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Factors influencing vertical urban development at the parcel scale: The case in Brisbane, Australia

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Abstract
Increasing urban density has become an important focus in mitigating the adverse impacts of urban sprawl. A common way to increase urban density is the development of multi-story residential housing, or vertical urban development (VUD). Compared to low-rise detached housing, VUD has been purported to be more effective in mitigating the adverse impact of urban sprawl. This paper examines factors influencing VUD through a case study of Brisbane, Australia. Three types of housing developments – low-rise detached houses, low-rise apartments, and medium- to high-rise apartments – are explored, with the latter two types classified as VUD. Building on the literature that suggests a range of environmental, socio-demographic, built environment, and planning regulations factors driving or constraining VUD, our study further explores how land parcel size and parcel change over time either through parcel amalgamation or subdivision as factors driving VUD. The findings show that parcel size and parcel amalgamation are key factors leading to VUD, particularly in the form of medium- to high-rise apartment development. On the other hand, land use upzoning alone does not appear to be sufficient to drive VUD. Our study enriches the understanding of the scale effects of land parcels and zoning regulation on vertical urban development, and contributes to parcel-based land use planning policies that are targeted at more intensive urban land use.

Keywords
Vertical urban development, building height, parcel size, parcel amalgamation, parcel subdivision

Introduction

After World War II, low-density urban sprawl has been the dominant paradigm for urban growth in many cities globally, particularly in North America, Europe and Australia (Goetz, 2013; Newton et al., 2017; Fertner et al., 2016). Urban sprawl has resulted in a range of environmental and social

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consequences, including agricultural land losses, high reliance on motor vehicles, long commuting times and increased infrastructure costs (Ewing, 1997; Tsai, 2005; Ruming, 2014; Carruthers, 2002). Various urban development strategies, including *Smart Growth, Compact Cities* and *Urban Consolidation,* have been put forward since the 20^{th} century to curtail the adverse impacts of urban sprawl (Daniels, 2001; Talen, 2005; Thomas and Cousins, 1996). These strategies aim to promote urban densification by directing new housing development into established residential areas. Benefits linked to these strategies include the slowdown of urban sprawl, increasing public transportation usage, reducing land consumption and improving air quality (Goetz, 2013). A common form of urban densification is vertical urban development (VUD) in the form of multi-story residential housing. Compared to low-rise detached houses, VUD has been purported to be a more effective option for urban densification (Burton et al., 2003; Palme and Ramírez, 2013). However, despite the benefits, VUD only accounts for a small share of the housing supply in low-density Western cities (e.g., National Housing Finance and Investment Corporation, 2020; Stats NZ, 2021).

City planners consider different factors for the placement of VUD, including environmental constraints (Grace Wong, 2004; Saiz, 2010), socio-demographic features (Burton, 2002; Tsai, 2005), planning regulations (Burton, 2002; Nolon and Bacher, 2008) and built environment factors (Abdullahi et al., 2015; Frenkel, 2007). However, less is understood on the scale effects of land parcel size and parcel size change either through parcel amalgamation – the process of merging two or more land parcels into one larger-sized parcel, or subdivision – the process of dividing one large parcel into two or more smaller-sized parcels. Some researchers have developed urban models to understand VUD (for example, see Koziatek and Dragicevic, 2017; Lin et al., 2014). These models largely rely on satellite images to identify and model VUD based on the regular grid cells ranging from 30 m × 30 m–300 m × 300 m (e.g. Lin et al., 2014; Benguigui et al., 2008; He et al., 2017). A notable exception is Koziatek and Dragićević (2017) who modelled VUD at the parcel scale. Given that it is the land parcels that serve as the base unit of building construction (Batty and Longley, 1994; Liu and Long, 2016), the heterogeneous size of parcels have a determinative impact on building form (Taima et al., 2019), and, thus, can potentially impact VUD (Gallagher et al., 2019; Fredrickson et al., 2016). A critical gap in the current scholarship is the understanding of the drivers of VUD at the parcel scale. This understanding is particularly important for developing urban planning strategies for more intensive urban land use (Mustafa et al., 2018). This is especially the case in cities such as Brisbane, a low-density city that has been expanding relatively rapidly with limited land for future expansion (Au-Yeung et al., 2009). Urban consolidation is increasingly the focus of planning policy in Brisbane, with an ambitious target of 94% of new dwellings to be achieved through infill development from 2016 to 2041 (Queensland Government, 2017). However, only limited progress in urban consolidation has been achieved so far (Bunker, 2014; Gallagher et al., 2020a, 2020b).

