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Urban Equilibrium for sustainable cities and the contribution of timber buildings to balance urban carbon emissions: A New Zealand case study

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ABSTRACT

In the current study, Urban Equilibrium is defined as the situation where buildings in an urban environment act as a balancing agent for the greenhouse gas emissions of the urban area; therefore the buildings act like carbon pools. Cities contribute significantly to pollution, and the move to more, and larger, cities is increasing. The whole-of-life role of timber in future urban developments as a contributor to balance urban carbon emissions is considered here using a new concept of Urban Equilibrium. When applied to Auckland, New Zealand, as a case study, maximising the use of timber in future urban developments demonstrated that Auckland's target of a 40% carbon emissions reduction by 2040 could be achieved 20% faster than planned while still meeting the city's future growth needs. This strategy is complementary to, and easy to integrate with, other strategies and policies for greenhouse gas mitigation. However, the Urban Equilibrium concept is broader than this and can also be applied in other aspects relating to the sustainability of urban environments. Urban Equilibrium fosters a framework of urban governance that integrates environmental and social development agendas with economic development. This holistic approach takes into account the various effects that economic development can have, and re-defines the concept of growth to include a moral obligation to future generations.

1. Introduction

Cities currently occupy 1% of the earth's surface but contain 50% of the world's population, consume 75% of the world's energy and emit 80% of the greenhouse gases (GHG) (Wuppertal Institute for Climate Environment and Energy, 2009). Ideally, *urban* areas should exist in *equilibrium* with the environment to be sustainable in the long term. The phrase "*Urban Equilibrium*" has already been used in relation to urban economies, land use, transport, housing supply/demand and planning (Capello, 2013; Dai et al., 2010; De Lara et al., 2012; Kilani et al., 2010; Simmonds et al., 2013; Verhoef and Nijkamp, 2008; Wu et al., 2004) but it has not been used previously in relation to urban GHG emissions and climate change (CC).

The current study introduces a new concept where Urban Equilibrium (UE) is applied in relation to urban GHG emissions and CC with a specific definition: *where the structures that define an urban environment act as a balancing agent for the greenhouse gas emissions of the urban area; therefore the buildings act like carbon pools* (David Turner, Executive Director of Sequal Lumber Ltd. Pers comm. 2014). In this novel concept of UE, the whole-of-life role of timber in future urban developments is evaluated for its contribution in balancing out urban carbon emissions and involves three types of carbon mitigation, as defined in Equation (1):

$$\text{UE} = \text{Sequestration optimisation} + \text{Storage maximisation} + \text{Emission minimisation} \quad (1)$$

This terminology is used throughout the paper. The UE approach emphasises the role of timber in future urban developments on the basis that the environmental benefits provided by such an approach will extend synergistically to social and economic areas. However, the UE approach is broader than that, and can be applied

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to different aspects within urban environments. Ideally, it builds on the 'sustainable city concept' developed by the United Nations that provides an operational model for sustainable cities. No one size fits all so policies and management measures need to be tailor-made to take into account the challenges and opportunities driven by the idiosyncrasies of different urban environments "*to ensure solutions that are both functional and economically feasible*" (Falconer and Mitchell, 2012; United Nations DESA, 2013). Hence, UE involves a systems approach that incorporates whole-of-life thinking within an entire urban environment, with the aim of assisting urban governors to manage pollutants in an urban system. By doing this, UE provides considerable scope for more sustainable future urban developments. Urban policy makers need to respond to future growth needs in cities while addressing GHG mitigation and this study demonstrates, in particular, the benefits of greater utilisation of timber in future building construction.

Timber has various carbon-mitigation benefits: trees remove (sequester) carbon as they grow, and wood is a long-term carbon store until trees and wooden products reach the end of their useful life and are either burnt or degrade. Only then is the carbon partially released back in the atmosphere. Evaluating the environmental benefits of using timber in construction is not new, but previous studies have generally involved only single buildings. The novelty of this project, and of the proposed UE concept, is to consider the advantages of multiple timber-building developments in an urban environment. Conducting an evaluation of alternative development options at an urban scale presents many challenges, complexities and uncertainties. For example, all the buildings within a built environment would need to be individually assessed, compared and their actual timber content summed to generate the overall urban figure, but this procedure is infeasible when considering future urban growth scenarios. Instead, the objectives of this study were to: raise awareness of the underlying potential of maximising the use of timber in future urban developments by incorporating and applying the concept of UE; and assess the broader implications this potential may have for urban governors to achieve sustainable urban environments. These objectives were achieved by assessing published literature to identify appropriate data then applying these in a high-level case study within Auckland, New Zealand. Such an approach can then be applied to any developing urban environment worldwide.

