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A study of plot ratio/building height restrictions in high density cities using 3D spatial analysis technology: A case in Hong Kong

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ABSTRACT

Hong Kong is an international metropolis with a highly dense population. As a result, it faces enormous challenges in terms of land supply. As part of the Hong Kong Government's initiative to increase land supply, the Civil Engineering and Development Department (CEDD) proposed minor relaxation of the maximum plot ratio/building height restrictions for 21 target sites in Kai Tak Development Area (KTDA). Although CEDD has explored the feasibility of increasing development intensity by assessing environmental impacts, infrastructure capacity and public consultation, these reviews and assessments were conducted based on the 2D GIS. Since the spatial distribution of land unit in the real world is three-dimensional, 3D GIS can help us look into the world in true perspective and make informed decisions. This study aims to investigate the viability of minor relaxation of maximum plot ratio/building height restrictions of 21 sites in KTDA through 3D modeling and 3D spatial analyses, including skyline, visual impact, shadow and solar exposure. Regarding to the 21 target sites, four scenarios with different plot ratios and building heights were built and compared. The results indicate that minor relaxation of maximum plot ratio and building height leads to (i) minor effect on skyline (ii) minor effect on visual impact and (iii) slight changes in shadow and solar exposure both in winter and summer. Therefore, in light of the findings from this study, scenario 4 is the recommended reasonable scale to relax the maximum plot ratio/building height restriction for the target sites in KTDA. Besides, this study can also be applied in the urban renewal studies and other new development areas in Hong Kong, or even in other densely populated cities.

Keywords: Development control, Planning decision, High density city, 3D spatial analysis, Plot ratio, 3D GIS

1 Introduction

As an international metropolis with a highly dense population, Hong Kong faces enormous challenges in terms of land supply. According to the Information Services Department of Hong Kong Special Administrative Region 2011, over seven million people lived in this tiny place of only 1104 km^2. Even worse, more than 75% of this land is covered with mountains or country parks, which are mostly unsuitable for commercial and residential development, which means some areas may have population densities of more than 400,000 people per km^2. Since land is a scarce and valuable resource in Hong Kong, the most imperative and difficult challenge is related to the land use. In addition, to meet the needs of both current and future developments, environmental and ecological factors should also be considered in the pursuit of sustainable land use (Shen et al., 2009).

With limited land and a huge population, Hong Kong has been struggling to develop every single piece of its land in the urban areas to maximum potential. In order to increase housing supply, the Hong Kong SAR Government has proposed to increase development density in the old Kai Tak Airport site. In Hong Kong, development intensity is mainly controlled by means of lease conditions, statutory outline zoning plans, and the Building (Planning) Regulations, which work inextricably to impose restrictions on site coverage, plot ratio, and building height of individual land lots. The Town Planning Board (TPB) is a statutory organization responsible for the approval of outline zoning plans and any subsequent amendments. In recent years there have been rising concerns over the possible undesirable effects of high-density development and objections for further relaxation of density control in the urban areas. The TPB therefore needs to consider applications to increase development intensity but at the same time ensure that density increase will not cause unacceptable environmental impacts on surrounding areas and that the proposed change will be in line with the Hong Kong Planning Standards Guidelines. To facilitate a more interactive debate on urban density and informed planning decisions toward better provision of urban space, the establishment of an objective and scientific instrument is necessary to help critically assess the actual environmental impact caused by changes in development density.

To achieve sustainable development and more efficient use of limited land resources in Hong Kong, the Government has adopted a multi-pronged approach to increase land supply in the short, medium and long term. In this regard, increasing development/redevelopment intensity of built-up areas by minor relaxation of the maximum plot ratio/building height restrictions becomes an option to increase land supply within a shorter timeframe. With a mission to create high-quality and vibrant living in Hong Kong, our study aims to investigate the viability of slightly increasing plot ratio/building height in high density cities. Therefore, this paper examines the applicability of 3D spatial analysis technology in assessing the impacts of change in development control parameters by means of a case study on the KTDA in Hong Kong.

As part of the Hong Kong Government's initiative to increase land supply, the Civil Engineering and Development Department (CEDD) proposed minor relaxation of maximum plot ratio/building height restrictions for three target areas, including 21 sites zoned as "Residential (B/C)", "Commercial (4/6)", "Mixed Use (2/3)" and "Government, Institution or Community" on the approved Kai Tak Outline Zoning Plan (KTOZP) No. S/K22/4(CEDD, 2015). It is estimated the proposed relaxation of plot ratio/building height would provide additional 129.800 m^2 to the Domestic Gross Floor Area (GFA) as well as 80,100m^2 to the Non-Domestic GFA respectively.

In general, development intensity can be explored by assessing the environmental impacts (i.e. Environmental Impact Assessment, EIA) and carrying capacity of infrastructure as well as public consultation in particular sites (MAUNSELL AECOM, 2006) (Environmental Protection Department, 1997). Findings of an EIA usually include prediction and evaluation of noise impact, air and water quality impact, waste management implications as well as the landscape and visual impact resulting from the proposed development. Besides, assessment of carrying capacities with respect to basic infrastructure provisions, like water supply and transportation system, helps to guide decision makers on land use allocation (Joardar, S. D., 1998). Additionally, public participation also plays an important part in the decision making process of town planning in Hong Kong (CEDD, 2008). Similarly, CEDD explored the feasibility of increasing development intensity of the target sites, and various reviews and assessments have been undertaken with due consideration of the capacity of both planned infrastructure and environment (CEDD, 2015). In general, all these previous research findings are fundamental and valued resources for this study.

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Although geographic information system (GIS) had been integrated in previous studies, it was mainly used as two-dimensional (2D) GIS. Since the spatial distribution of the land unit in the real world is three-dimensional (3D), 3D GIS can help us look into the world in true perspective and make informed decisions. To be more specific, with the aid of 3D GIS, a number of 3D spatial analyses on skyline, visual impact, shadow and solar exposure can be conducted.

In light of the above, this research aims to investigate the viability of minor relaxation of maximum plot ratio/building height restrictions of 21 sites in KTDA through 3D modeling and 3D spatial analyses. The specific objectives of this research are as follows:

1) To establish and verify 3D models of Kai Tak and surrounding areas by collecting and integrating 3D data (such as building, infrastructure and terrain data);
2) To conduct 3D spatial analyses of different plot ratio/building height scenarios based on the 3D models, including skyline, visual impact, shadow and solar exposure.

The proposed methodology and analysis results will be able to support in-depth "what-if" analyses of four different scenarios for the KTDA within the restrictions of both Building Department and Planning Department, and even for planning decision making. These vivid 3D simulation and analysis results would enable decision makers to make scientific decisions for sustainable urban development.

2 Literature Review

Spatial analysis is a general term to describe mathematical methods that use locational information in order to better understand processes generating observed attribute values (Fotheringham and Rogerson, 2009). Löchl (2010) summarized that such techniques are used in many fields, including biology, geography, ethnology, epidemiology, sociology and statistics. In addition, certain spatial analysis, modelling and simulation techniques are assessed for solving location problems and informing spatial allocation and deployment of resources. As illustrated by Goodchild (2009), spatial analysts face an important challenge, to develop a new methodological understanding that is consistent both with the traditional tenets of the scientific method, and with the realities of current practice.

Meanwhile, in urban planning, decision and policy makers are often faced with the problems of dealing with systems in which natural and human factors are interrelated and lack of realistic representations of reality. Ranzinger and Gleixner (1997) described that urban planners and architects have used 2D drawing plans and building elaborate models from wood and pasteboard to convey their ideas for decades. However, all these methods generally have some drawbacks, such as realistic impression, easy adaption to changes or simple comparison between different variants. Therefore, the old methodology could not meet the demand of more influence in planning processes, the advanced technologies (e.g. GIS and remote sensing) are highly necessary to be introduced in current stage. Metaxas et al. (2009) presented how remote sensing and spatially-related technologies can supply planners, engineers, managers, and analysts with information that can be employed to improve urban environment planning and maintenance efforts. The ultimate goal is to protect the environment and contribute to sustainable development. GIS and remote sensing technologies are employed mainly to provide information concerning the sensitivity of the existing environment, i.e. storing and visualizing data, but also for data modelling and analysis. Nevertheless, most cases address a particular environmental application rather than provide a generally applicable approach.

GIS is one of the main analysis tools currently. Many researches make use of GIS as their analysis tool; especially in relation with geographical data (Katzchner et al., 2004). The main reason is that GIS could present an excellent way of transferring complex scientific information into a form that can be easily understood by decision makers and the general public (Matzarakis et al., 2004). GIS has the capability in calculating the true 3D areas when you input various data sources, it is especially benefit for a complex or hilly terrain area like Hong Kong. As we know that 2D GIS has been widely used in major industries, especially in the process of urban construction and development control. Yaakup et al. (2003) discussed and demonstrated the development of GIS database and its integration and application for development control in Malaysia. Yaakup et al. (2005) also used GIS to look into urbanization, urban planning and management in Malaysia. The physical, socio-economic and environmental aspects are particularly of major concerns and should be taken into consideration in the planning process. They applied GIS technology to manage the local plan which includes land use zoning, development density, plot ratio, and building height. They also employed GIS as an invaluable tool for evaluation various scenarios that take into account the socio-economic characteristic of urban dwellers, the constraints of physical development, availability of land and land suitability for different kind of development can be generated. However, only 2D GIS was applied in this study which could not afford a vivid and comprehensive result to the decision makers and public. The similar situation was presented for Kai Tak Forum organized by the sub-committee on South East Kowloon Development Review of the Harbour-front Enhancement Committee (2005). Some participates concerned about the environmental impact, safety, substantial land take and sterilization of waterfront area when the redevelopment is conducted for Kai Tak Area. They overviewed of approximately 250 public comments received in the stage 1 public participation. However, all these comments are from the public participants who look into the 2D drawings and written proposals, there is no vivid simulation for the environmental impacts when the surroundings changes. Therefore, 2D GIS is unable to meet the demands of rapid urban development.

