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A research agenda for the retrofitting of residential buildings in China – A case study

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ABSTRACT

The high-rise residential buildings of China will soon need retrofitting and any such retrofitting should include consideration of new energy saving methods and 'green' technologies. A research agenda is needed to meet this challenge. This paper presents a research agenda for the 'green' retrofitting of residential buildings. The agenda is based on the input of 25 national and international experts which was produced by a novel methodology specifically designed to discuss the key questions relating to the retrofitting of residential buildings. This methodology, based on Problem Tree Analysis, proved an effective method of producing an agenda for the research that is needed to facilitate such change. The research needs are presented under six headings. Stages for undertaking the research activities under each of these headings have been identified. The agenda highlights that the challenge of retrofitting is holistic and includes not just engineering and construction actions but economic, social and governmental requirements. Key aspects of the research agenda include the need for better macro-economic and micro-economic models and a better understanding of people's needs and expectations. These topics are discussed together with recent research findings both from China and other countries.

1. Introduction

The pace of change in the towns and cities of China has been rapid. Between 1980 and 2014 China's economic success has resulted in the growth of the urban population from 191 million to 749 million (CGPRC, 2014). Such an increase is unprecedented in modern times. In only 30 years the level of urbanization has risen from 20% to today's 54%. By 2030 it is estimated that Chinese cities will be home to about 1 billion people, approximately 70% of the country's population. Despite the current slow-down in the Chinese economy urbanization and the movement of the people to the cities will continue: urbanization is the main enabler for the reduction of poverty and is the basis of the country's development potential (Zhang, 2016).

The majority of the urban population in China live in high-rise residential buildings. (We define high-rise residential buildings as buildings of more than eight storeys high.) This form of housing is now the predominant residential model for all the main cities of China. Prior to 1990 the industrial cities of China typically housed residents in 5 or 6 story work-unit type residential housing often linked to specific industrial units. The majority of these residences were designed and constructed in the late 1970s and 1980s and are now being demolished.

Rapid urbanization has caused great pressures on energy, resources and the environment (Li and Yao, 2009).

Building energy demands have increased dramatically (Liang et al., 2007; Gao et al., 2004) and continue to increase. Experience from other countries indicates that buildings in developed countries contribute some 35–40% of the energy use of a country (EU, 2010). As in other countries, new buildings in China need to be designed to be energy efficient and constructed with 'green' technologies to make best use of depleting resources and reduce carbon emissions.

Not with standing the challenge of constructing new buildings to new energy standards there is now increasing recognition in China that the high cost of demolishing and rebuilding existing buildings means that consideration must now be given to refurbishment and retrofitting. (In China the commonly accepted term is 'reconstruction'.) Where existing buildings need to be reconstructed a reduction in operational energy requirements is a priority. This applies to all building types: government buildings, public buildings, (commercial and retail buildings), and residential buildings. Residential apartments in China are usually acquired with leases of between 50 and 70 years' duration. If these buildings are to last anywhere near this timespan they are likely to require major retrofitting at least once in their lifetime if they are not

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to deteriorate to a state which will make them un-inhabitable long before their anticipated end of life. Previous research, (CII-HK, 2005; Loveday and Vadodaria, 2013) has shown that retrofitting is not just a technical issue but a socio-economic issue. The authors of this paper were unaware of any holistic research agenda for the retrofitting of residential buildings in China. This was the impetus for their research.

The potential benefit of efficient effective retrofitting in terms of energy savings is high. In 2015 the average electricity consumption of urban residential buildings was 1690 kWh per year per household. It continues to grow as demand for a higher quality of life increases (Hu et al., 2017). The energy efficiency retrofit of residential buildings undertaken in north China has shown that full-scale retrofit of a multi-storey building can produce a good indoor thermal environment and meet the 50% energy saving target set by the government (Chen et al., 2015). A recent (2013) study reported that the energy saving in the Hot Summer, Cold Winter Zone of China concluded that energy requirements for a retrofitted residential building could reduce by 31.5% if the Chinese National Standard were satisfied and 45.0% if the local (Chongqing) standard was met (Xu et al., 2013). It is however recognised that reaching such levels of energy saving are dependent on public participation (Liu et al., 2015) and subsequent occupant behaviour patterns.

Retrofitting may be undertaken at several levels: a light touch or renewal; medium intervention; extensive intervention; comprehensive refurbishment; and demolition (Shah, 2012). The action required at any point in the building's life-time will depend upon the performance and the condition of the building. Extensive intervention requires the full replacement of some parts of the building, building-fabric changes, plus re-modelling building services to meet current building standards and 'future proofing' the building for the next 20–25 years. Whilst not always the primary reason for retrofitting, any retrofitting should include full consideration and renewal of the energy systems for the building. This may be termed 'deep energy retrofitting'. With deep energy retrofitting the entire fabric and conventional systems of the building have to be evaluated, redesigned and reconstructed in an integrated way. Airtightness of the building envelope is imperative if substantial energy savings are to be made (Gillott et al., 2013).