New Zealand is at the upper end of the international urbanisation spectrum with over 87% of the population living in urban environments. The country is currently facing an important challenge to keep its international image of being sustainable with a healthy and socially connected population (Otago University, 2014). Auckland is the largest city in New Zealand with approximately one-third of the country's population. With 1.4M (Million) people spread over 500,000 ha and a projected 1M additional people over the next 30 years, business-as-usual urban development would result in a 39% increase in GHG emissions over the next 20 years (Auckland Council, 2014a). However, Auckland Council has set in place an alternative vision of becoming the world's most liveable city while meeting forecasted urban growth through the Auckland Plan. To accommodate the projected population growth, Auckland Council foresees "*adopt[ing] a Rural Urban Boundary in Auckland's Unitary Plan that provides for land capacity over the next 30 years for 280,000 new dwellings within the 2010 Metropolitan Urban Limit baseline, 160,000 new dwellings in new greenfield land, satellite towns and other rural and coastal towns, and at least 1400 ha of new greenfield business land.*" (Auckland Council, 2014a) Part of the Plan's implementation will require the city to reduce urban GHG emissions and increase energy efficiency, resilience and adaptation to CC.

The aspirational GHG emissions target is a 40% reduction by 2040, compared with 1990 levels, while accommodating the projected (1M) additional people (Auckland Council, 2014a, b). The plan envisioned the adoption of a series of emission mitigation pathways. The contributions of the various different pathways and the expected total emission reduction for the 20 year period 2011–2031 are shown in Fig. 1. If all these actions were adopted as suggested by the plan then a 40% emission reduction by 2031 would be possible (ARUP, 2012a; b; Auckland Council, 2014b).

Auckland was chosen for the case study because its governance aims lend themselves to the implementation of additional strategies using the UE concept. The aim of the current study was to estimate at a high level the additional emission reduction achievable by including the amounts of carbon sequestered and stored, and the emissions eliminated as a result of using timber in all new buildings constructed in Auckland over the next 30 years. The analysis involved: (1) assessing published literature to obtain relevant input data; (2) designing the case study framework; and (3) calculating the carbon storage and sequestration benefits of incorporating timber into new buildings over the next 30 years.

2. Methods

2.1. Retrieval of relevant literature

Relevant literature was retrieved to obtain data regarding the environmental benefits of using timber in building construction and its effects on urban GHG emission reduction. Various keyword phrases (see Supplementary File) were searched during the period February 2014–April 2015 using Elsevier's Science Direct and Scopus databases, and also using Google Scholar.

2.2. Case study design

The basic premise of the case study was the projected need for 280,000 new dwellings within the Metropolitan Urban Limit (MUL) baseline and 160,000 new dwellings in new greenfield and satellite towns and other rural and coastal towns to be constructed in Auckland for the next 30 years (Auckland Council, 2014a).

Auckland Council expects medium-to-high rise building development to occur within the MUL and a low-to-medium rise development in the new greenfield land, satellite towns and other rural and coastal towns (Auckland Council, 2014a). In this high-level case study, the city development has been assumed to happen linearly over the 30-year time frame considered by the Auckland Council. This will result in an average of 14,660 new dwellings being constructed per year for the next 30 years of which 9330 residential units will be within the MUL (assumed 50% medium-rise and 50% high-rise), 5330 units will be other areas within the Rural Urban Boundary per year (assumed 50% low-rise and 50% medium-rise).

Supporting social infrastructure development (e.g. hospitals, courts, schools, etc) is also expected to be built or adapted (Auckland Council, 2014a). The forecast 1.7M m^2 of additional education and health floor-space development averages 55,000 $m^2\ y^{-1}$ over a 30-year timeframe (Auckland Council, 2014a). Educational buildings were used as a proxy for social infrastructure adaptation as the Plan identifies young people as a top priority. By 2040, the population of children is expected to increase by almost 100,000 (Auckland Council, 2014a), which equates to an approximate increase of 3300 students per year.

Auckland's forecasted commercial space needs shows that, by 2041, an additional 2.97M m^2 of office floor space and 1.8M m^2 of retail floor space will be needed compared to 2011 (Auckland Council, 2013). The increase equates to 99,000 m^2 of office space and 60,000 m^2 of retail floor area annually.