Evaluating the Environmental Implications of Density

A comparative case study on the relationship between density, urban block typology and sky view factor performance

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Abstract. *This study explores the relationship between density, built form typologies and their respective environmental quality in terms of Sky View Factor (SVF) distribution on both the facade and ground levels by examining representative residential precincts and urban street blocks. The findings demonstrate that the performances in terms of facade and ground level SVF distribution vary across cases under study. The differences in the variations of their SVF performances as a result of the increase of density suggest that alternative urban block typologies can be explored, when targeting at higher density development, that provide different spatial configurations and an equally good or better SVF performance than that of some of the existing urban block and precinct typologies.*
Keywords. *density; urban street block; precinct; typology; Sky View Factor; environmental performance.*

Introduction

Background

The debate on the merits and effectiveness of relatively denser and more compact urban development pattern as an approach to achieve the goal of urban sustainability as compared with low-density resource-consuming urban sprawl has been going on for a while in the realm of academic research as well as design and planning practices (Newman and Kenworthy, 1989; Newman and Kenworthy, 1992; Jenks et al., 1996; Gordon and Richardson, 1989; Neuman, 2005). In the context of the cities in Asia and many other developing countries that are characterized by large population, limited buildable land

1960: Housing a Growing Nation | 1970: The Experiment of the New Town | 1980: Towards a Total Living Environment | 1990: Character and Identity | 2000: onwards

Figure 1
The evolution of Singapore's public housing new towns. (Image courtesy of Singapore's Housing Development Board)

and fast urbanization rate, high density urban development may seem to be inevitable.

As a city-state with very limited land resources, Singapore is renowned for its large scale urban public housing program which helps to accommodate over 80% of almost five million population in satellite towns equipped with full-featured facilities and a pleasant living environment. Over the years, several conceptual planning models and various residential building typologies have been implemented to facilitate the development of high-density public housing new towns. This is briefly represented in Figure 1. Considering that the future built environment in Singapore is likely to remain high density, the present research seeks to provide a guide on alternative building typologies that can produce good environmental quality and conducive living environments.

For the purpose of this study, the foremost issue to address is the scale of analysis. Methodologies and tools related to macro-scale regional urban studies and micro-scale building level simulations have been developed in the past decades. However, concerns have been raised on the lack of studies related to urban environmental analysis in the intermediate scale (Ratti and Richens, 2004) that is represented by urban street blocks or precincts. It is argued that urban street blocks or precincts are the fundamental components of urban fabric in that 1) they are composed of buildings of relatively homogenous characteristics, 2) they are the urban elements whose composition will shape the character of urban public spaces and semi public spaces, and 3) they are likely to have substantial impacts on people's experiences, perceptions and attitudes towards their living environment. As such, the environmental quality on the urban street block or precinct level is likely to have significant implications on both the performance of the constituent individual buildings and the overall environmental quality of the urban fabric in which the urban block or precinct is situated in a wider context.

The second issue concerns the environmental aspects that intermediate scale of urban analysis might focus on. Two aspects seem to be most prominent. One is related to the environmental quality of urban open space as it is most pertinent to people's outdoor experience, perception and comfort. Environmental quality here encompasses a wide range of qualitative aspects of urban built environment such as daylight availability, solar access, thermal comfort, perceived openness, etc., whereas urban open space is defined in this study as the ground-level un-built area or intermediate urban spaces in between buildings in the spatial context of an urban street block or residential precinct, rather than green areas or recreational spaces as generally implied by this term. Another aspect concerns the environmental quality of building façade as it is directly or indirectly related to the "potential" of the interior behind the façade to achieve good environmental quality that may have implications on human comfort and perception and building performance in terms of energy consumption. Although it is widely acknowledged that both aspects are associated with the contextual geometry and the spatial configuration of the built form, more studies are needed to addressed the connection between environmental performance and built form typology in, especially, the context of high density urban development.

Our study explores the relationship between

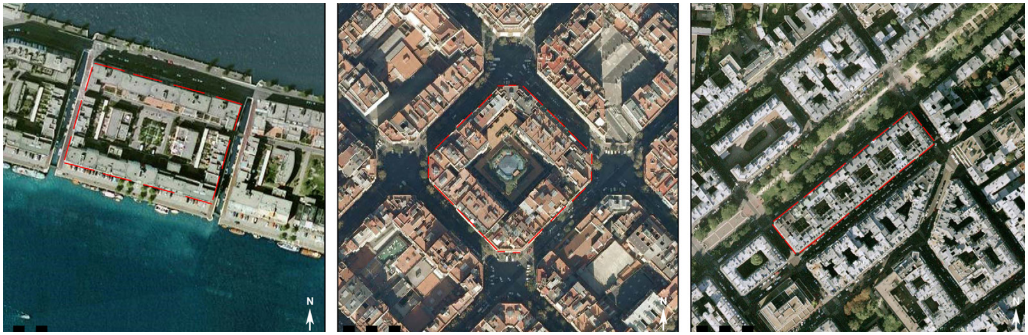


Figure 2
Aerial image of the international urban block cases. Amsterdam 001 (left), Barcelona 001 (middle), Paris 002 (right).

density, built form typologies and their respective environmental quality on both the level of urban open space and the level of building façade by examining existing residential precincts in Singapore's public housing new towns and representative urban street blocks in selected international cities. For the purpose of this paper, we will focus on one aspect of the study. We will examine, through comparison, the "performance" of selected built form typologies in terms of daylight availability as indicated by Sky View Factor (SVF) in the same built density in order to explore the environmental implications of different built form typologies for a specific density scenario.