Previous studies have explored factors influencing VUD based on the regular grid cell-scale analysis (e.g. Lin et al., 2014; Benguigui et al., 2008; He et al., 2017), but less is understood on the scale effects of land parcel size and parcel size change in relation to VUD. To this end, the aim of this study is to explore the relationship between VUD and the driving factors by examining factors that influence the development of multi-story residential housing at the parcel scale. We first identified the occurrence and extent of VUD from 2009 to 2014 at a fine parcel scale using data derived from LiDAR and cadastral databases. A multinomial logistic regression model was then applied to explore the relationships between VUD and a set of explanatory factors at the parcel scale by placing a particular focus on the land parcel size factors represented by parcel size and parcel size changes, along with environmental constraints, socio-demographics, planning regulations and built environment factors. The following section reviews the VUD literature. Next, the study area, data and methodology used to identify VUD and investigate the relationship between VUD and the aforementioned factors are presented. Then results are presented and discussed. Finally, the conclusion section outlines how the findings contribute to parcel-based planning policies that are targeted at more intensive urban land uses.

Overview of literature on VUD

Factors influencing VUD

City planners consider multiple factors that contribute to the placement of vertical urban development (Al-Kodmany, 2017). Environmental constraints such as elevation and land slope have been identified as constraining VUD (Foley et al., 2005), while demographic characteristics such as population density have been found to promote VUD (Burton, 2002; Tsai, 2005). Access to roads and public transport as well as to services, amenities and job opportunities have also been found as influential criteria for VUD (Koziatek and Dragicevic, 2017; Lin et al., 2014). On the other hand, zoning and development control by government through the specification of land use and design requirements, including allowable use, allowable housing types, maximum housing height, number of storeys and minimum lot size requirements also regulate VUD (Talen, 2012). Specifically, low-density zoning in urban areas may restrict the development of multi-story residential housing. Accordingly, upzoning – changing the zoning by government planning authority to allow for higher-value or more dense land use – has been adopted by policymakers to increase the buildable capacity of land and increase urban density (Gabbe, 2017: 1). However, upzoning may not necessarily lead to multi-story housing development due to land parcel size restrictions (Conzen, 1960).

Considering that land parcels are the basic units for building construction (Batty and Longley, 1994; Liu and Long, 2016), the parcel size can determine building size. For example, larger buildings are usually constructed on larger parcels (Gao and Asami, 2007). The economy of scale theory in residential construction also suggests that larger buildings, such as multi-story buildings, are usually associated with larger land sizes, at least up to a point (Ott et al., 2012). However, in many parts of the world, the availability of large parcels is decreasing due to a historical process of subdividing large parcels into fragmented and smaller-size parcels (for example, see Hiller et al., 2013; Abdulaal, 1990; Inostroza et al., 2013). To alleviate the constraints imposed by this small-lot morphological frame, parcel amalgamation or land assembly – the practice of acquiring small adjacent parcels to form a larger size parcel of land for redevelopment – is becoming more common (for example, see Golland, 2003; Louw, 2008; Hastings and Adams, 2005; Lin, 2005). Fredrickson et al. (2016) and Gallagher et al. (2019) examined how property boundaries change to facilitate urban consolidation. Their results indicate that parcel amalgamation is a key mechanism for achieving urban consolidation through densification. However, the scale effect of parcel size and the size change on VUD is less understood, and few studies have attempted to quantify or model the impact of the scale effect of land parcels on VUD.

