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Challenges for modeling carbon emissions of high-rise public residential buildings in Hong Kong

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Abstract

The approach of low or zero carbon building (L/ZCB) has attracted increasing attention in both academic and professional fields as the carbon emissions attributable to buildings kept increasing in the past decades. However, there exist challenges with modeling the carbon emissions of high-rise buildings in high-density urban environments. The aim of this paper is to examine the challenges and develop strategies for modeling carbon emissions in high-rise public residential buildings within the context of Hong Kong. The paper first reviews the challenges facing the modeling of the carbon emissions of high-rise buildings both generally and in Hong Kong, and examines their relevant implications for building design decision making. The approaches to establishing reference building models, e.g. example, real and theoretical reference building, are investigated drawing on the regulatory and practical guidance for carbon emission modeling in Hong Kong. The paper then develops a simulation approach to analyzing the obstacles to building energy modeling for typical high-rise public residential buildings in Hong Kong. Considering the urban environmental factors that may contribute to biased results for energy simulation, this paper is focused on the technical issues during the conversion of data from BIM model to energy simulation software. Thermal zones and user behavior are also addressed since technical and subjective assumptions could lead the simulation to a wrong direction. Understanding of such challenges enables the energy simulation to perform smoothly and also informs carbon emission modeling for high-rise L/ZCBs in other urban settings.

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Keywords: Challenge, high-rise building, energy modelling, building energy use

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1. Introduction

Residential, commercial and institutional buildings account for almost 92% of electricity use and 60% of greenhouse gas (GHG) emissions in Hong Kong [1]. Hong Kong now has roughly 2,671,900 stocks of living quarters as at end-October 2014 [2] with a substantial increase annually. Tackling GHG emissions from buildings is a critical component to achieving governmental goals for substantial GHG reduction and long-term sustainability in Hong Kong. In particular, the HKSAR Government has pledged to achieve a reduction in carbon intensity of at least 50-60% on the 2005 baseline by 2020 [3]. In 2010, the Environmental Protection Department and the Electrical and Mechanical Services Department (EMSD) drew up a set of "Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for buildings (Commercial, Residential or Institutional Purpose) in Hong Kong".

To address these, it is vital to familiar with the building energy performance and the energy analysis of most buildings is easily handled by using simulation software. However, for the majority of public residential buildings in Hong Kong with more than 40 stories, it is still a big challenge for building energy simulations and modelers. Because the atmosphere conditions change with altitude, high-rise buildings can experience significant differences in environmental factors between the lower floors and the higher floors. These include differences in air temperature, barometric pressure, and wind speed. The urban environment imposes additional environmental factors because of shading and refection from surrounding buildings. These environmental factors create a microclimate that can vary from floor to floor of a high-rise building.

Besides environmental factors, modeling high-rise building is always a challenge. The conversion of data from BIM model to building energy simulation is not simply straightforward, although data transfer through gbXML or IFC has been recognized as an effective way connecting BIM model with energy simulation programs. Interoperability issues still occur during such transitions.

As part of the research reported in this paper, we used OpenStudio and IES VE to model a proposed design of a 40-story public residential building in Hong Kong. This research provides an ideal case study for exploring the simulation challenges for high-rise public residential buildings in a high-density urban environment under tropical weather conditions. The study employs literature review and technical analysis to demonstrate current challenges that are faced during modeling of high-rise buildings.

2. Literature review of modeling of the carbon emissions of high-rise buildings

The definitions of high-rise or tall buildings, measured by meters or number of stories vary in different regions or countries. The definition provided by the Hong Kong Fire Services Department refers high-rise buildings to a building of which the uppermost story exceeds 30 m above the point of staircase discharge at ground floor level.

Table 1. Definition of high-rise buildings

An example of a column heading	Description
National Fire Protection Association 101®, Life Safety Code, 2012 edition	A high-rise building is a building more than 23 meters in height, measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story.
Council on Tall Buildings and Urban Habitat	A tall building is a building of perhaps 14 or more stories (i.e. or over 50 meters in height); A super-tall building is a building over 300 meters in height, and A mega-tall is a building over 600 meters height.
Code of practice for minimum fire service installations and equipment and inspection, testing and maintenance of installations and equipment (Fire Services Department HK, 2012)	Any building of which the floor of the uppermost story exceeds 30 m above the point of staircase discharge at ground floor level.