With the in-depth application of computer graphics and database technology, 3D GIS with its unique visualization advantages plays an important role in a variety of planning decision processes. 3D GIS can be combined with the original 2D GIS to communicate complex geographic phenomena. An increasing number of researchers applied 3D GIS to assist in decision making for urban development. In the decision making process, various research works and experiments were conducted using 3D spatial analysis technology. Ranzinger and Gleixner (1997) showed the feasibility and potential benefits of using a 3D-city model for urban planning. Zhang et al. (2004) tended to analyze urban development issues based on 3D city models. They outlined a list of possible 3D spatial analyses including visibility, flood, energy, solar panel, and air pollution. Similarly, Mak et al. (2005) made use of 3D GIS to construct, assess, and analyze the city skyline of Hong Kong. The results showed that 3D GIS is effective in implementing the recommendation of Hong Kong urban design guidelines, such as the quantitative measurement of building height, visibility of ridgeline, and skyline. Alternatively, some researchers were devoted to the studies on issues including climate (Li et al., 2004) and urban routes (Hill et al., 2011). Moreover, some analysis can be only analyzed using 3D modeling techniques, for example the visibility. Yu et al. (2007) demonstrated the use of 3D GIS and form of regression analysis to estimate the value of views in high-rise apartments. They focused on the value of sea views in private high-rise residential properties located near the eastern coast of Singapore. The results showed that an unobstructed sea view will add an average premium of 15% to the property price.

3D GIS and spatial analysis could afford the stakeholders scientific and objective results, especially when they are presented with different alternatives and asked to choose one. However, one of the main problems we met when using the 3D modeling and spatial analysis technology is data sharing, which is must always be considered and encouraged. To overcome this problem, in our study we bought the existed surrounding data from the Hong Kong Lands Department and generated the 3D models for the areas which are still under construction by ourselves. Another limitation is the processing area size and time which depend on the hardware configuration of the computer. If the study area is too large, sometimes the computer cannot work or need more time to process.

Although these studies focused on applying 3D spatial analysis technologies to solve some of the issues in urban development, few studies have emphasized the issue of development control – the effect of relaxation of the maximum plot ratio/building height constraints on the environment. Therefore, in our study, we will focus on the research of investigating the viability of minor relaxation of maximum plot ratio/building height restrictions using 3D models and spatial analyses technology.

3 Research methodology

3.1 Overview of the research

The framework of this study is described comprehensively in Fig. 1. Firstly, based on the approved Kai Tak Outline Zoning Plan and available 3D spatial data, 3D models of Kai Tak and surrounding areas can be established. Then, various 3D spatial analyses on skyline, visual impact, shadow and solar exposure can be conducted. Results of the above analyses will be compared under four different plot ratio/building height scenarios. Finally, research findings referring to previous research on the carrying capacity of environment and infrastructure will be presented.

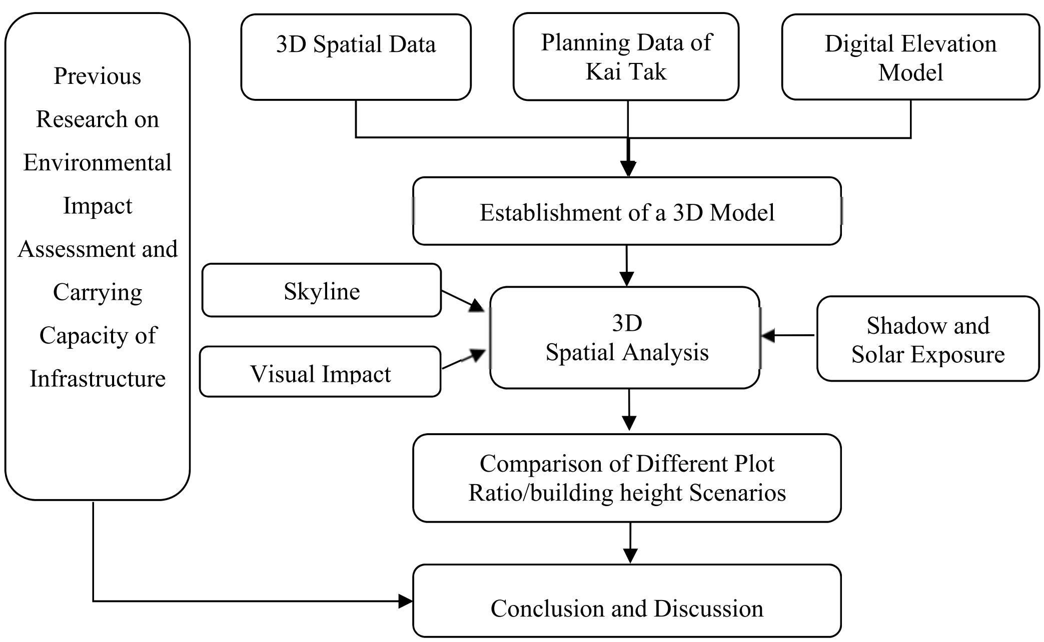

Fig. 1. Framework of the study

3.2 Study area and 3D spatial data collection

A case study is selected in Hong Kong which is a modern city with a highly dense population. The study areas are defined based on the terrain, visual envelope and mountain

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ridge-line, referring to the EIA ordinance from Environmental Protection Department (Environmental Protection Department, 1997). Fig. 2 shows two area boundaries. The inner area boundary in red is the Kai Tak rebuilt planning area where 21 target sites are scattered across (marked in Fig. 3). The outer area boundary in green, within a 500m radius of the planning area, represents the landscape of adjacent region being affected potentially.

Fig. 2. Study areas

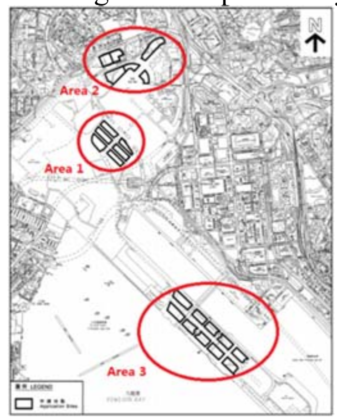

Fig. 3. 21target sites distributed in 3 areas

The 3D spatial data of built-up areas are available from the Hong Kong Lands Department (LandsD), including general footprint, the overall height of the building and information of infrastructure and terrain. Fig. 4 presents an example of the 3D data covering the highlighted area (in pink) as displayed in ArcGIS. For those land units with no existing 3D models, i.e. the KTDA, 3D models will be established according to the planning scheme through Esri CityEngine software.

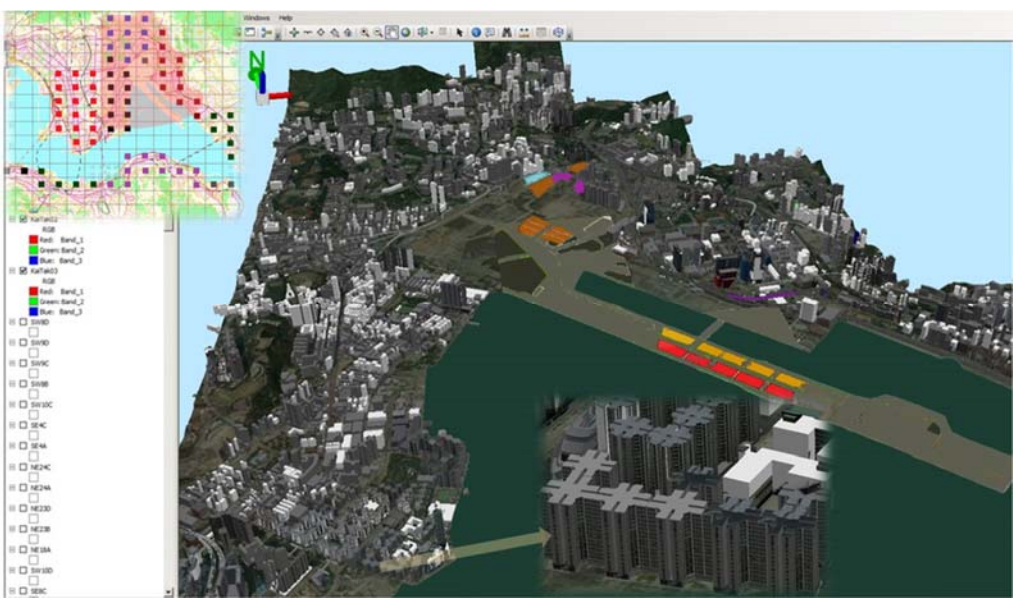

Fig. 4. Example of the visualization of the 3D spatial data

3.3 3D Modeling

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The establishment of new buildings should conform to the planning regulations of both TPB (TPB, 2015) (TPB, 2012) and Building Department (Building Department, 2012). To be more specific, restrictions on zoning, building height, site area as well as corresponding plot ratio and site coverage can be found from the outline zoning plan released by the TPB. We should also refer to the building (planning) regulations for statutory control on the plot ratio, site coverage imposed by the Building Department.

Regarding to the 21 target sites, four scenarios with different plot ratios and building heights will be built for our study. Scenario 1 (S1) is the original plan, which follows the maximum plot ratio/building height defined by KTOZP or Building Planning Regulations (BPR). Scenario 2 (S2) is the approved plot ratio/building height proposed by CEDD. Scenario 3 (S3) and Scenario 4 (S4) referring to further increased plot ratio/building height will be assumed in this study. Relationship between S1, S2, S3 and S4 can be explained as:

$$S3=S2\times(1+(S2-S1)/2S1) \quad (1)$$
$$S4=S2\times(1+(S2-S1)/S1) \quad (2)$$

Tables 1, 2, 3 show the modeling rules of four scenarios for each target site in Areas 1, 2, 3, respectively. For the Gross Floor Area (GFA)/floor and building height items, results were calculated based on Formula (1) and (2) above. As shown in Fig. 5, take the site of 1k1 in Area 1 for example, if the plot ratio in S2 increases by 22% (from 4.5 to 5.5), then, compared with S2, plot ratios in S3 would increase by half of this growth rate (11%) to 6.1, while plot ratio in S4 would increase by the same growth rate of 22% to 6.7. Similar formulas were applied to the calculation of building height in each scenario. If we assume each floor has the same area with a height of 2.9 m, the GFA/floor and site coverage in each scenario would be obtained. In the same way, rules for establishing scenarios of other sites can be acquired.

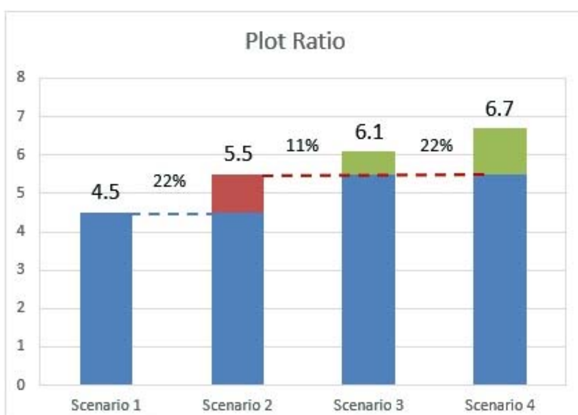

Fig. 5. Bar chart of Plot Ratio calculation for four scenarios.