Modelling urban expansion and VUD

Cities have been identified as dynamic and complex systems, where land use transitions can be simulated using urban models (Batty, 2009). A large number of urban models have been developed over the past decades to help understand urban development dynamics (Batty and Xie, 1994; Clarke et al., 1997; Feng and Liu, 2013). The types of urban models range from integrated land use transport modelling (ILUTM) (Hunt and Simmonds, 1993) to cellular automata (CA) (Liu et al., 2021) and agent-based models (ABM) (An, 2012). Urban land use transition rules have been identified using approaches ranging from traditional statistical methods such as analytical hierarchy process (AHP) (Aburas et al., 2017) and logistic regression (Wu, 2002), to non-statistical methods such as the artificial neural network (ANN) (Li and Yeh, 2002), ant colony optimization (ACO) (Li et al., 2007; Liu et al., 2008) and other optimization methods (Cao et al., 2015; Kamusoko and Gamba, 2015). Among these methods, logistic regression is the primary choice in many studies, mainly due to its solid statistical foundation in exploring the association between categorical variables (e.g. several urban land use states) and multiple independent variables, such as various physical, socioeconomic and built environment factors. However, most urban models focus on urban expansion (Hu and Lo, 2007; Li et al., 2013; Oueslati et al., 2015), with only limited research on VUD (Mustafa et al., 2018; Wang et al., 2019).

Given the different urban development processes and densities, the factors affecting VUD may not be the same as those for urban expansion, and even for the same factors impacting both processes, the relative importance may vary (Loibl and Toetzer, 2003). For example, Zhang et al. (2017) found that population density is the primary driver of urban expansion, while fixed investment is the primary driver of vertical urban development in Guangzhou. Similarly, Mustafa et al. (2018) examined the factors influencing urban expansion and densification processes in Wallonia (Belgium) and compared factors influencing four classes of urban areas: non-, low-, medium- and high-density built-up areas. Their results indicate that all the controlling factors show distinctive variations.

The limited work on modelling VUD used raster-based remote sensing data (see, for example Lin et al., 2014; Zhang et al., 2017). Raster representations disregard the constraints and opportunities of the urban morphological frame on urban redevelopment (Siksna, 1997; Asami and Ohtaki, 2000; Wheeler, 2003; Stell and Tait, 2016). On the other hand, the relationship between parcel size and building height and density is evident according to the economy of scale associated with residential building construction (Ott et al., 2012). There are also minimum parcel size requirements for building construction in zoning regulations (Glaeser et al., 2006). Therefore, it would be more accurate to model VUD using a parcel-based urban model.

In this paper, we examine factors driving VUD by considering three types of housing development – low-rise detached houses, low-rise apartments, and medium- to high-rise apartments – with the latter two types classified as VUD. Our work contributes to the ongoing scholarship towards modelling VUD at land parcel scale.

Study area, data and methods

Study area

Brisbane is the capital city of the State of Queensland (Figure S1). It is located in the centre of South East Queensland (SEQ), one of the fastest-growing metropolitan regions in Australia. Historical development of SEQ has been documented as an inefficient, ‘land hungry’ form of development (Queensland Government, 2017: 103), and its rapid expansion along with family subdivision practices in the 1970s through to early 2000s highlighted the need for better management as part of early regional planning for SEQ (Queensland Government, 2017). Brisbane has experienced fast urban expansion since the initial settlement in the 19th century (Queensland Government, 2017), with city blocks and lot sizes being reduced through subdivision and the urban landscape transforming from a state of cohesion to fragmentation (Sanders and Schroder, 2008).

Brisbane’s population is projected to increase by 38% from 2016 to 2041 (Queensland Government, 2018). An additional 188,200 new dwellings will be needed accordingly (Queensland Government, 2017). As greenfield land is limited, infill development is planned to accommodate these additional housing units (Queensland Government, 2017). To fulfil the ambitious target of 94% of additional dwellings sourced from infill development from 2016 to 2041, Brisbane has applied multiple strategies, including upzoning to allow for a higher floor area ratio of new buildings (Brisbane City Council, 2014). However, there has been limited success in meeting these stated aims (Bunker, 2014; Gallagher et al., 2020a, 2020b). In this context, it is considered most suitable to investigate the mechanisms behind VUD in this area.

We selected Brisbane's 20 inner-city suburbs (Figure S1) as our study area. These suburbs, located within a 3 km radius from Brisbane's central business district (CBD), are referred to as the core of Brisbane (Stimson and Taylor, 1998; PRDnationwide Corporate Head Office, 2019). It is anticipated that this area will accommodate a higher-density population compared with other suburbs of Brisbane.