Achieving this level of performance on existing buildings is not easy. This will be a major challenge for the construction industry in China, an industry that has up to this moment in time been predominantly focused on the construction of new buildings. New technologies, new skills and new business processes will need to be developed. Given the need for reducing carbon dioxide output and reducing the impact of the construction industry it is considered that any discussion should be based on a low-carbon or Green Building construction approach (EPA U.S. Environmental Protection Agency, 2009). This approach, also known as Sustainable Building includes consideration of durability; the energy required for heating; the energy required for cooling; the potential for using renewable energy; impact on daylight; environmental impact; indoor air quality and acoustics; structural stability, fire safety; aesthetic quality; effect on cultural heritage; life-cycle cost; need for ongoing care and maintenance; disturbance to tenants and the site; buildability, etc. Hakkinen (2012).

What are the requirements for the low-energy, 'green' retrofitting of high-rise residential buildings in China? To discuss these requirements a workshop meeting of international experts was held in the city of Chongqing China. To ensure that their thinking was grounded in the context of China the meeting also included experts from the city of Chongqing and other parts of China. Other senior national and regional government officials and industry representatives provided contextual information to assist the experts' discussions. The aim of the workshop was to develop a research agenda for the green retrofitting of residential buildings in China. The objectives were: to identify the problems of retrofitting residential buildings their causes and their effects; to propose a framework of research objectives; and to provide a basis for reviewing existing research and identifying new research questions and new research projects.

This paper describes the methodology used at the workshop event and key aspects from the findings that now provide a research agenda for retrofitting residential buildings in China. The findings from the workshop are presented and discussed in the context of other recent research. The paper is designed to direct future research initiatives required to establish new policy and confirm or amend existing policies.

2. Research method

The research method was based on workshop exercises and the subsequent discussions undertaken by the selected group of experts. These expert researchers worked in groups to a structured methodology designed to identify the problems relating to retrofitting residential buildings together with their related causes and effects. From these data it was then possible to develop a series of research objectives. The objectives were presented in the form of an Objective Tree, a framework of research topics.

This methodology was based on the established technique commonly known as Problem Tree Analysis, a participatory tool for mapping out main problems, along with their causes and effects, supporting project planners to identify clear and manageable goals and the *strategy* of how to achieve them (Dillion, 2017). This is a proven approach to problem solving in business organisations, frequently used for strategic planning. It has been used by the authors for strategic planning with both small groups e.g. 10 people and large groups e.g. 150 people. The methodology ensures a holistic approach to the problem and seeks a wide perspective on all the issues relating to a topic and how they relate to one another. The authors consider it is ideally suited to discussing the complex inter-linked problems of the built environment. Its use in the context of establishing a research agenda is not common but the authors consider the approach to be a powerful tool that can establish consensus on research problems and then develop research objectives much faster than other traditional methods such as interviewing, surveys, use of the Delphi technique etc. Bryman and Bell (2007).

All the researchers at the workshop were experts in topics relating to low carbon, energy saving, green building. Attendance for the meeting was by invitation only. There were 18 'core members' of the group. Of these all had degree or equivalent qualifications and were members of professional institutions or associations. Seventeen had Ph.Ds. in related topics. Eleven were Professors at leading academic institutions. The group was carefully selected on the basis the group would have a wide range of knowledge and not be biased towards any specific solution or approach to the problems to be discussed. In addition to the 'core' members there were some 7 other experts who attended for part of the meeting to contribute to specific discussions by providing contextual information e.g. climate change issues and the effects of the urbanization. All the attendees could be considered 'stakeholders' in the sustainable built environment. They included: Architects; Building Scientists; an Economist, Construction Management experts; a Designer; a Materials Scientist; and government and industry representatives. They came from UK, Holland, Germany, Australia, South America, China, and Hong Kong. Careful selection of the experts ensured a multi-disciplinary approach to the problem.

The method followed a structured linear process that comprised eight stages. Each stage had specific actions: Preparation for the Workshop; the Provision of Contextual Information; Problem Analysis; Identifying the Objectives; Consolidation of the Objectives into a Single Objective Tree; Prioritization of Problems; Impact Analysis; and a Review of Workshop Outcomes. This is shown diagrammatically in Fig. 1 which includes the actions and outcomes from each stage.

In preparation for the workshop all attendees were provided with identical information relating to the problem and invited to produce a short statement of their background and expertise and how this could contribute to the discussion. On the afternoon before the workshop a site visit was made to typical apartment buildings to familiarize the