Despite ample examples of modeling high-rise buildings, a set of widely accepted rules are still lacking. The common practice adopted by prior studies are modeling: 1) one or multiple flats of an intermediary story [4, 5]; 2) one typical story [6, 7]; and three representative floors (i.e., ground, middle floor and top floor) [8]. It is argued that the first two exercises are adopted because they are appropriate to meet the specific research objective. For the latter, the researcher used the value of shading mask to justify that within certain number of floors this value does not deviate much [8]. Besides these rules, the modeling normally simplifies other possible conditions, for example ignoring the presence of adjacent buildings [9].

In addition, a systems approach is still lacking in modeling high-rise ZCBs. The simulation of design strategies is normally carried out in a separate manner, rendering the building's systems features ignored. For example, prior studies normally focus on one strategy, e.g., the usage of solid oxide fuel cell tri-generation system [10], district cooling systems [11], or secondary loop chilled water [12]. However, the interdependence between building fabrics, building services systems and the renewable energy usage are still largely not known.

The purpose of modeling the energy consumption is to inform the decision-making. However, current practice of modeling high-rise building for achieving zero carbon target still encounter significant challenges to help with the decision-making. The topmost challenge is the absence of a common ZCB definition for high-rise buildings in the voluntary or the mandatory policies. It is of great importance to clarify the scope of the energy consumption included in the definition scope (e.g., the light appliances and plugs, the usage of renewable energy). For example, if light appliances are excluded from the definition (see the UK example), the use of energy-efficient lightings may not be prioritized in the ZCB energy modeling. Large body of research has revealed the relationship between building energy performance and occupant behavior [13-16]. Now building performance regarding envelop as well as its interior system can be simulated by many building energy simulation software, quantifying the energy use from occupancy is still a challenge. Interactions between occupants and building systems such as thermostats, windows, lights and blinds can have a dramatic impact on the total energy use of a building. Such occupant behavior has been shown to affect the energy performance of a building by up to a factor of 30% [17]. Also, the use of renewable energy in the high-rise buildings is of relevance to the design strategies; the lack of specific requirements of the renewable energy might impede the uptake of possible renewable energy in the modeling.

3. Challenges in energy modeling for high-rise public residential buildings in Hong Kong

3.1. Urban Environment and building type

Hong Kong has the highest population and employment density for the urban area. Looking at the building level, some areas may have more than 400,000 people per square kilometer [2]. The city is located in a tropical atmosphere, throughout the troposphere, air temperature decreases almost linearly with altitude at a rate of approximately 1°C per 150 meters [18]. Barometric pressure decreases more slowly, and wind speed, on the other hand, increases with altitude. Since the buildings interact with the atmosphere through convective heat transfer between the outside air and the exterior surfaces of the building envelope, and through the exchange of air between the outside and inside of the building via infiltration [18].

Similar as atmosphere, urban environmental factors also vary with altitude. The lower floors of a building, for instance, often receive more shading than the upper floors. The effect of shading from surrounding buildings could be accurately computed using detailed surface geometry. However, effects of the urban environment on local wind patterns and air temperature are still impossible to simulate because wind speed, wind direction, and air temperatures are usually read from the weather files. For example, using TMY2 weather files for Hong Kong can be problematic because the data typically come from meteorological stations at Hong Kong's airport, where is far away from the effects of the urban environment.

3.2. Data transition from BIM to energy modeling

Although the native Revit BIM data provides considerable 'intelligence' relative to more basic CAD data, which consist of dumb shapes and lines, it does not contain the volumetric/zonal data required by building performance analysis tools such as OpenStudio and IES VE. The data must be superimposed on top of the native Revit architectural model. Fig 1 illustrates the transition working flow from BIM model to building energy simulation (BES).