Table 1
Modeling rules of four scenarios for each target site in Area 1.

Area 1	1K1	1K2	1K3	1L1	1L2	1L3
Zone	R(B)2	R(B)2	R(B)2	R(B)2	R(B)2	R(B)3
Site Area (m^2)	9,719	9,699	11,263	7,317	9,482	8,803
Kai Tak OZP						
Max. Plot Ratio	4.5	4.5	4.5	4.5	4.5	3.5
Max. Site Coverage	40%	40%	40%	40%	40%	44%
Max. Building Height(m)	110	110	110	100	100	50/100

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BPR						
Max. Plot Ratio	9.0	9.0	9.0	9.0	9.0	7.5/10.0
Max. Site Coverage	37.5%	37.5%	37.5%	37.5%	37.5%	42%/40%
Scenario 1 (original)						
Plot Ratio	4.5	4.5	4.5	4.5	4.5	3.5
Site Coverage	11.8%	11.8%	11.8%	13.0%	13.0%	20.3%/10.1%
GFA/floor(m^2)	576	575	668	477	618	893/446
Building Height(m)	110	110	110	100	100	50/100
Scenario 2 (approved)						
Plot Ratio	5.5	5.5	5.4	5.4	5.4	4.2
Site Coverage	12.2%	12.2%	12.0%	13.0%	13.0%	24.3%/10.1%
GFA/floor(m^2)	596	594	678	477	618	1072/446
Building Height(m)	130	130	130	120	120	50/120
Scenario 3						
Plot Ratio	6.1	6.1	5.9	5.9	5.9	4.6
Site Coverage	12.6%	12.6%	12.2%	13.1%	13.1%	22.2%/10.2%
GFA/floor(m^2)	614	612	688	481	623	978/451
Building Height(m)	140	140	140	130	130	60/130
Scenario 4						
Plot Ratio	6.7	6.7	6.5	6.5	6.5	5.0
Site Coverage	12.9%	12.9%	12.5%	13.4%	13.4%	24.1%/10.3%
GFA/floor(m^2)	629	628	707	492	638	1063/455
Building Height(m)	150	150	150	140	140	60/140

Table 2

Modeling rules of four scenarios for each target site in Area 2.

Area 2		**1D2**	**1D3**	**1E1**	**1E2**	**1F1**
Zone		G/IC	G/IC	Mixed Use (3)	C(6)	Mixed Use (2)
Site Area (m^2)		20,088*(7/8)		16,937	7,211+6,929	16,260
Kai Tak OZP						
Max. Plot Ratio	Domestic	-	-	4.75	-	5.0
	Non-domestic	-	-	2.25	6.0	2.0
Max. Site Coverage		-	-	65%	65%	65%
Max. Building Height(m)		100	60	100	100	125/150
BPR						
Max. Plot Ratio		-	-	15	-	15
Max. Site Coverage		-	-	65%	-	65%
Scenario 1 (original)						
Plot Ratio	Domestic	-	-	4.75	-	5.0
	Non-domestic			2.25	6.0	2.0
Site Coverage	Domestic	-	-	13.7%	-	11.6%/9.6%
	Non-domestic				17.4%	
GFA/floor(m^2)	Domestic	-	-	2333	-	943/785
	Non-domestic	4519	6026		1254+1205	
Building Height(m)		100	60	100	100	125/150
Scenario 2 (approved)						
Plot Ratio	Domestic	-	-	6.0	-	6.1
	Non-domestic	-	-	2.2	7.2	2.0
Site Coverage	Domestic			14.5%	-	12.2%/10.4%
	Non-domestic				17.4%	
GFA/floor(m^2)	Domestic			2455	-	991/845
	Non-domestic	4519	6026		1254+1205	
Building Height(m)		120	80	120	120	145/170

Scenario 3						
Plot Ratio	Domestic	-	-	6.5	-	6.7
	Non-domestic	-	-	2.5	7.8	2.3
Site Coverage	Domestic			14.5%	-	12.5%/11.1%
	Non-domestic				17.4%	
GFA/floor(m^2)	Domestic			2455	-	1019/902
	Non-domestic	4519	6026		1254+1205	
Building Height(m)		130	90	130	130	155/175
Scenario 4						
Plot Ratio	Domestic	-	-	7.0	-	7.4
	Non-domestic	-	-	2.5	8.5	2.3
Site Coverage	Domestic			14.5%	-	13%/11.9%
	Non-domestic				17.6%	
GFA/floor(m^2)	Domestic			2455	-	1057/969
	Non-domestic	4519	6026		1269+1219	
Building Height(m)		140	100	140	140	165/180

Table 3
Modeling rules of four scenarios for each target site in Area 3.

Area 3	**4A1**	**4B1**	**4B2**	**4B3**	**4B4**
Zone	R(C)	R(C)	R(C)	R(C)	R(C)
Site Area (m^2)	13,524	9,578	9,047	9,844	9,692
Kai Tak OZP					
Max. Plot Ratio	3.0	3.0	3.0	3.0	3.0
Max. Site Coverage	47%	47%	47%	47%	47%
Max. Building Height(m)	65/80	55	55	65	55
BPR					
Max. Plot Ratio	10.0	8.0	8.0	10.0	8.0
Max. Site Coverage	40%	41%	41%	40%	41%
Scenario 1 (original)					
Plot Ratio	3.0	3.0	3.0	3.0	3.0
Site Coverage	13.3%/10.8%	15.8%	15.8%	13.3%	15.8%
GFA/floor(m^2)	905/735	1515	1431	1317	1533
Building Height(m)	65/80	55	55	65	55
Scenario 2 (approved)					
Plot Ratio	3.4	3.8	4.4	3.9	3.7
Site Coverage	12.3%/12.3%	16.9%	17%	15.0%	16.5%
GFA/floor(m^2)	833/833	1623	1539	1484	1599
Building Height(m)	80/80	65	75	75	65
Scenario 3					
Plot Ratio	3.6	4.3	5.4	4.5	4.1
Site Coverage	12.2%/12.2%	17.8%	19.5%	16.3%	16.9%
GFA/floor(m^2)	830/830	1706	1770	1605	1646
Building Height(m)	85/85	70	80	80	70
Scenario 4					
Plot Ratio	3.8	4.8	6.4	5.0	4.5
Site Coverage	12.2%/12.2	18.5	21.8	17	17.4
GFA/floor(m^2)	827/827	1777	1975	1679	1686
Building Height(m)	90/90	75	85	85	75

Area 3	**4A2**	**4C1**	**4C2**	**4C3**	**4C4**
Zone	C(4)	C(4)	C(4)	C(4)	C(4)
Site Area (m^2)	12,976	9,502	9,771	11,094	10,694
Kai Tak OZP					
Max. Plot Ratio	4.0	4.0	4.0	4.0	4.0
Max. Site Coverage	80%	80%	80%	80%	80%
Max. GFA(m^2)	51,904	38,008	39,084	44,376	42,776
Max. Building Height(m)	45	45	55	45	45

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BPR					
Max. Plot Ratio	-	-	-	-	-
Max. Site Coverage	-	-	-	-	-
Scenario 1 (original)					
Plot Ratio	4.0	4.0	4.0	4.0	4.0
Site Coverage	25.7%	25.7%	21.0%	25.7%	25.7%
GFA/floor(m^2)	3344	2449	2060	2859	2756
Building Height(m)	45	45	55	45	45
Scenario 2 (approved)					
Plot Ratio	5.0	5.0	5.9	5.0	5.0
Site Coverage	26.3%	26.3%	26.3%	26.3%	26.3%
GFA/floor(m^2)	3420	2505	2572	2924	2819
Building Height(m)	55	55	65	55	55
Scenario 3					
Plot Ratio	5.5	5.5	6.8	5.5	5.5
Site Coverage	26.5%	26.5%	28.1%	26.5%	26.5%
GFA/floor(m^2)	3449	2525	2752	2949	2842
Building Height(m)	60	60	70	60	60
Scenario 4					
Plot Ratio	6.0	6.0	8.7	6.0	6.0
Site Coverage	26.7%	26.7%	33.6%	26.7%	26.7%
GFA/floor(m^2)	3473	2543	3286	2969	2862
Building Height(m)	65	65	75	65	65

3D modeling is the process of developing a mathematical representation of any 3D surface of an object via specialized software (3D modeling, 2015). To make comprehensive comparison among different scenarios, 3D models were created based on a simple design without considering more details in this pilot study, such as the texture/façade, podium design, and building materials of the proposed buildings. Commercial software ArcGIS and CityEngine developed by Esri (Environmental Systems Research Institute) were employed to model 3D buildings. ArcGIS was applied to model the footprint of buildings (shown in Fig. 6). A footprint is a 2D object, called polygon comprised by a set of feature lines each made by connecting a pair of vertex, also called feature points, with geographic coordinate information.

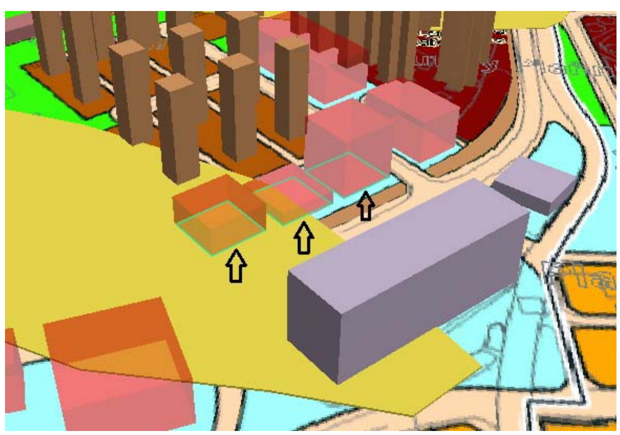


Fig. 6. Footprint of buildings

All footprints were modelled in and around three target areas on the land layout published by TPB (Fig. 7). To assess the impact of various factors, an assumption was made that all buildings are modeled into the standard rectangular. Then, all 2D footprints are transformed to 3D models using CityEngine (Fig. 8). After completion, all 3D building models will be combined in one scene in different view directions (Fig. 9) with other 3D buildings and topographic data for the following analyses.