Methodology

The case study approach is applied for this study. In total, seven representative urban street blocks and residential precincts were selected and examined. Please refer to Table 1 for some of the key density and geometric variables of the selected cases.

Two urban blocks were selected from the cities of Barcelona and Paris, respectively (Figure 2). They represent the high built density, high site coverage of traditional European urban fabric that is composed of medium-rise, deep plan and compact urban street blocks with internal courtyards functioning as light wells, service area or backyards. Another residential block was selected from the more

Table 1
Summary of the urban street blocks and residential precincts under study.

Name	Floor Area Ratio	Site Area (m2)	Site Coverage	Current Number of Stories	Area/Perimeter Ratio
Amsterdam 001	2.71	15264.7	43.06%	8	2.3 – 6.74 (4 in average)
Barcelona 001	4.61	14604.2	65.79%	7	14.67
Paris 002	5.29	6450.68	75.52%	7	7.32
Precinct 002	3.83	28466.5	23.95% * 41.82% **	16	3.17 - 3.68 (3.45 in average)
Precinct 003	3.18	20280.6	19.86% * 34.94% **	16	2.91
Precinct 004	3.47	30001.3	21.66% * 36.36% **	16	2.74
Precinct 005	3.32	30203.9	20.72% * 34.44% **	16	2.6 - 3.25 (3.02 in average)
*Exclusive of Multi-Story Car Park **Inclusive of Multi-Story Car Park					

recently developed Java Island in Amsterdam. It represents a modern interpretation of the traditional European urban block with, however, relatively lower built density. Taller and longer medium-rise slab buildings are aligned with the North and the South side of the site where more daylight and solar access are available. Lower and narrower buildings aligning the East and the West side of the site that face the artificial canal in between two blocks are used to define the semi-public space of the internal courtyard within each block, and they, together with the low-rise pavilions scattered around the courtyard, create a more intimate sense of scale.

Four residential precincts were also selected from one of the public housing new towns in Singapore which has some of the highest average built density (Figure 3). These precincts represent some of the current design and planning approaches implemented in high density new town development. They are all composed of clustered high-rise tower blocks ranging from 15 to 18 stories. The building height is relatively uniform for the precincts selected is because this area is in the flight path of air planes and, therefore, under strict height control. A low-rise multi-story car park (MSCP) is provided for each precinct that occupies a substantial proportion of the ground level open space. As compensation, intensively landscaped roof gardens are created on top of the MSCP. Although these precincts have similar built density, they vary a lot in terms of built form typology regarding building geometry and the spatial relationship between buildings. Some are aligned along the peripheral of the site like traditional perimeter urban blocks with the MSCP occupying the centre of the precinct (Precinct 002); some are arranged in a radiating pattern to facilitate wind penetration (Precinct 003); some are more closely clustered in order to balance between maximizing South-orientation for the primary façade and land use efficiency (Precinct 004); and others are arranged in a row with minor rotation to align with the site boundary while re-orienting the primary façade to the South (Precinct 005). It should be noted that the actual design intetnions for these precincts are far more extensive.

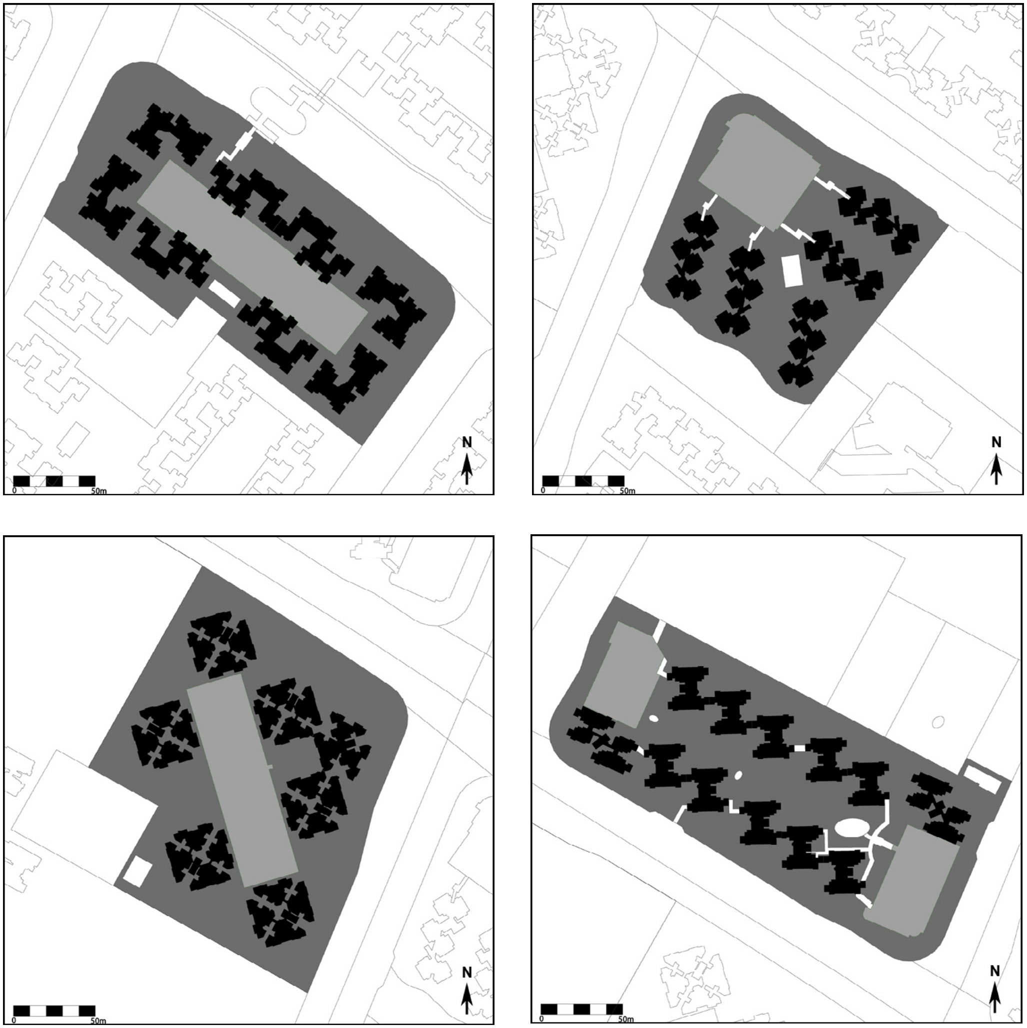
In this study, built density is measured by Floor Area Ratio (FAR) or Plot Ratio which indicates the usable floor area per unit site area for a given site. Increasing building height is one of the most effective ways to increase built density. Therefore, for the current study the relationship between built density and environmental performance for each urban block typology is explored by gradually increasing building height and examining the environmental performance of the urban block under the respective heights.