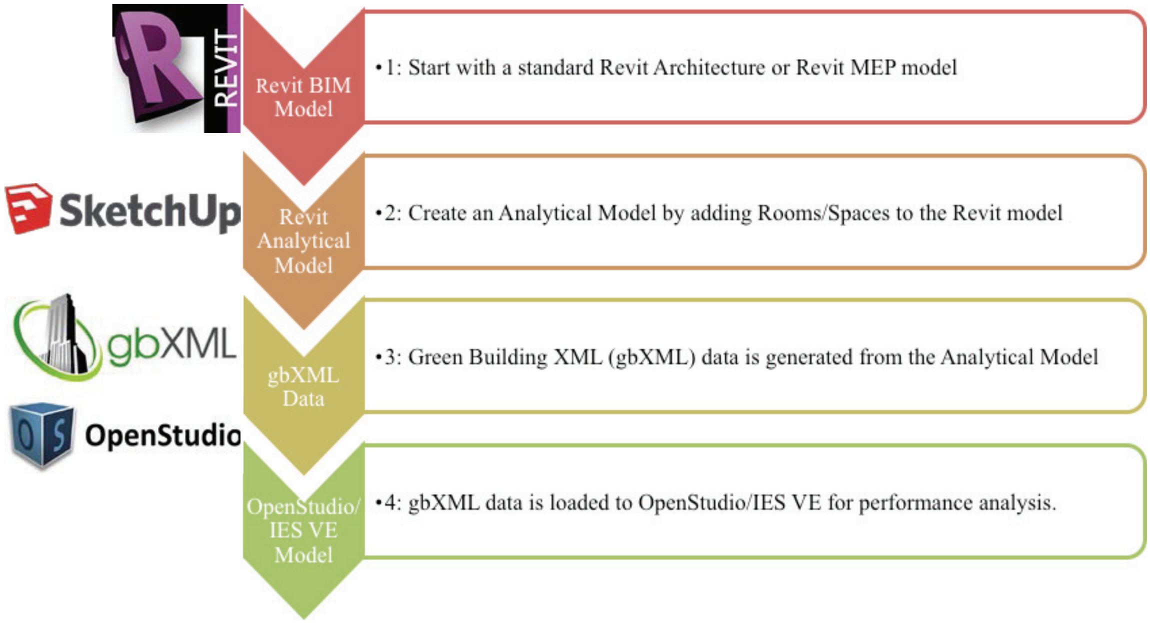

Fig. 1. Transition working flow from BIM model to BES

Currently there are two ways transferring Revit BIM model to building energy simulation software: first one is to use Revit Plugin within the BES software, e.g. IES VE and second method is to use built-in Revit gbXML export menu option. Interoperability with BIM is achieved through basically the same underlying processes regardless of which of the two methods is used. Both methods use the same Revit gbXML export and same BES gbXML import capabilities. The most challenging part during the transition is to accurately define the 'rooms' or 'spaces' in the model. As current building model using by HKHA's Modular Flat Design (MDF) cannot be transferred into rooms directly in Revit.

3.3. Modular flat design (MFD) in Hong Kong's high-rise residential buildings

Hong Kong Housing Authority (HKHA) rationalized its tool kits for mass customization after implementing site-specific design. In 2008, HKHA has further developed a new design strategy by adopting a new BIM library of Modular Flat Design for mass customization in public rental housing [19]. This new BIM library consists of a whole spectrum of small modular flats (1-Person/2-Person and 2-3 Person flats) and family modular flats (1-Bedroom and 2-Bedroom flats) (Fig.2).

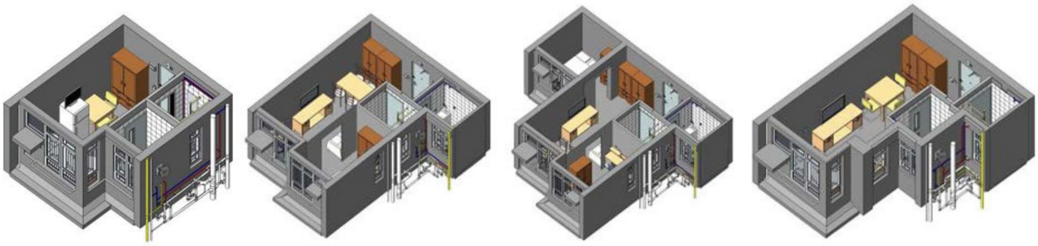

Fig. 2. From left to right (a) 1-2 person flat unit module; (b) 1-bedroom flat unit module; (c) 2-3 person flat unit module; (d) 2-bedroom flat unit module. Source: [20]

In order to better demonstrate technical challenges when transfer BIM data into BES through gbXML, three typical examples from a case study modeling 40-story public residential building (Fig 3) are given below:

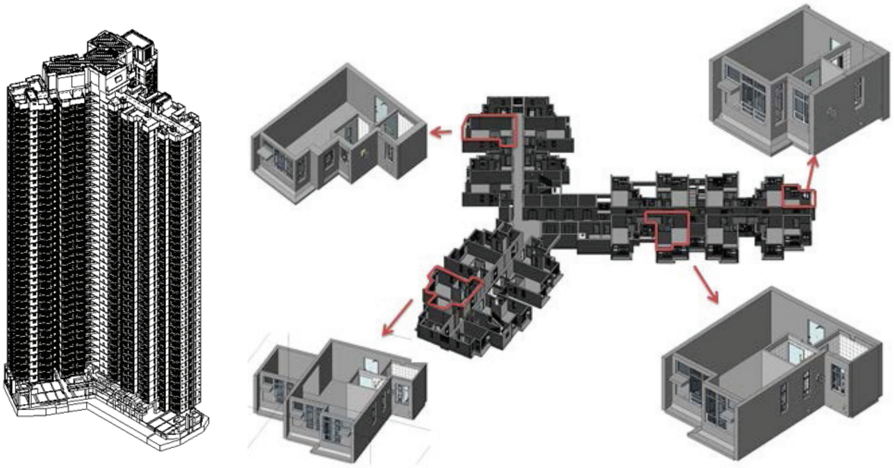

Fig. 3. Sampled 40-story public residential building and its typical floor comprised with modular flats (courtesy of HKHA and Yau Lee)

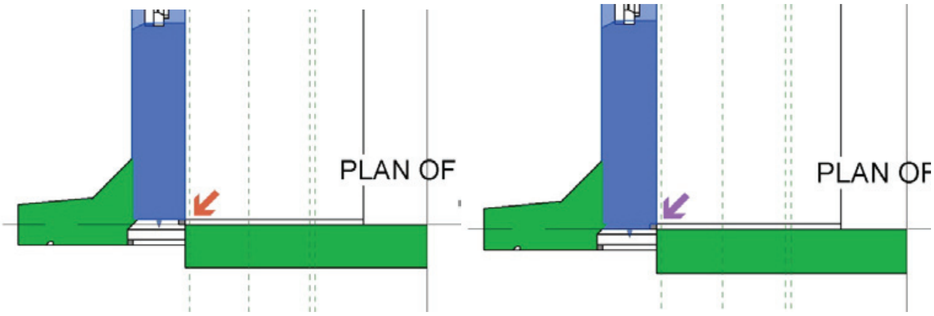

Fig.4. Issues of overhang facade.

a: Incomplete space boundary leads to space gap between wall and floor. For the modular flat with façade attaching overhangs at the bottom, a small gap were targeted (Fig. 4) due to that the wall was constructed on the overhang rather than the floor, although floor was attached to the overhang, according to the space formulation rules the space can only be formed by roof, wall and floor. The overhang was defined as a generic model in the Revit family and it can't be transferred well in the gbXML transition.

b: Multi-walls lead to incorrect space formulation. In the five modular flats adopted in this project, the BIM model shows perfect reflection of each apartment with pre-casted living room, bedroom and washing room, kitchen. In the model, there are more than one type of walls, some of them were made of ceramic tiles and attached with interior walls, these added "walls" make the Revit difficult to justify which wall should be calculated when formulating the space (Fig 5). To solve this, it is therefore suggested to simplify multi-walls into one 'thicker' wall with multi-layers.

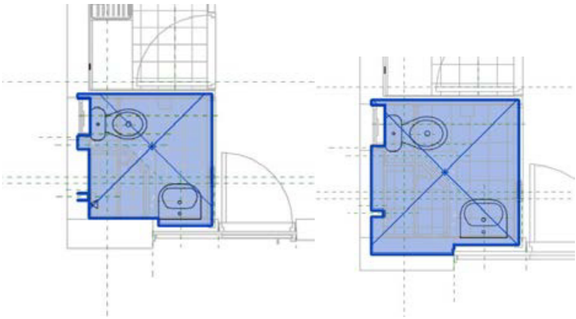

Fig. 5. Issues of combined walls

c: Wrong placement of windows lead to errors in gbXML transition. The position of some windows lead to false set up for windows formulation in gbXML, the reason is simple, for some type of the windows (Revit family code: MW1 & 3), the size is too large and part of the window had exceeded the wall edge. This works fine with BIM model but it creates problems in gbXML transition, because once the window exceeds the length of its placed wall, it will create a slim side window on its attached side wall (Fig 6). To avoid this, the modeler should be careful of the position of window's placement.