Fig. 7. Footprint in three areas

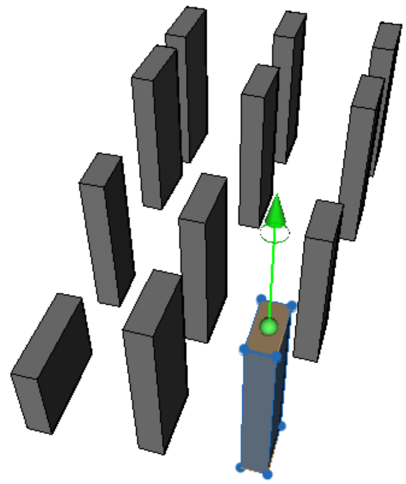


Fig. 8. Transformation from 2D to 3D

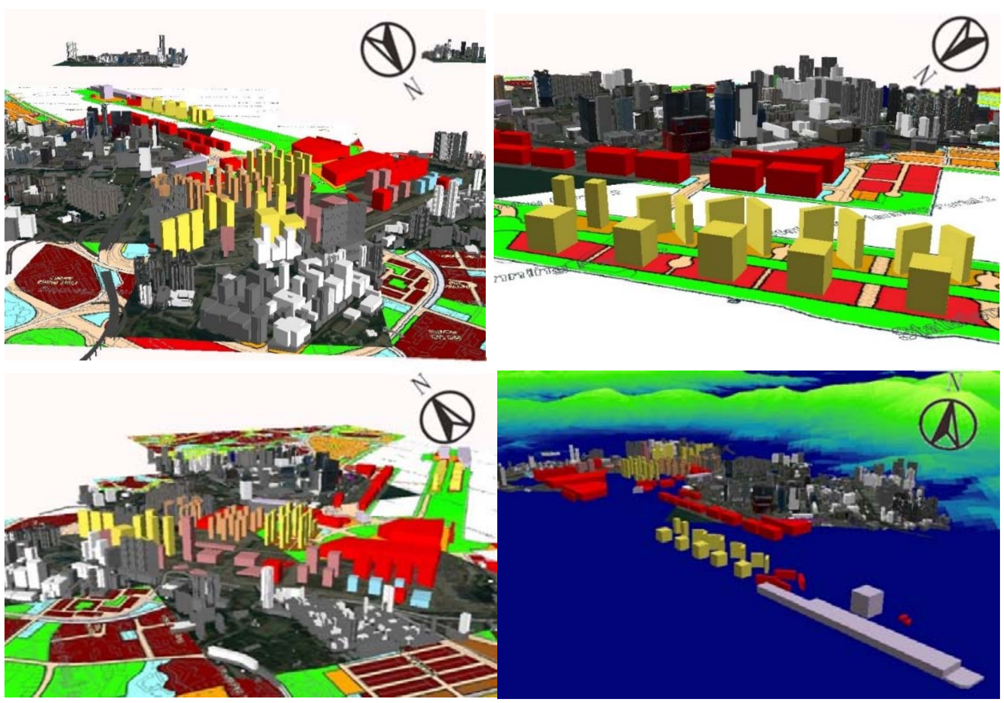


Fig. 9. 3D Models of KTDA in different view directions and perspectives

3.4 Three-dimensional spatial analyses

3.4.1 Skyline

A skyline is the horizon that a city's overall structure, human intervention in a non-urban setting, nature and creates. City skylines serve as a kind of fingerprint as no two skylines are alike. For this reason, skylines are always presented to establish a city location as well as used for the city renewal (Skyline, 2015). Skyline in 3D scene is used to compare the difference among four scenarios. As Fig. 10 shows, two skylines were selected to compare the visual effects for four different scenarios. In this way, the increased building height can be investigated to what extent affect the city skyline.

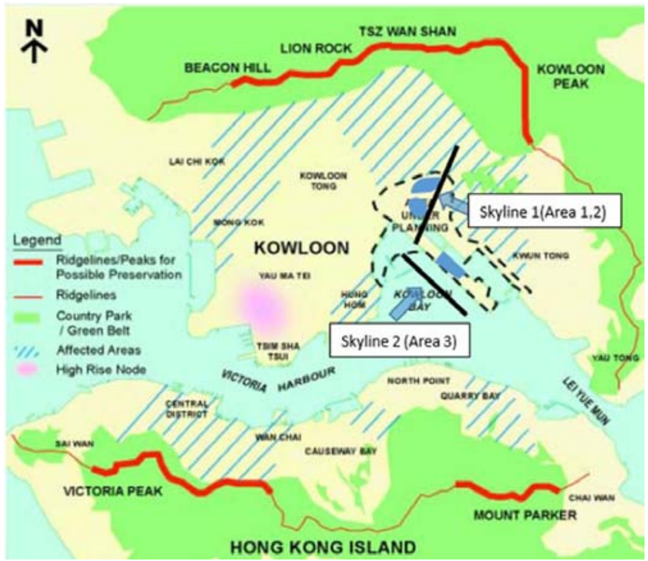


Fig. 10. Two skylines comparison for different scenarios.

3.4.2 Visual impact

Urban renewal should match with the unique topographical and landscape setting of the city, especially the maintenance of the dramatic mountain backdrop (Planning Department and RMUM Hong Kong Limited, 2002). The objective is to promote Hong Kong's image as a world-class city by enhancing the quality of our build environment from both functional and aesthetic perspectives.

According to urban design guidelines published by the Urban Planning Department, ridgelines/peaks are valuable assets, especially those in Kowloon and Hong Kong Island which is shown in Fig. 11 (Planning Department and RMUM Hong Kong Limited, 2002). Therefore, conservation of ridgelines is an important step and deserves particular attention in urban development. As shown in Fig. 12, seven vantage points were chose around Victoria Harbor as start reference points for consideration of views to ridgelines/peaks. In consideration of the redevelopments, existing and future views from these seven vantage points to ridgelines/peaks on the other side of the harbor were examined. In view of the location of our study area, only three vantage points along the Victoria Harbor were selected, including Quarry Bay Park, Hong Kong Convention & Exhibition Center New Wing and Sun Yat Sen Memorial Park. Then, view corridors from the vantage points were established to preserve views to the ridgeline in Kowloon Island shown in Fig.11.

Guo J., Sun B.X., Qin Z., Wong S.W., Wong M.S., Yeung C.W., *Shen Q.P. (2017). A study of plot ratio/building height restrictions in high density cities using 3D spatial analysis technology: A case in Hong Kong, Habitat International, 65, July 2017, 13-31. DOI: 10.1016/j.habitatint.2017.04.012, July. (SCI, IF=2.029, Ranked 7/55 in Planning & Development, 6/39 in Urban Studies by JCR in 2015).

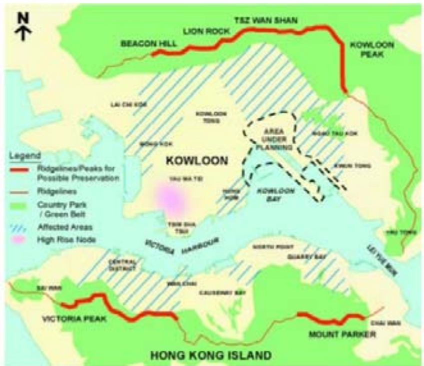


Fig. 11. Ridgelines of Kowloon and Hong Kong Island **Fig. 12.** Proposed vantage points

（**Source:** Planning Department and RMUM Hong Kong Limited, 2002）

According to the urban design guidelines, to protect these ridgelines/peaks, at least 20% building free zone (see Fig. 13) is recommended to be maintained based on the Metroplan (1991) guidelines. This zone is formed by a pair of two lines: ridgelines and limit of roofline.

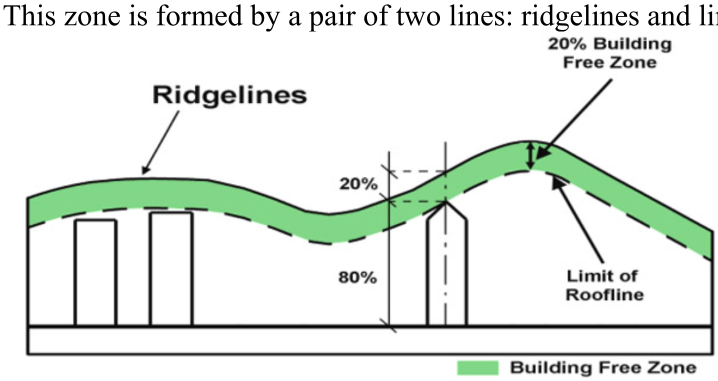


Fig. 13. Schematic diagram of building free zone

Following this recommendation, the roofline limit of the building free zone for the ridgeline in Kowloon was modeled by using sampling point methods in 3D scene (see Fig. 14). From the selected three vantage points to the limit of the roofline, these sampling points in red shown in Fig. 14 were created with one degree interval between each pair of sightlines along the ridgelines in Kowloon area. Then, the visual impact between these complete sample points and the three chosen vantage points can be analyzed in 3D scene.

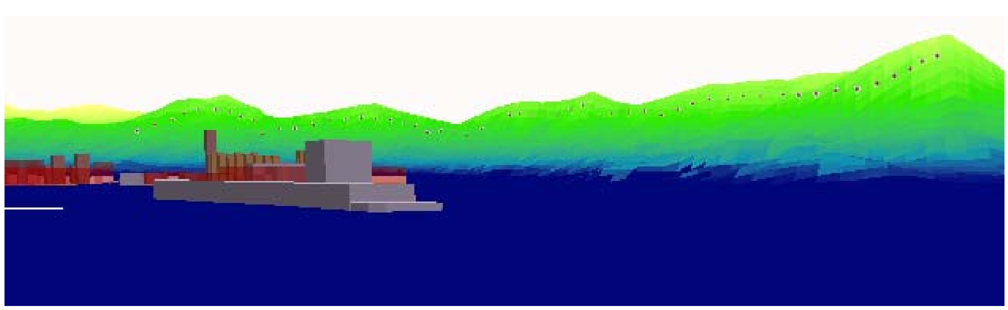


Fig. 14. Sample points on limit of roofline

3.4.3 Shadow and Solar Exposure

As part of electromagnetic radiation emitted by the sun, sunlight is visible during the day when the sun is above the horizon of the Earth (Sunlight, 2015). A shadow described here is a region where the sunlight is obstructed by an opaque object. It occupies all 3D volume behind an object with light in front of it (Shadow, 2015). To measure the solar exposure, sun exposure hours are usually used.