The environmental variable examined in this study is Sky View Factor (SVF) which is the ratio of the visible sky patch from a specific point to the unobstructed sky dome, and this factor has been suggested to have implications on Urban Heat Island, daylight availability and solar radiation exchange in urban canyons (Cheng et al., 2006; Fuehrer and Friehe, 2000; Harman et al., 2004; Oke, 1981; Oke, 1988; Ratti et al., 2003; Svensson, 2004). The research questions, for a specific urban block typology, are: 1) how is its current performance in terms of Sky View Factor distribution on both the ground and the façade level? 2) how may the performance vary as a result of the increase of built density due to the increase of building height when the other density and spatial parameters such as site coverage and spacing between buildings are kept the same as the existing ones? and 3) assuming the same built density, how is the relative SVF performance across these urban block typologies?

3D models of the selected urban blocks and precincts and their respective context were created in the 3D animation software Houdini (www.sidefx.com). A series of customized Digital Assets (DA) tools were developed in Houdini to calculate SVF for both the un-built ground surface and building facade. Using these DA tools, building height is manipulated by parametrically increasing the number of stories, and the simulation results derived from each iteration are summarized and exported automatically.

Initially, the simulation was conducted for a

Figure 3
Planes of the residential precincts selected from Singapore's new towns. Precinct 002 (top left), Precinct 003 (top right), Precinct 004 (bottom left), Precinct 005 (bottom right),



600m by 600m area with the urban block under study located in the centre in order to examine the current performance of the urban block in its existing context (Figure 4). However, it was realized that the results are not comparable in that the contextual built form in reality is not consistent and the incongruent spatial relationship between the urban block and its surrounding buildings may distort the results.

A "normalization" process was implemented instead to transform the irregular shape of the site boundary to a rectangle while keeping the area, orientation, proportion, and building setback relatively the same as the current ones, resulting in a geometrically equivalent urban block with almost the

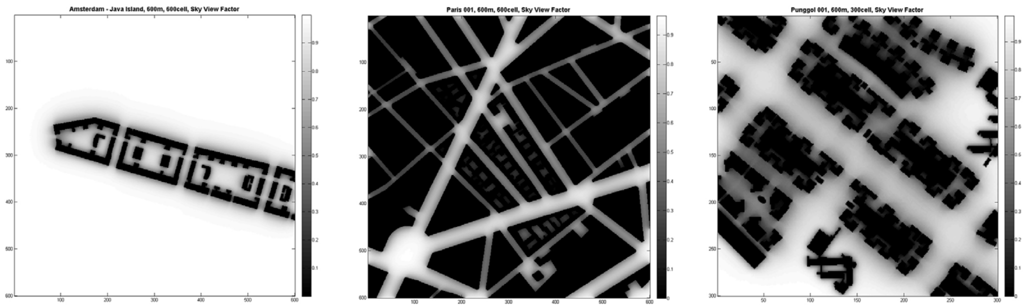


Figure 4
Ground level SVF simulation initially conducted for a 600x600m area for some of urban fabrics under study.

same spatial and geometric characteristics as the original one. The "normalized" urban block was then replicated in the form of a 3 by 3 matrix, with the distance between the replicated urban blocks equal to the width of the road around the original urban block (Figure 5). The rationale is that the evaluation of the theoretical environmental performance, as opposed to the actual environmental performance, for a specific type of urban block is only valid when the urban block is situated in a context composed of the same type of urban blocks as itself and in an urban grid structure similar to that of the existing one. 3D model of this 3x3 matrix was then created in the Houdini software for each case.