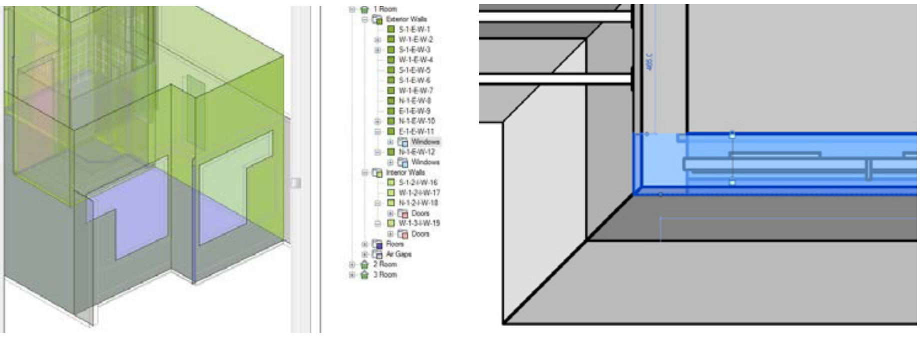

Fig. 6. Issues of windows' placement in gbXML and Revit model

3.4. Thermal zones division

The large scale of high-rise buildings means that many thermal zones may be required to fully simulate the building. For the selected public residential building, each floor consists of 25 modular flats, considering they all have different geometrical locations and orientations, the entire layout could be divided into 25 thermal zones, adding up to 1000 zones for the whole building, which leads to very large input files and long simulation run times.

Common practice is to select and simulate only a few floors, such as the top floor, one typical floor in the middle, first floor and ground floor. The results are multiplied by a factor to arrive at an estimate for the entire building. One problem with multipliers is that they may reduce the accuracy of the overall results. Because multipliers do not capture the variations of environmental factors from floor to floor, the floors that are to be explicitly modeled must be chosen carefully to ensure that they are representative.

3.5. Modeling human behavior

For high-rise buildings, it is difficult to precisely simulate occupants' interaction with building control systems, most previous studies regarding occupant behavior are conducted for individual building systems (lighting, shading, appliance using pattern, etc.), there are significant differences between the studies in terms of building size and type, relevant control devices, duration of observation/survey, measured environmental factors and cultural diversity.

All those uncertainties when translating into input parameters for simulations could lead to biased result, one way to deal with this as current simulation software simulates occupant behavior in a static/restricted way [21], as general assumptions are applied to describe user presence and action in a building or a room. Probability density function (PDF) has been proposed to be an effective method providing more accurate input parameters by integrating monitored data and statistically based results.

3.6. Carbon emission calculation

In Hong Kong, two power companies are generating and selling electricity in the market. One of the power companies uses primarily coal for generating electricity but the other uses natural gas as well. The carbon dioxide emission per unit electricity consumed, therefore, depends on from which power company the electricity was generated. For the purpose of converting electricity consumption into the equivalent carbon dioxide emission, an average value, weighted by the market shares of the two power companies, is used irrespective of from which power company a simulated building will be fed with electricity supply. Besides electricity, buildings in Hong Kong may also use gas for water heating, cooking and other purposes. The followings show the conversion factors that are used by BEAM Plus (assessment scheme for buildings by HKGBC) for carbon emission calculation: 1) Electricity - 0.7 kg CO2 per kWh electricity consumed; 2) Town Gas - 0.592 kg CO2 per unit of town gas consumed (1 unit of town gas = 48 mega-joules consumed); 3) Natural Gas - 2.31 kg CO2 per kg of natural gas consumed.

This method roughly estimates the amount of carbon emissions by adding a calculation factor converting from energy consumption. The uncertainties of the calculation are mainly because those conversion factors are not constant values, which may vary according to the market shares of energy companies as well as different percentages of fuel mix for different type of buildings.

4. Conclusions

This paper has examined the challenges for modeling carbon emissions in high-rise public residential buildings within the context of Hong Kong. The new modular flat design that HKHA is promoting in current public housing projects has brought substantial benefits to both building quality and cost effectiveness. However, the building models cannot be seamlessly utilized in energy simulation programs due to its nature incompatibilities. This paper has provided a transition approach from BIM model to building energy simulation and proposed some typical issues when transferring BIM data into an energy model for a public residential building in Hong Kong.

While the building physics models and algorithms used by building energy simulation programs are now fairly mature, there are distinct shortcomings in quantifying the energy use attributable to the environmental and occupancy impact. The paper has also analyzed such challenging factors in energy modeling as well as how carbon emissions are calculated for residential buildings in Hong Kong's context. Understanding such challenging factors for a better energy simulation will also inform carbon emission modeling for high-rises in other urban settings.

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