sized building (to be repaired)"

"Professional Multiplier #3"=0.39

"Professional Multiplier #2"=0.25

"Professional Workforce #2"=
"Medium sized building (to be repaired)"*"Professional Multiplier #2"

"Professional Workforce #1"="Small sized building (to be repaired)"*"Professional Multiplier #1"

"Aged Buildings (small sized)"= INTEG ("Changes #1"-"Demolition #1"-"Repaired #1",
5574)

iNSPECT= 0.1

"Professional Multiple #3"=1

MBIS Policy=2000

"Professional Multiplier #1"=0.18

"WORKFORCE GAP (D-S)"=(Professional Workforce Demand-Professional Workforce Supply)/Professional Workforce Supply

Professional Workforce Supply= INTEG (New Entrants-Drop Out,440)