With regard to the criteria for comparison, it would appear there is limited current literature which suggest an "optimal" Sky View Factor value or value range. As the façade SVF value decreases, daylight availability might be compromised and, therefore, energy consumption due to the use of artificial lighting might increase. However, the energy consumption due to the use of air conditioning might decrease as a result of the drop of direct and indirect solar heat gain. This trend may be reversed as the façade SVF value increases. In this regard, a façade SVF ranging from 0.2 to 0.4 is temporarily applied in this study as a preferred state for comparison that leaves out both the extreme "high" end and the extreme "low" end of the façade SVF range. For ground level SVF, on the other hand, the value may range from 0 to 1. Based on the assumption that a "high" ground SVF may lead to more direct solar heat gain and an increase of ambient temperature and a "low" ground SVF may imply low exterior daylight level and stronger sense of crowdedness, a value from 0.2 to 0.5 is temporarily applied as a preferred ground SVF value range. The preferred SVF value range used in this study may subject to further validation test.

Initially, the percentage of facade area ($0.2<SVF<0.4$) under certain density was calculated as an indicator of facade daylighting and solar access quality for each urban block. However, it was realized that this indicator only reflects the impact of the surrounding geometry on SVF distribution on facade of an urban block at a given building height regardless of its density. A new variable was then

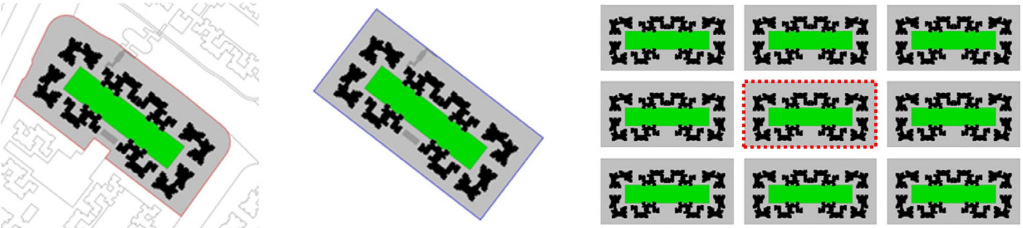


Figure 5
Example of the normalization and replication processes: (left) original precinct; (middle) normalized precinct; (right) 3x3 replication of the precinct for simulation

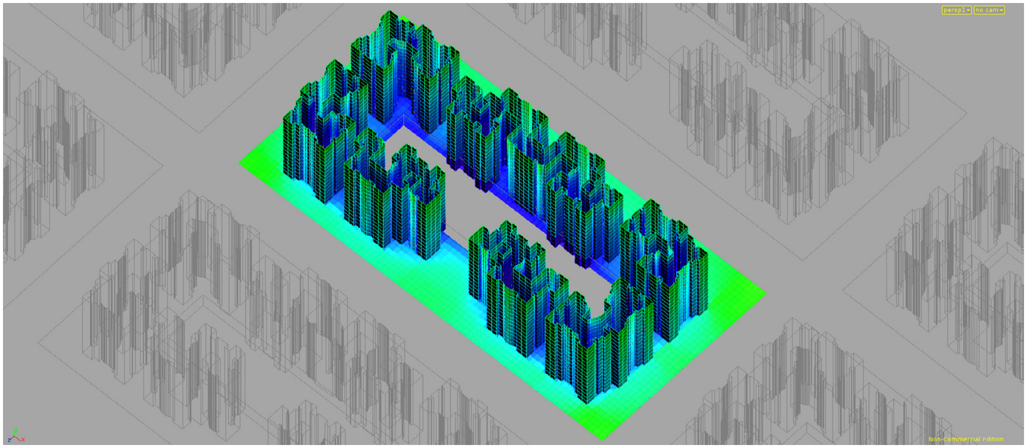


Figure 6
Visualization of the SVF on both unbuilt ground area and facade for Precinct 002 under its current building height (average number of stories = 16) in Houdini.

introduced that calculates the ratio of total facade area (0.2<SVF<0.4) to total floor area. This variable is more meaningful than the percentage of facade variable in that it relates the facade SVF performance of an urban block to its built density at a given building height. This "weighted" ratio tells us the amount of facade area of desirable SVF quality (0.2<SVF<0.4) per unit floor area. Similarly, the ratio of total unbuilt ground area (0.2<SVF<0.5) to total floor area was calculated as an indicator of ground level SVF quality that suggests the amount of unbuilt ground area of desirable SVF quality per unit floor area.

Results and Analysis

The simulation was conducted for each of the seven urban block cases using their respective 3x3 matrix 3D model. The SVF on both unbuilt ground area and facade was calculated only for the centre block by taking into account the impact of the surrounding built form. Figure 6 shows an example of the SVF values as visualized in the Houdini software.

Sky View Factor on building facade

Regarding SVF distribution on building façade under existing building height, most of the façade for the Amsterdam block (90.04%) and the Barcelona block (99.46%) has a SVF larger than 0.2. SVF distribution among the five value ranges examined is relatively even for the Paris block, except that there is a relatively larger proportion of façade that has SVF between 0.2 and 0.3. The façade SVF distribution for

Table 2
Summary of the façade SVF distribution for the seven cases under their respective existing heights