Based on this analysis, we aim to investigate the impact of minor increased plot ratio/building height on shadow and solar exposure through the differences between scenarios 2 versus 3, and scenarios 2 versus 4. The differences include sunlight hours as well as solar exposure distribution.

Three study areas were determined based on solar altitude and sunlight shadow. With careful consideration of the effect of surrounding mountains, a 20° solar altitude is reasonable and finally adopted for the analysis of solar exposure. Besides, due to the difference of sun azimuth and altitude between summer and winter, both seasons for the three areas were considered in this study. The three study areas are shown in Fig. 15 both in winter and summer. Then, the calculations of average sunlight hours per day can be conducted.

4 Analysis and findings

4.1 Skyline

Fig. 16 presents skyline 1 of three target areas in four scenarios. Each scenario shows the buildings both in Area 1 (yellow buildings on the left) and Area 2 (yellow buildings on the right). The height of the buildings in Areas 1 and 2 is gradually increased from scenarios 1 to 4. The degree of increase is not obviously significant. Thus, the negative effect of increasing plot ratio/building height on the scene of skyline 1 is not significant.

Similarly, four different scenarios for scenes of skyline 2 are shown in Fig. 17. Each scenario presents the buildings in Area 3 (buildings in yellow). The height of buildings in Area 3 is gradually increased from scenarios 1 to 4. In the same manner, with relatively insignificant height increase, the negative effect of increasing plot ratio/building height on the scene of skyline 2 is also reasonable and acceptable. Moreover, compared with traditional baseline photographs for landscape assessment, 3D GIS provides a more vivid and convenient method for visualization.

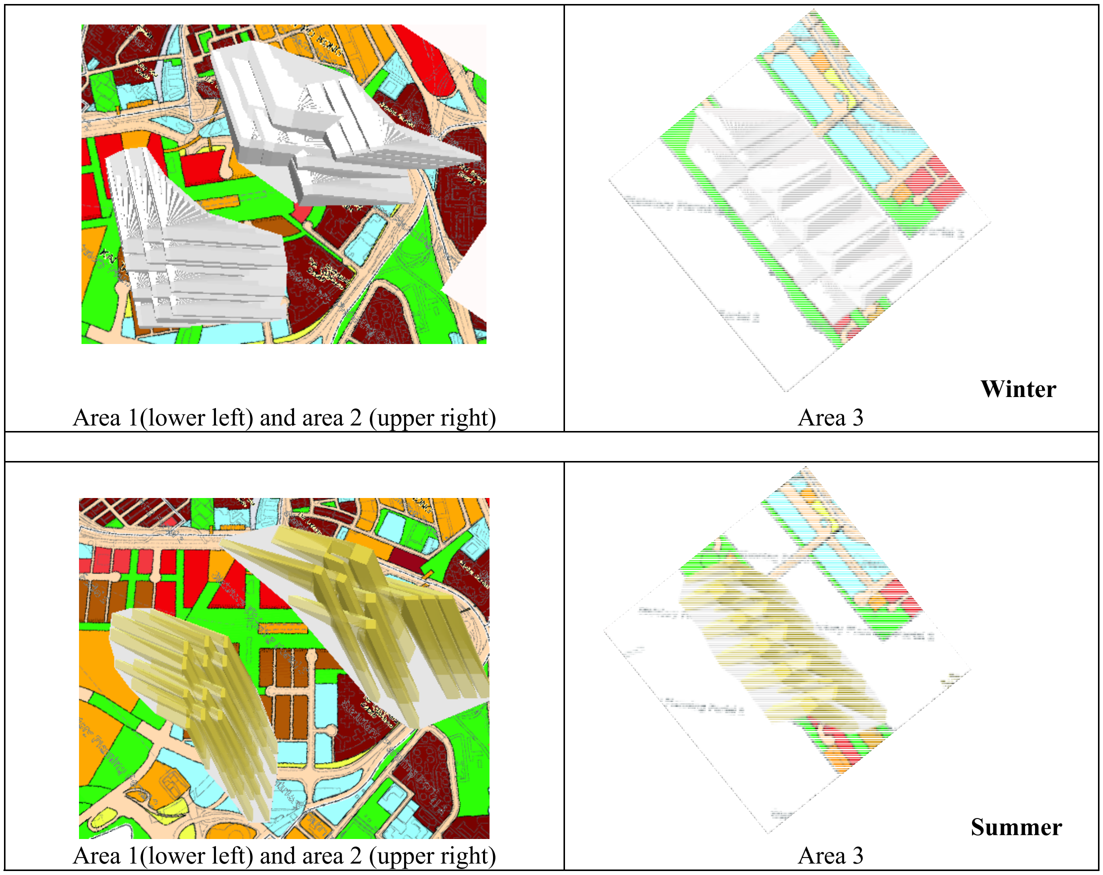
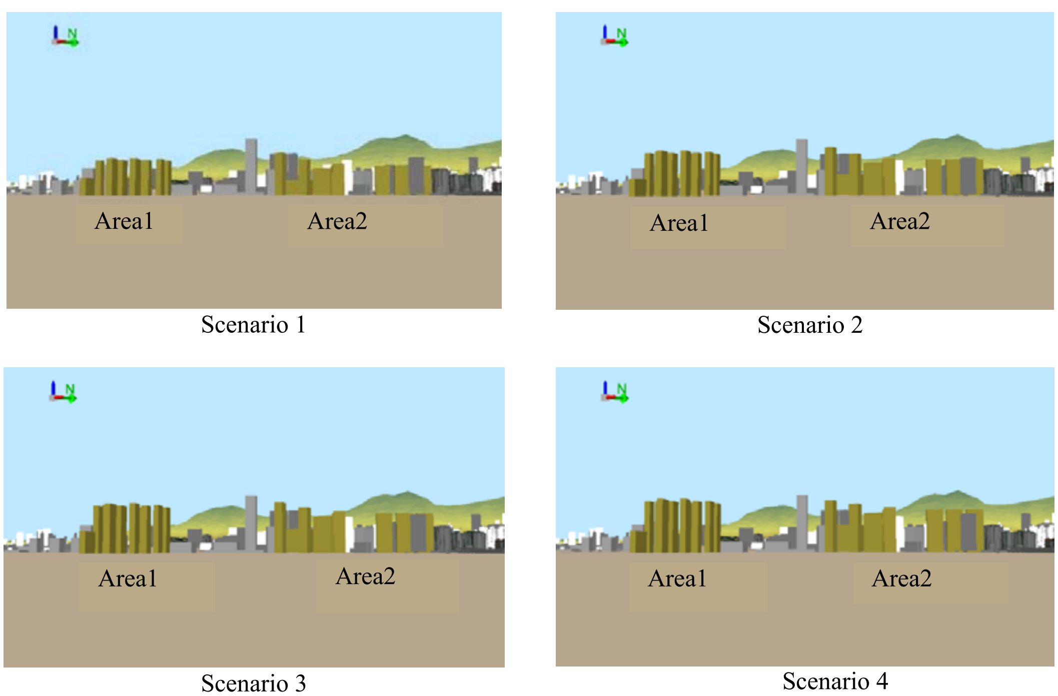


Fig. 15. Three selected study areas for solar exposure analysis



Guo J., Sun B.X., Qin Z., Wong S.W., Wong M.S., Yeung C.W., *Shen Q.P. (2017). A study of plot ratio/building height restrictions in high density cities using 3D spatial analysis technology: A case in Hong Kong, Habitat International, 65, July 2017, 13-31. DOI: 10.1016/j.habitatint.2017.04.012, July. (SCI, IF=2.029, Ranked 7/55 in Planning & Development, 6/39 in Urban Studies by JCR in 2015).

Fig. 16. Scenes of Skyline 1

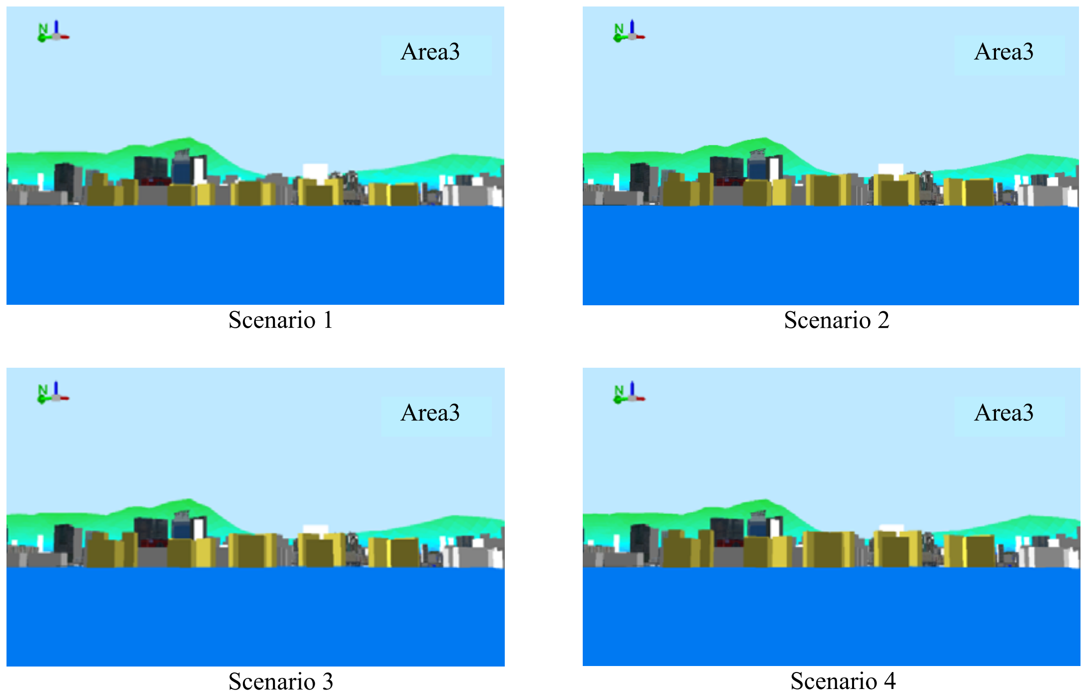


Fig. 17. Scenes of Skyline 2

4.2 Visual impact

According to the building free zone guideline mentioned above, visibility between sampling points along the ridgeline and three vantage points in the 3D scene was analyzed. With continuous increases in heights for four scenarios, blocked sightlines only existed in scenario 4 at the vantage point of Quarry Bay Park. Fig. 18 shows that three bundles of sightlines in red from two sample points are blocked at Quarry Bay Park vantage point in scenario 4.