Data and pre-processing

We used two data sources – the digital cadastral database (DCDB) and LiDAR data – at two time points, 2009 and 2014, to identify VUD. Both data sources are available for most Australian urban areas. The DCDB was obtained from the Queensland Spatial Catalogue in shapefile format which defines all land parcel boundaries in Queensland (Queensland Government, 2021). It is available free of charge under the government's public data policy. The LiDAR data was obtained free of charge from Geoscience Australia (Geoscience Australia, 2021). This data was in LAS format – a file format designed for the interchange and archiving of LiDAR point cloud data, with each LiDAR point having a classification assigned to it that defines the type of object, including 'ground', 'building' and 'water'. This data has a high level of classification accuracy, with 98% for ground points and 95% for other classes. For each year, we used 50 tiles of LiDAR points to cover the whole study area, each tile covering 1km by 1 km on the ground. The LiDAR data was used to identify the occurrence of new housing development (see Supplementary Material for detail). These new housing developments were classified into one of the three dwelling types – low-rise houses, low-rise apartments, and medium- to high-rise apartments – with the latter two categories are defined as VUD. These dwelling types were then assigned to the land parcels to facilitate the parcel-scale analysis.

We used the DCDB data to measure the land parcel size and parcel change as factors driving VUD. We sourced parcel size data from the 2009 DCDB. We classified parcel change into three types, including parcel amalgamation, parcel subdivision and no change by comparing the 2009 and 2014 parcels, following the method introduced by Fredrickson et al. (2016).

We also used data measuring the environmental, socioeconomic and policy dimensions of the areas to explore factors influencing VUD. We selected elevation, land slope and land use type in 2009 as environmental constraints. Elevation and slope data with a spatial resolution of 5 metre were sourced from Geoscience Australia (Geoscience Australia, 2021). Land use types in 2009 were defined to be either vacant or land occupied with building, using data obtained from multiple sources, including the 2009 LiDAR data, Google Earth, Google Street View and Nearmap. These resources usually dated back to 2009, with specific dates depending on the site.

We quantified the built environment features using a land use mix indicator and four accessibility measures, including distance to main roads, public transport stations, shops and river (see Table S1 for detail). The planning policy factors include housing density control and zoning change (i.e. upzoning). Using the zoning codes from the Brisbane City Plan 2000 (Brisbane City Council, 2000), we identified two types of density control: low-density residential and medium- to high-density residential. For zoning change, we identified the upzoning by comparing the zoning codes in the 2000 and 2014 Brisbane City Plans (Brisbane City Council, 2000; 2014). The location where the maximum allowable number of building storeys has increased by at least one story was identified as upzoning.

Finally, we sourced from the 2011 Census of Population and Housing data to quantify the socioeconomic factors, including population density and number of persons in employment at the Statistical Area Level 1 (SA1), the smallest spatial unit for the release of the Census data (Australian Bureau of Statistics, 2011). These two socioeconomic factors were selected based on existing studies (Frenkel, 2007; Koziatek and Dragićević, 2017). We selected the 2011 census as it is the closest census data to 2009.

Analytical methods

We first conducted a correlation analysis amongst all variables to assess the potential existence of collinearity amongst different variables (Table S2). In 2009, there were 26,278 land parcels in the study area. To reduce the potential spatial autocorrelation amongst the dependent and explanatory variables, we followed a commonly applied practice (e.g. Arsanjani et al., 2013; Puertas et al., 2014) to select land parcels with a distance between its centroid and the centroid of the nearest land parcel greater than 30m. This resulted in 19,959 land parcels for further consideration. We then coded the parcels with new residential development from 2009 to 2014 as 1 and those without new residential development as 0. Given that the number of parcels with no development are substantially larger than those with development (i.e. 19,379 vs. 580), which if used, may result in biased parameter estimation (Cheng and Masser, 2003), we decided to randomly select an equal number of parcels from those without development to balance the samples between developed and non-development parcels. Subsequently, the total numbers of sample parcels used in the regression analysis were 1160.