Name	FAR	Site Coverage	Current Number of Stories	% of Façade of which the SVF is within				
				0 - 0.1	0.1 - 0.2	0.2 - 0.3	0.3 - 0.4	0.4 - 0.5
Amsterdam 001	2.71	43.06%	8	8.12%	1.79%	18.86%	34.10%	37.08%
Barcelona 001	4.61	65.79%	7	0.00%	0.53%	29.45%	39.48%	30.53%
Paris 002	5.29	75.52%	7	18.61%	12.52%	30.66%	19.60%	18.61%
Precinct 002	3.83	23.95%*	16	31.29%	24.44%	20.40%	14.94%	8.93%
Precinct 003	3.18	19.86%*	16	36.96%	21.53%	21.47%	12.91%	7.13%
Precinct 004	3.47	21.66%*	16	50.47%	15.82%	14.23%	12.54%	6.95%
Precinct 005	3.32	20.72%*	16	35.19%	25.30%	18.84%	12.85%	7.82%
* Exclusive of multi-story car park								

all four Singapore precincts seem to be skewed to the lower end of the value range. More than half of the façade for each of the four precincts has a SVF lower than 0.2. Regarding the facade SVF value range under study (0.2-0.4), the Barcelona block has the highest percentage of facade area with a SVF between 0.2 to 0.4 (68.93%), and this is followed by the Amsterdam block (52.96%), Singapore Precinct 002 (35.43%), Precinct 003 (34.38%), Precinct 005 (31.69%), and Precinct 004 (26.77%) (Table 2).

In this paper, WFA (Weighted Facade Area) is used temporarilly to denote the ratio of total facade area (0.2<SVF<0.4) to total floor area and WGA (Weighted Ground Area) is used temporarilly to denote the ratio of total unbuilt ground area (0.2<SVF<0.5) to total floor area. In terms of WFA, all four Singapore precincts perform relatively better than the rest three cases under their existing building heights, with Precinct 003 performing the best ($WFA_{Precinct003}$=0.353). This is followed by Precinct 005 ($WFA_{Precinct005}$=0.311), Precinct 002 ($WFA_{Precinct002}$=0.310) and Precinct 004 ($WFA_{Precinct004}$=0.293). The Amsterdam urban block also achieved a relatively high WFA value of 0.305. The Paris and the Barcelona cases have the lowest values ($WFA_{Barcelona001}$=0.206, $WFA_{Pairs002}$=0.141). The results suggest that, if same amount of floor area is considered, the four Singapore precincts and the Amsterdam urban block can provide more façade area of good SVF quality than both the Paris and the Barcelona urban blocks under their respective existing heights (Figure 7, Table 3).

By increasing the building height gradually to 30 stories hypothetically, the façade SVF performances of all four Singapore precincts decrease in quite similar rate (the average decreasing rate of WFA for every increase of number of stories is 3% for Precinct 002, Precinct 003 and Precinct 005 and 2% for Precinct 004). The WFA for the Amsterdam urban block also decreases as its height was increased gradually to 25 stories. Although the WFA fluctuates up and down, the average variation is relatively lower than that of the four Singapore precincts (the average decreasing rate of WFA for every increase of number of stories is 1%). The WFA value for both the Barcelona and the Paris urban blocks drops significantly as their buildings were increased to 20 stories gradually. For every increase of number of stories, the WFA will drop by 5% in average for the Barcelona block and 8% for the Paris block. The results suggest that, in terms of the variation of facade SVF performance as a result of the increase of building height, the decreasing trend is relatively smooth and similar for the four Singapore precincts. Although the trend of variation for the Amsterdam block fluctuates, the average decreasing rate of WFA is relatively small. Both the Barcelona and the Paris blocks show significant drop of facade SVF performance when increasing the building height to achieve higher built density. It should be noted that the variation of building height is only theoretical for the purpose of this study. Increasing density by increasing building height may not be applicable in practice for some areas, such as those that are subject to stringent local building height regulations.

Sky View Factor at ground level

Regarding the SVF distribution on ground level under existing building height, most of the unbuilt ground area for both the Amsterdam block and the Barcelona block have a SVF between 0.2 to 0.5, whereas the SVF of nearly two thirds of the ground area in the Paris block (71.37%) is below 0.2. The ground level SVF for the four Singapore precincts expands to a wider range with value up to 0.7. However, the ground level SVF distribution varies across the four precincts. The SVF of 75.39% of the unbuilt ground area of Precinct 003 is within 0.2 to 0.5, followed by Precinct 002 (65.4%), Precinct 004 (64.08%), and Precinct 005 (58.05%) (Table 4).

In terms of weighted unbuilt ground area (0.2<SVF<0.5), the Amsterdam block seems to have the highest WGA value ($WGA_{Amsterdam001}$=0.213), indicating that, for every unit floor area, a 0.213 unit of unbuilt ground area has a desirable SVF value between 0.2 to 0.5. This is followed by the four Singapore precincts ($WGA_{Precinct003}$=0.154, $WGA_{Precinct004}$=0.118, $WGA_{Precinct005}$=0.115, $WGA_{Precinct002}$=0.1).