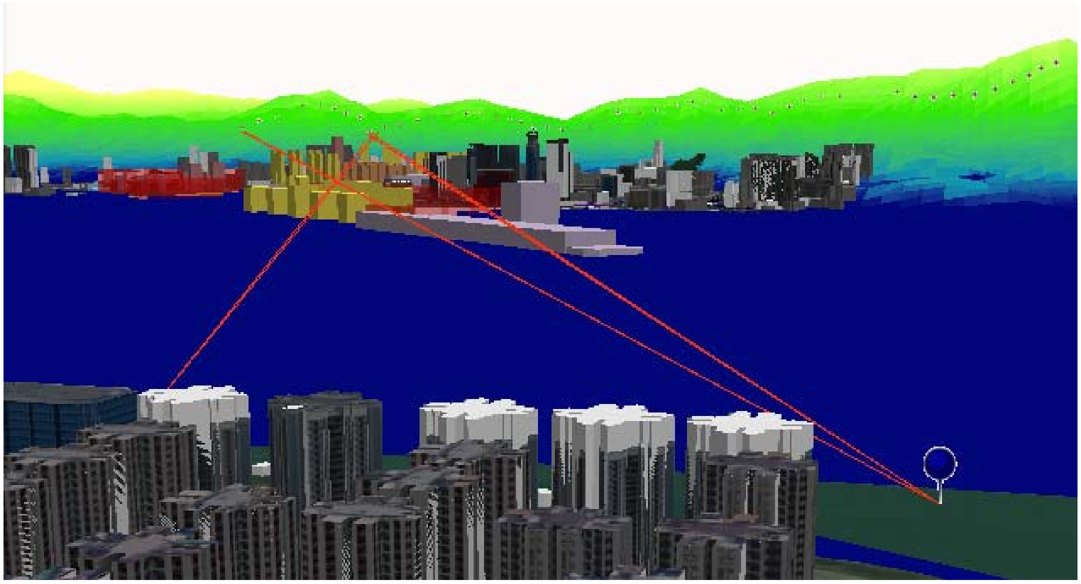


Fig. 18. Blocked sightlines and the Quarry Bay Park vantage point in Scenario 4

In order to calculate the blocked areas and corresponding percentages, for each blocked sightline, the maximum block angle, the sum of total block angles, and the maximum angle for each sampling points are measured and presented in Fig. 19. Furthermore, two types of angles are described and calculated for the three bundle sightlines. The first one is the maximum blocked angle, which means the angle between the leftmost and rightmost bundle of sightlines being blocked as building height increased in different scenarios. The other one is the sum of angle for blocked bundle of sightlines, which indicates the summation of all block angles for adjacent pairs of sightlines within the same bundle.

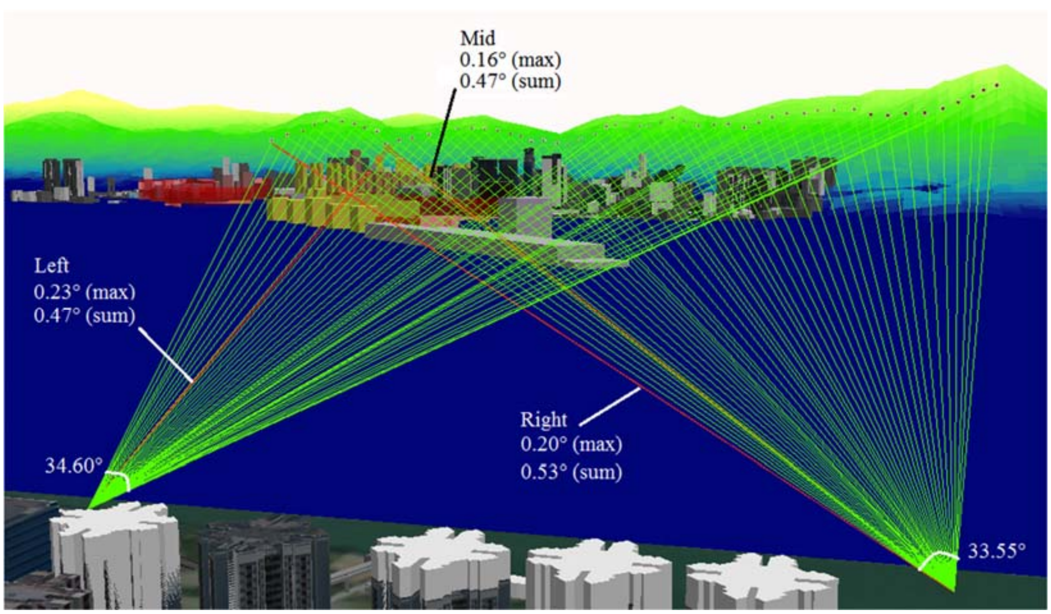


Fig. 19. Angle of sightlines blocked and angle of all sightlines for each vantage point

Guo J., Sun B.X., Qin Z., Wong S.W., Wong M.S., Yeung C.W., *Shen Q.P. (2017). A study of plot ratio/building height restrictions in high density cities using 3D spatial analysis technology: A case in Hong Kong, Habitat International, 65, July 2017, 13-31. DOI: 10.1016/j.habitatint.2017.04.012, July. (SCI, IF=2.029, Ranked 7/55 in Planning & Development, 6/39 in Urban Studies by JCR in 2015).

A block percentage (shown in Table 4) was calculated based on the above angles presented in Fig. 19. Specifically, block percentage for maximum block angle was calculated by the maximum blocked angle of a bundle of sightline over the maximum angle of a sample point for each vantage point. Similarly, the block percentage for sum of block angle was calculated by the sum of blocked angle of a bundle sightline over the maximum angle of a sample point for each vantage point. Figures in Table 4 indicate that the negative visual impact on the conservation of ridgelines is relatively insignificant as the plot ratio/building height increase.

Table 4.
Block ratio of the sightlines between sample points and vantage points.

Blocked sightlines	Left Bundle	Mid Bundle	Right Bundle
Block percentage (maximum blocked angle)	0.66%	0.60%	0.48%
Block percentage (sum of blocked angles)	1.38%	1.40%	1.58%

4.3 Shadow and solar exposure

For the three target areas, a calculation of average sunlight hours per day was conducted. For comprehensive analysis, the results are presented in 3D scenes for the three areas based on the selected regions both in winter (see Fig. 20) and summer (see Fig. 21). Specifically, Fig. 20 shows eight classes of sunlight hours from (0, 1] to (7, 8] in different hues. From these results, it is noticed that the differences between scenarios 2 and 3, scenarios 2 and 4 are not obvious. Therefore, a quantitative analysis is required for these 3D scenes in winter for further comparison.

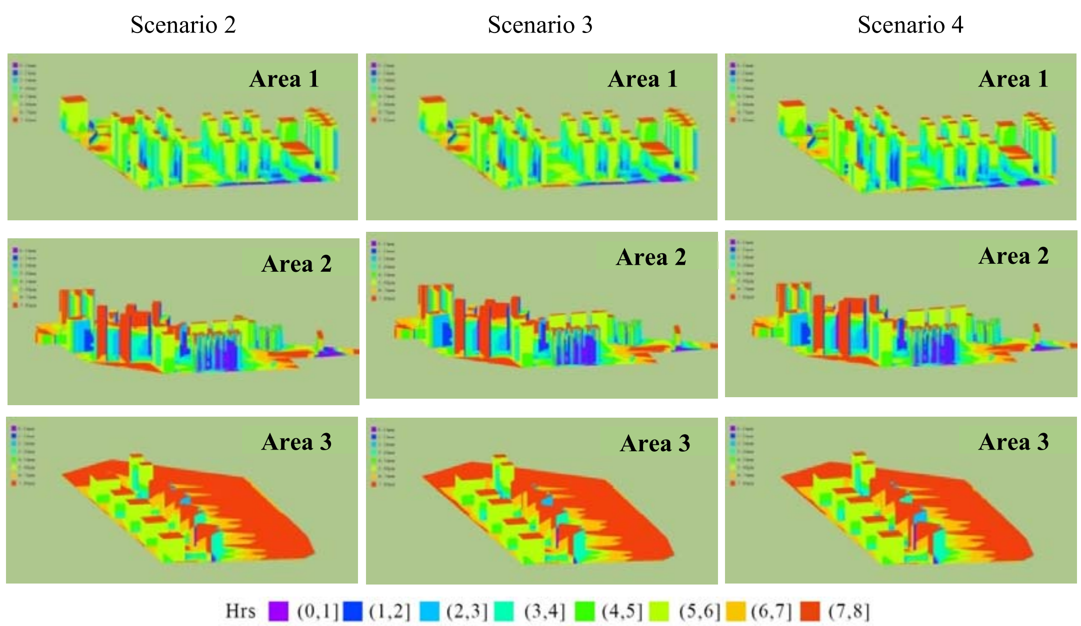


Fig. 20. Results of average sunlight hours per day in winter

Similarly, Fig.21 shows ten classes of sunlight hours from (0, 1] to (9, 10] in different hues. Similar to Fig.20, the differences between scenarios 2 and 3, scenarios 2 and 4 are not apparent. A quantitative analysis thereby is also required for these 3D scenes in summer.

Guo J., Sun B.X., Qin Z., Wong S.W., Wong M.S., Yeung C.W., *Shen Q.P. (2017). A study of plot ratio/building height restrictions in high density cities using 3D spatial analysis technology: A case in Hong Kong, Habitat International, 65, July 2017, 13-31. DOI: 10.1016/j.habitatint.2017.04.012, July. (SCI, IF=2.029, Ranked 7/55 in Planning & Development, 6/39 in Urban Studies by JCR in 2015).