Figure 7
The relationship between façade area (0.2<SVF<0.4) per unit floor area and building height

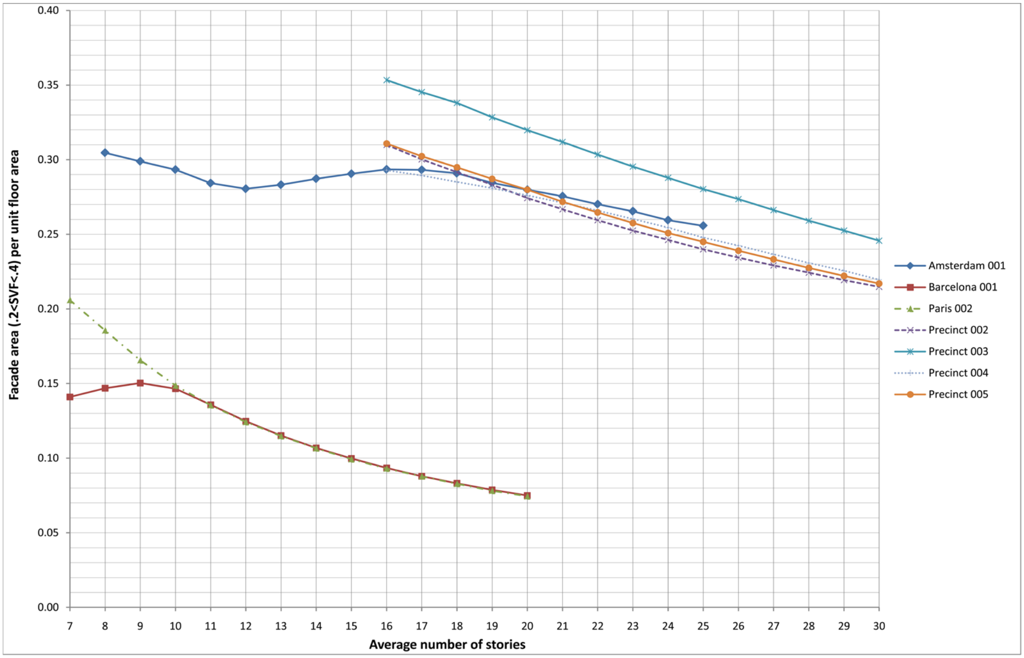


Table 3
Facade area (0.2<SVF<0.4) per unit floor area under different building height

Name	Average Number of Stories																							
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Amsterdam 001		0.305	0.299	0.293	0.284	0.28	0.283	0.287	0.291	0.293	0.293	0.291	0.284	0.28	0.276	0.27	0.265	0.259	0.256					
Barcelona 001	0.141	0.147	0.15	0.147	0.136	0.125	0.115	0.107	0.1	0.093	0.088	0.083	0.079	0.075										
Paris 002	0.206	0.186	0.166	0.149	0.135	0.124	0.115	0.107	0.099	0.093	0.088	0.083	0.078	0.074										
Precinct 002										0.31	0.3	0.292	0.283	0.274	0.267	0.259	0.253	0.246	0.24	0.234	0.229	0.224	0.219	0.215
Precinct 003										0.353	0.345	0.338	0.328	0.32	0.312	0.303	0.295	0.288	0.28	0.274	0.266	0.259	0.253	0.246
Precinct 004										0.293	0.289	0.285	0.281	0.276	0.271	0.266	0.26	0.255	0.248	0.242	0.237	0.231	0.226	0.22
Precinct 005										0.311	0.302	0.295	0.287	0.28	0.272	0.265	0.258	0.251	0.245	0.239	0.233	0.228	0.222	0.217

Table 4
Summary of the ground level SVF distribution for the seven cases under their respective existing heights

Name	FAR	Site Coverage	Current Number of Stories	% of Unbuilt Ground Area of which the SVF is within						
				0 - 0.1	0.1 - 0.2	0.2 - 0.3	0.3 - 0.4	0.4 - 0.5	0.5 - 0.6	0.6 - 0.7
Amsterdam 001	2.71	43.06%	8	0.03%	1.16%	20.63%	57.19%	20.99%		
Barcelona 001	4.61	65.79%	7	0.00%	0.61%	44.40%	38.42%	16.57%		
Paris 002	5.29	75.52%	7	52.94%	18.43%	28.21%	0.42%	0.00%		
Precinct 002	3.83	23.95%*	16	15.42%	9.99%	7.77%	30.77%	26.86%	9.19%	
Precinct 003	3.18	19.86%*	16	5.04%	15.35%	29.22%	22.28%	23.89%	4.22%	
Precinct 004	3.47	21.66%*	16	11.76%	7.22%	8.75%	21.93%	33.40%	16.94%	
Precinct 005	3.32	20.72%*	16	9.67%	25.74%	16.86%	25.88%	15.31%	6.33%	0.21%
* Exclusive of multi-story car park										

Both the Barcelona block and the Paris block scored relatively the worst ($WGA_{Barcelona001}$=0.074, $WGA_{Paris002}$=0.013). The results suggest that under the existing building height, the Amsterdam block seems to perform the best in terms of ground level SVF quality. The four Singapore precincts perform relatively worse, with Precinct 003 performing relatively better than the other three precincts. Neither the Paris block nor the Barcelona seem to be promising regarding ground level SVF quality (Figure 8, Table 5).

As the building height increases gradually, the ground level SVF quality decreases for all seven cases. The ground level SVF performance for both the Paris block and the Barcelona block drop most significantly - every increase of number of stories will result in a 33.5% reduction in WGA value for the Paris block and 25.3% for the Barcelona block. The ground level SVF performance for the Amsterdam block drops in a relatively slower rate - every increase of number of stories will result in a 12.1% reduction in WGA value. The variation of ground level SVF quality for all four Singapore precincts is relatively smooth, the average reduction of WGA for every increase of number of stories is 7%, 5.7%, 4.3% and 3.35% for

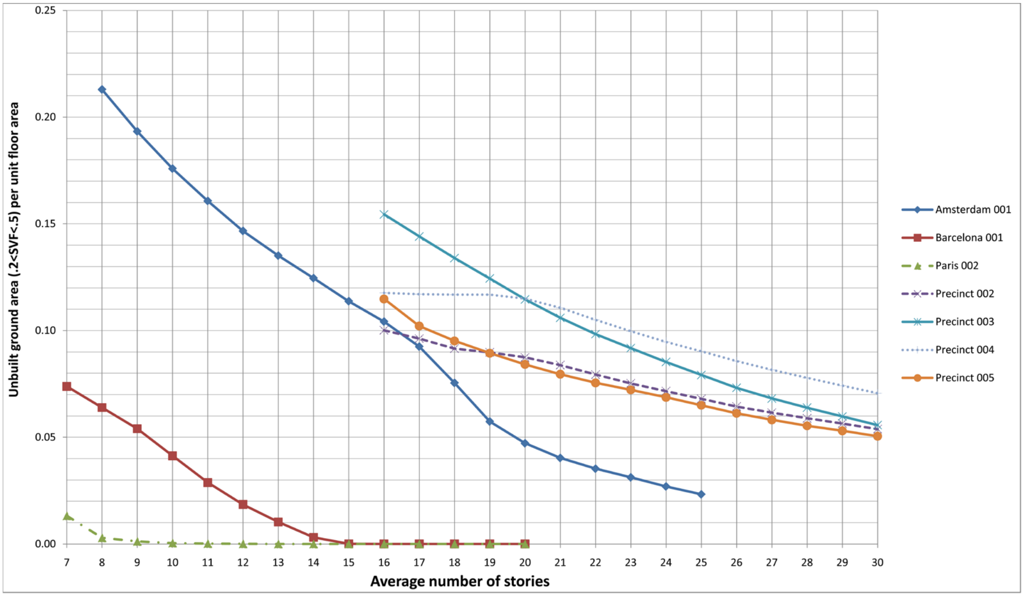


Figure 8
The relationship between unbuilt ground area (0.2<SVF<0.5) per unit floor area and building height

Table 5
Unbuilt ground area (0.2<SVF<0.5) per unit floor area under different building height

Name	Average Number of Stories																							
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Amsterdam 001		0.213	0.193	0.176	0.161	0.147	0.135	0.125	0.114	0.104	0.092	0.075	0.057	0.047	0.040	0.035	0.031	0.027	0.023					
Barcelona 001	0.074	0.064	0.054	0.041	0.029	0.019	0.010	0.003	0.000	0.000	0.000	0.000	0.000	0.000										
Paris 002	0.013	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000										
Precinct 002										0.100	0.096	0.092	0.090	0.087	0.084	0.079	0.075	0.072	0.068	0.064	0.062	0.059	0.056	0.054
Precinct 003										0.154	0.144	0.134	0.124	0.115	0.106	0.098	0.092	0.085	0.079	0.073	0.068	0.064	0.060	0.056
Precinct 004										0.118	0.117	0.117	0.117	0.115	0.111	0.105	0.100	0.095	0.090	0.086	0.082	0.078	0.074	0.071
Precinct 005										0.115	0.102	0.095	0.089	0.084	0.080	0.075	0.072	0.069	0.065	0.061	0.058	0.055	0.053	0.050

Precinct 003, Precinct 005, Precinct 002 and Precinct 004, respectively. The results suggest that, the variation of ground level SVF as a result of the variation of building height for the four Singapore precincts seem to be relatively smaller and smoother than that for the Barcelona and Paris blocks, with the Amsterdam block's sensitivity being relatively moderate among the seven cases.

Discussion and Conclusion

Based on the assumptions applied and the criteria temporarily implemented in this study, the results indicate that the current SVF performance on both facade and ground levels varies across the seven cases under study. The Barcelona block and the Paris block seem to perform the worst. Although the Amsterdam block outperforms the four Singapore precincts in terms of ground level SVF quality, it scores slightly lower than the four precincts on facade SVF quality.

The trends of SVF performance variation suggest that the urban block typologies under study react differently to the variation of built density due to the variation of building height. The results indicate that the SVF performance on facade and ground levels for both the Barcelona block and the Paris block are most sensitive to the variation of density solely induced by the change of building height. This might be related to the relatively larger proportion of facade and ground area of their courtyards and the relatively narrower street in between urban blocks. Therefore, the facade and ground area with good SVF quality due to each incremental increase of building height may decrease faster than that for the other urban block typologies that has relatively larger spacing between buildings.

Although the variation of the facade SVF performance for the Amsterdam block is not that smooth, on average the variation is the smallest, suggesting that the facade SVF quality of this urban block typology is relatively less sensitive to the variation of built density due to the change of building height alone. The large spacing between the two parallel slab blocks that have the majority of the facade area may have contributed to the low sensitivity of the facade SVF quality to the variation of building height for this urban block typology. The ground level SVF performance for the Amsterdam block seems to be more sensitive to the variation of building height than that for the four precincts. This is probably related to the nature of the courtyard of this Amsterdam urban block typology. Under the current height, the courtyard of the block is relatively spacious and more than 98% of the unbuilt ground area has a SVF larger than 0.2. This value decreases as the two slab buildings go up, suggesting that the ground level SVF quality of the courtyard is quite sensitive to the variation of the height of surrounding buildings.