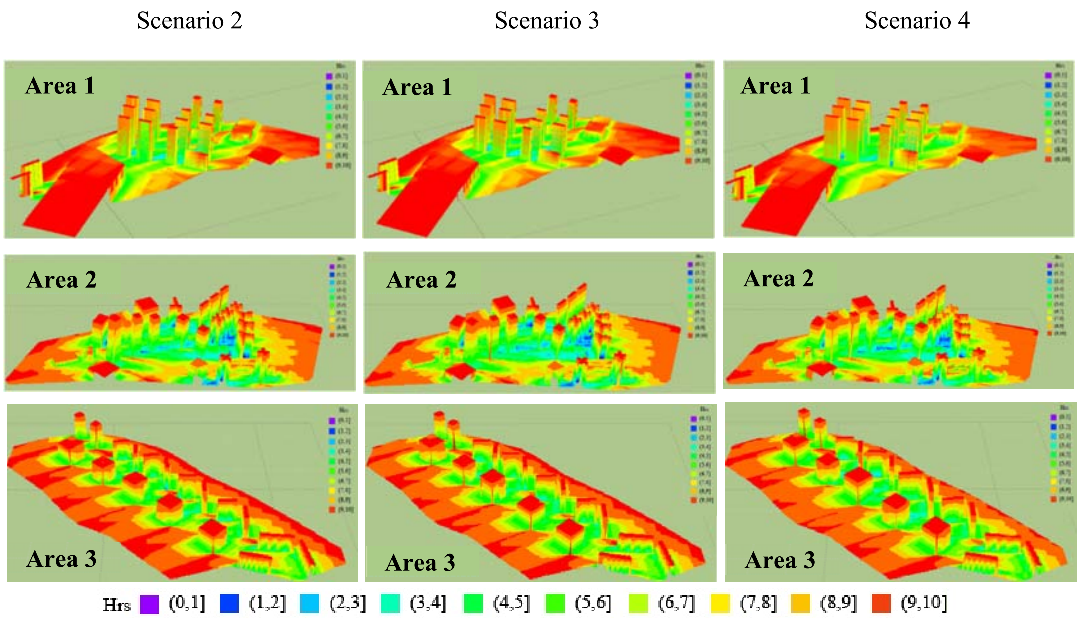


Fig. 21. Results of average sunlight hours per day in summer

For further comparison of different scenarios for the three target areas in winter, the area size and corresponding percentage of building surface portions and ground for each category of sunlight hour were quantified. Statistical results for the three areas are shown respectively in Table 5. It is noticed that, due to the gradual increase in height for scenarios 2, 3 and 4, the area size of the category with the longest sunlight decreased accordingly for Areas 1, 2 and 3.

Table 5.
Area size and corresponding percentage for different categories of sunlight hours in winter.

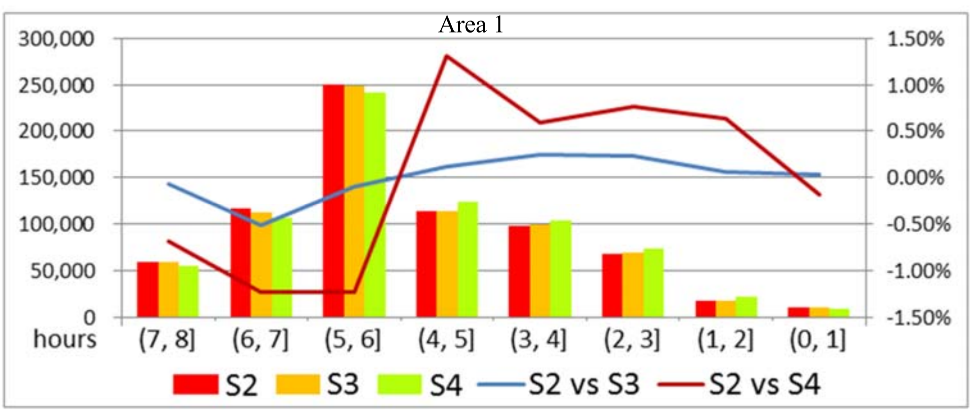
Area 1		Scenario 2 (m^2)		Scenario 3 (m^2)		Scenario 4 (m^2)	
(7, 8] hours	red	8.16%	59869	8.09%	59152	7.47%	54956
(6, 7] hours	orange	15.81%	115995	15.30%	111898	14.58%	107241
(5, 6] hours	light green	34.08%	250052	33.97%	248460	32.85%	241611
(4, 5] hours	green	15.46%	113411	15.57%	115868	16.77%	123336
(3, 4] hours	light blue	13.46%	98751	13.70%	101207	14.05%	103369
(2, 3] hours	blue	9.25%	67897	9.48%	69351	10.02%	73724
(1, 2] hours	dark blue	2.37%	17421	2.43%	17794	3.01%	22167
(0, 1] hours	purple	1.42%	10415	1.45%	10612	1.23%	9069
Total		100%	733815	100%	734346	100%	735476

Area 2		Scenario 2(m^2)		Scenario 3 (m^2)		Scenario 4 (m^2)	
(7, 8] hours	red	21.83%	213138	20.74%	202816	19.54%	180260
(6, 7] hours	orange	10.61%	103611	10.36%	101349	9.97%	92183
(5, 6] hours	light green	15.63%	152627	16.66%	162899	17.80%	179472
(4, 5] hours	green	13.75%	134261	13.95%	136439	13.50%	136188
(3, 4] hours	light blue	11.58%	113029	12.18%	119062	11.78%	118793

(2, 3] hours	blue	12.59%	122933	12.50%	122229	12.91%	130155
(1, 2] hours	dark blue	7.61%	74336	7.56%	73917	8.01%	80754
(0, 1] hours	purple	6.38%	62254	6.04%	59103	6.50%	65538
Total		100%	976191	100%	977816	100%	1008483

Area 3		Scenario 2(m^2)		Scenario 3 (m^2)		Scenario 4 (m^2)	
(7, 8] hours	red	34.00%	164205	32.97%	158557	31.05%	154167
(6, 7] hours	orange	33.93%	163871	33.41%	160649	33.87%	163167
(5, 6] hours	light green	13.75%	66405	14.36%	69052	14.12%	70126
(4, 5] hours	green	11.15%	53864	11.59%	55707	11.64%	57815
(3, 4] hours	light blue	3.31%	16002	3.62%	17395	3.69%	18309
(2, 3] hours	blue	3.00%	14488	3.11%	14958	4.54%	22544
(1, 2] hours	dark blue	0.59%	2826	0.63%	3046	0.76%	3775
(0, 1] hours	purple	0.28%	1343	0.31%	1473	0.33%	1658
Total		100%	483008	100%	486010	100%	490565

To further examine the variation trend of sunlight hours for different scenarios, the difference in area size and corresponding percentage between scenarios 2 and 3, scenarios 2 and 4 were calculated and illustrated in blue and red curves in Fig. 22, respectively. According to Table 5, the figures were also presented in histograms (see Fig. 22): the left legend presents the area size, while the right legend indicates the variation rate of two curves. From the figure, the extent of changes for Areas 1, 2 and 3 is relatively small (within 1.5%). The two curves indicate that the difference at the longest sunlight categories, namely the (7, 8] and (6, 7] would be reduced because of the increased building height. Meanwhile, shorter sunlight categories, such as (5, 6], (4, 5], (3, 4], (2, 3] and (1, 2], would be increased accordingly. For the shortest sunlight category, since the height is almost close to the ground level, the difference is fluctuated around 0%. However, all changes are insignificant, which indicates that effect of the increase in the maximum plot ratio/building height in winter is not significant.



Area 2

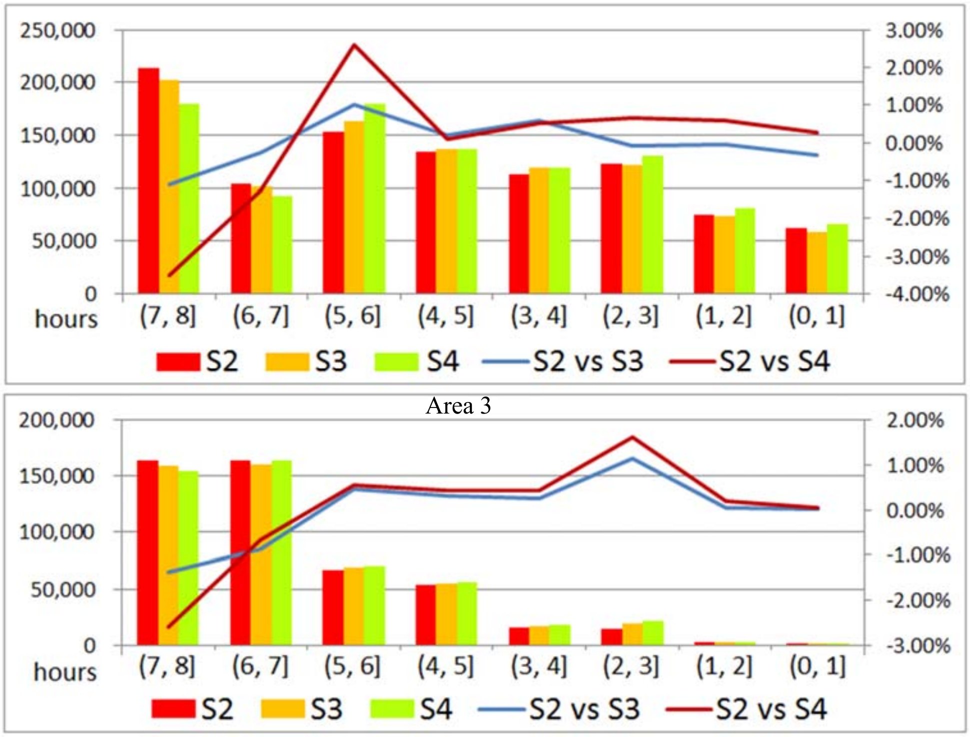


Fig. 22. Differences between S2 and S3, and between S2 and S4 in winter

Similarly, Table 6 shows the statistical results of the area size and their corresponding percentage of buildings surface portions and the ground for the three areas in summer. Compared with Table 5, there are ten categories of sunlight hours for scenarios 2, 3, and 4 in summer.

Table 6.
Area size and corresponding percentage for different categories of sunlight hours in summer.

Area 1		Scenario 2 (m^2)		Scenario 3 (m^2)		Scenario 4 (m^2)	
(9, 10] hours	red	29.39%	175425	29.27%	175225	28.89%	173250
(8, 9] hours	dark orange	16.59%	99050	16.63%	99525	17.25%	100800
(7, 8] hours	orange	12.63%	75400	12.53%	75000	10.97%	67675
(6, 7] hours	yellow	12.21%	72875	12.11%	72475	11.80%	72825
(5, 6] hours	yellow green	13.46%	80375	13.68%	81900	13.65%	84250
(4, 5] hours	light green	8.42%	50275	8.28%	49550	8.87%	54725
(3, 4] hours	green	3.53%	21100	3.74%	22375	3.62%	22325
(2, 3] hours	light blue	3.27%	19525	3.29%	19700	3.15%	19425
(1, 2] hours	blue	0.49%	2950	0.47%	2825	1.79%	6075

(0, 1] hours	dark blue	0.00%	0	0.00%	0	0.02%	100
Total			596975		598575		601450

Area 2		Scenario 2 (m^2)		Scenario 3 (m^2)		Scenario 4 (m^2)	
(9, 10] hours	red	27.01%	248300	26.77%	249125	26.90%	252050
(8, 9] hours	dark orange	19.20%	176525	18.82%	175150	19.20%	179900
(7, 8] hours	orange	12.95%	119050	12.71%	118275	12.42%	116375
(6, 7] hours	yellow	11.50%	105750	11.18%	104000	10.81%	101275
(5, 6] hours	yellow green	11.38%	104650	10.82%	100675	11.08%	103850
(4, 5] hours	light green	7.84%	72100	8.40%	78125	7.86%	73675
(3, 4] hours	green	5.58%	51275	6.25%	58150	6.53%	61175
(2, 3] hours	light blue	2.65%	24400	2.92%	27150	2.92%	27350
(1, 2] hours	blue	1.27%	11700	1.44%	13375	1.51%	14125
(0, 1] hours	dark blue	0.60%	5525	0.70%	6550	0.76%	7125
Total			919275		930575		936900

Area 3		Scenario 2 (m^2)		Scenario 3 (m^2)		Scenario 4 (m^2)	
(9, 10] hours	red	40.68%	222760	40.58%	230980	40.09%	241360
(8, 9] hours	dark orange	18.82%	103060	18.00%	102460	17.82%	107320
(7, 8] hours	orange	14.26%	78060	13.29%	75680	13.16%	79260
(6, 7] hours	yellow	13.04%	71380	13.62%	77540	13.23%	79640
(5, 6] hours	yellow green	9.94%	54440	10.37%	59020	10.31%	62060
(4, 5] hours	light green	2.54%	13900	2.99%	17040	3.67%	22100
(3, 4] hours	green	0.68%	3700	1.08%	6160	1.53%	9240
(2, 3] hours	light blue	0.04%	220	0.06%	360	0.19%	1120
(1, 2] hours	blue	0.01%	40	0.00%	0	0	0
(0, 1] hours	dark blue	0.00%	0	0.00%	0	0	0
Total			547560		569240		602100

Similarly, in accordance with Table 6, Fig. 23 was drawn to compare the sunlight hours for the three target areas in summer. Differences in area sizes and corresponding percentages of building surface portions and the ground with ten categories of sunlight hours between scenarios 2 and 3, scenarios 2 and 4 were identified. The trend of differences for the three areas is very consistent. The two curves present that the difference at longer sunlight categories, such as (9, 10], (8, 9] and (6, 7], would be reduced due to the increased building height. While, for shorter sunlight categories, such as (3, 4], (2, 3], the difference would be increased accordingly. For the shortest sunlight category, the vibration rate also fluctuates around 0%. Specifically, for middle categories such as (5, 6] and (4, 5], the vibration rate may not be fixed for different study areas because of the various layouts and directions of buildings. Sunlight hours are increased in Areas 1, 3 and decreased in Area 2. The possible reason is that the spacing between the buildings in Area 2 is relatively larger than that in Areas 1 and 3. In general, all changes are insignificant, which shows that the impact of increased plot ratio/building height on shadow and solar exposure in summer is relatively small.

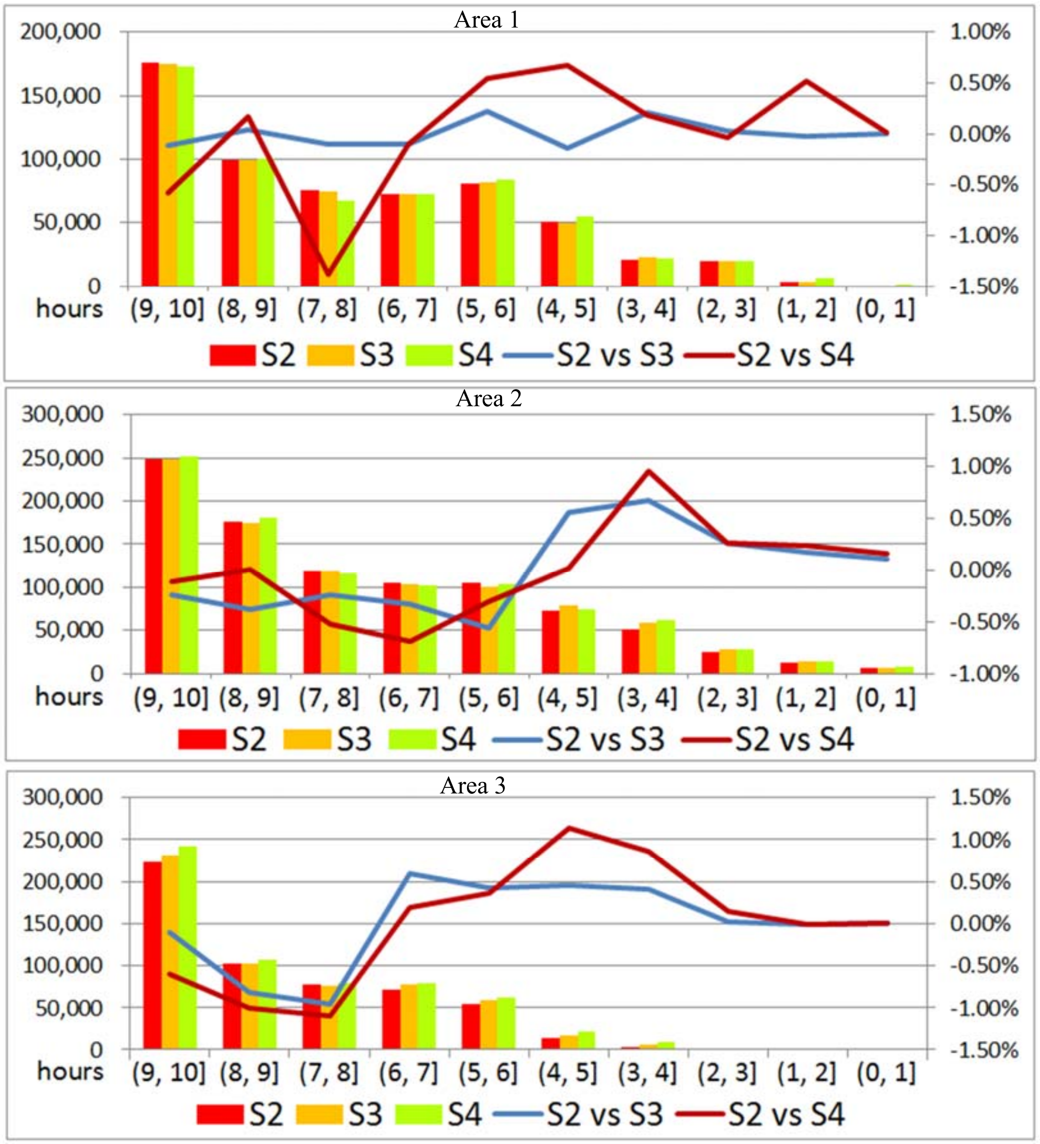


Fig. 23. Differences between S2 and S3, and between S2 and S4 in summer

5 Conclusion

3D GIS technology was employed in this study to conduct 3D spatial analyses based on 3D modeling, which could not be achieved using 2D GIS and can improve the public's understanding and provide more vivid visualizations than 2D GIS. This study used the 3D GIS technology to focus on plot ratio/building height issues and simulate the sounding environment changes for different scenarios. The effects of increasing plot ratio/building height toward skyline, visual impact, shadow and solar exposure for the three target areas in four scenarios were successfully observed and presented. The detailed comparison between different scenarios with various plot ratio/building height was also presented.

Based on the results of spatial analyses, minor relaxation of maximum plot ratio/ building height leads to the following conclusions:

(1) For skyline analyses, two skylines were drawn to check the profiles of the target areas in different scenarios. The negative effect of increasing plot ratio/building height on the scene of skylines 1 and 2 is not significant, which is reasonable and acceptable.
(2) For visual impact analyses, with continuous increased height for the four scenarios, it is found that the blocked sightlines only existed in the scenario 4 at the vantage point of Quarry Bay Park. A total of three bundles of sightlines were blocked at this vantage point. Comparing the calculated figures, the negative visual impact on the conservation of ridgelines is relatively insignificant with the increase of plot ratio/building height.
(3) For shadow and solar exposure analyses, the conditions in both winter and summer were considered for different scenarios in three areas. After calculating the average sunlight hours per day and comparing the area sizes and corresponding percentages for different categories of sunlight hours, the difference curves for scenarios 2 and 3, scenarios 2 and 4 were illustrated. All changes are insignificant, which indicates that shadow and solar exposure impact of increased plot ratio/building height in summer is relatively small.
(4) Considering the results of 3D spatial analyses, scenario 4 is the recommended reasonable scale for relaxation of the maximum plot ratio/building height restriction for the target site in KTDA.

To probe the effects of minor relaxation of the maximum plot ratio/building height restrictions of Kai Tak development area, 3D modeling and 3D spatial analysis technology were employed. This study used 3D GIS to simulate the impacts of various development densities on urban skyline, mountain ridgeline, and shadow and solar exposure, which could provide objective data and conclusions to assist planners, developers and decision makers in making better informed decisions. The findings firstly indicate that the government or the public can assess the environmental impact of land development density for the density city from a holistic view based on rationales, and make effective and farsighted decisions according to the results of spatial analysis.

To verify the effect of minor increase in plot ratio/building height, only simple 3D models were established in this study. For further study, more realistic and complicated 3D models should be designed and created in terms of different building shapes and materials, reasonable layout and directions, as well as podium and car park design employment.

To a certain extent, more impact factors should be considered to investigate the viability of increasing development intensity in future studies. Except for the KTDA, this study can also be applied in the urban renewal studies or new development areas in Hong Kong, or even in other similar densely populated cities.

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