On the other hand, for the four Singapore precincts, the variation of the percentage of the ground area with a SVF larger than 0.2 do not seem to be very dramatic as the building height increases. This is probably related to the convolution of building façade, which in its initial design intention is to increase façade area for service areas such as kitchen and bathroom but has created a substantial proportion of ground area of relatively little view to the sky due to self-obstruction of the buildings. The proportion of these areas with low SVF (<0.2) increases in a low rate, resulting in a relatively smooth decrease of ground area with SVF between 0.2 to 0.5.

Since the current SVF quality for both the Barcelona and the Paris urban blocks are worse than that for the four Singapore precincts, the Amsterdam block was selected for further comparison in equal built density scenario. Assuming increasing the density of the Amsterdam block to the currently highest density among the four Singapore precincts ($FAR_{Precinct002}$=3.83) by increasing its number of stories to 13 stories, resulting in an FAR of 4.02, it will be able to obtain an WFA of 0.283 and WGA of 0.135, the former is lower but still close to that for the four Singapore precincts, whereas the latter is higher than that for the Singapore precincts, except for Precinct 003.

Moreover, if the density of the Amsterdam block and the four Singapore precincts are pushed to that of the current Paris block (FAR=5.29), the Amsterdam block needs to be increased to 18 stories, and 22, 27, 24 and 26 stories for Precinct 002 to Precinct 005, respectively (Figure 9). Under such height, the WFA for the Amsterdam block will drop to 0.291, which is higher than that for the four Singapore precincts ($WFA_{Precinct002}$=0.259, $WFA_{Precinct003}$=0.266, $WFA_{Precinct004}$=0.255, $WFA_{Precinct005}$=0.239) at their respective heights. The WGA for the Amsterdam block will drop to 0.075, which is lower than that for the Precinct 002 and Precinct 004 ($WFA_{Precinct002}$=0.079, $WFA_{Precinct004}$=0.095) but still higher than that for Precinct 003 and Precinct 005 precincts ($WFA_{Precinct003}$=0.068, $WFA_{Precinct005}$=0.061).

This suggests that, theoretically, by adapting the Amsterdam urban block typology, it is possible to use buildings lower than the that of Singapore precincts selected to achieve the existing Singapore precincts' density while obtaining SVF quality close to that of the four Singapore precincts. It is also possible to achieve a density higher than that of the four Singapore precincts while obtaining a better SVF performance on both facade and ground level. Therefore, the Amsterdam urban block typology seems to host good potential to be further investigated as an alternative typology to achieve higher density while maintaining relatively good SVF performance.

The findings demonstrate that the performances in terms of facade and ground level SVF distribution vary across the urban street blocks and residential precincts under study. The differences in the variations of their SVF performances as a result of the increase of density due to the change of building height alone suggest that alternative urban block typologies can be explored, when targeting at higher density development, that provide different spatial configurations and an equally good or better SVF performance than that of some of the existing urban block and precinct typologies.

Limitations and Future Studies

The simulation of this study is conducted based on actual built form of the urban block and precinct cases selected without any simplification. The results might be affected by factors such as the way the buildings are clustered, oriented or located on the site. Future studies may need to look into to what extent can the actual built form be abstracted to relatively more generic form without losing its design characteristics that still performs similarly to the

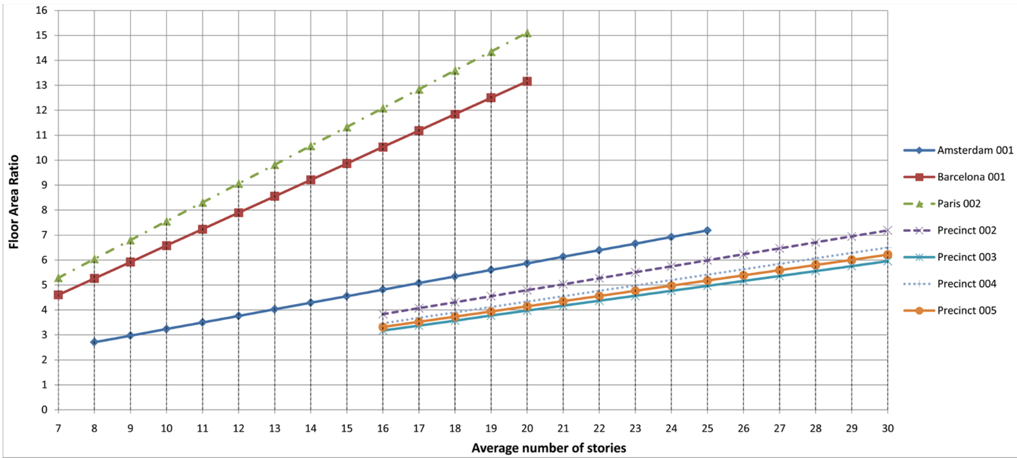


Figure 9
The relationship between building height and Floor Area Ratio.

original form.

A significant difference between the four Singapore precincts and the three urban blocks is that the former have substantial façade convolution whereas the latter are not. Further study is needed to explore whether and to what extend façade convolution may affect SVF performance.

The preferred SVF value range used in this study is adopted temporarily based on simple assumptions. Further study is needed to validate the assumptions by relating it to other environmental and energy variables such as solar heat gain, ambient temperature and household energy consumption that may have applied widely acknowledged or relatively more robust benchmarks.

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