We used a multinomial logistic regression to analyse the relationship between VUD and a set of potential driving factors (see Supplementary Material for detail). We constructed two regression models. In Model 1, we considered the environmental, socioeconomic and policy factors as independent variables to explain the driving factors of VUD. In Model 2, we added parcel size and parcel size change either through parcel amalgamation or subdivision to include the potential impact of land parcel size factors. We used the pseudo R-squared to evaluate the model fit of the regression analysis, with a higher pseudo R-squared value indicating a better model fit.

Results

Identification of VUD

A total of 580 new housing developments were identified in the study area from 2009 to 2014. The majority of the newly-built properties were low-rise houses (394), followed by the medium- to high-rise apartments (145) and low-rise apartments (41) (Figure S3).

Figure S4 illustrates how land use in 2009 (left column) was transformed into new housing developments with different types in 2014 (right column) through either a parcel size change or a zoning change (middle column). The majority of VUD occurred on parcels with amalgamation (95), followed by the fixed parcel (79) and parcel subdivision (12). Despite the small share of upzoning (40 out of 580), 35 out of the 40 upzoned parcels have been developed into medium- to high-rise apartment VUD types.

Factors influencing VUD

First, the correlation coefficient of every set of two independent variables is less than 0.6, indicating a low level of pairwise correlation (Table S2). Results from the two multinomial logistic regression models for VUD are presented in Table 1. By adding parcel size factors in Model 2, the model has generated a higher pseudo R^2 value, improving the model's explanatory power for land use change. The signs and significances of most variables are generally consistent between the two models, but there are also discrepancies, especially between the parameters for the three types of housing developments, which are discussed below.

Table 1. Variables and coefficients of the multinominal logistic regression model.

		Model 1						Model 2					
		Low-rise house		Low-rise apartment		Medium- to high- rise apartment		Low-rise house		Low-rise apartment		Medium- to high-rise apartment	
Category	Independent variables	B	OR	B	OR	B	OR	B	OR	B	OR	B	OR
Environmental constraints	Intercept	0.99*		−1.8*		−3.34**		1.26**		−2.75*		−6.33*	
	Land use type in 2009:												
	Building	−1.87*	0.15	−1.03*	0.36	−1.91*		−2.24*	0.11	−0.07	0.93	−0.73	0.48
	Elevation	0.2**	1.23	0.23	1.26	0.51**	1.915	0.25**	1.29	0.28	1.32	0.79*	2.21
	Slope	0.07	1.07	−0.16	0.85	−0.36**	0.699	0.06	1.06	−0.1	0.91	−0.44	0.65
Parcel size factors	Parcel size							3.01*	20.37	8.94*	7626.03	10.47*	35,310.96
	Parcel size change types:												
	Parcel amalgamation							−1.63	0.2	4.88*	131.59	6.58*	721.55
	Parcel subdivision							5.54*	254.97	3.54*	34.47	1.84	6.31
Built environment	Distance to the nearest main road	0.15	1.16	0.26*	1.3	−0.39**	1.410	0.2*	1.22	0.25	1.29	−0.64*	0.53
	Distance to the nearest public transport stations	0.04	1.04	−0.22	0.8	−0.09	0.701	0.01	1.01	−0.2	0.82	−0.18	0.84
	Distance to the nearest convenience shops	0.15*	1.16	−0.08	0.93	0.16	1.259	0.13	1.14	−0.19	0.83	0.28	1.32
	Distance to River	−0.11	0.9	−0.11	0.9	−0.65*	1.187	−0.2*	0.82	−0.1	0.9	−0.51	0.6
	Entropy	−0.11	0.89	0.15	1.16	0.16	1.483	−0.14	0.87	0.3	1.34	0.51*	1.66
Planning regulation	Zoning types:												
	Medium- to high-density Residential	−0.05	0.95	1.42*	4.14	3.69**	0.009	0.07	1.07	1.26*	3.53	4.13*	62.3
	Land use zoning change:												
	Upzoning	−1.88**	0.15	0.09	1.1	0.87**	51.209	−1.76*	0.17	−1.38*	0.25	−0.89	0.41
Socio-demographics	Population density (Census SA1 group)	−0.03	0.97	−0.19	0.83	−0.06	1.115	−0.17	0.84	0.01	1.01	0.41*	1.51
	Number of persons in employment	−0.11	0.89	−0.09	0.91	0.62*	1.477	−0.18	0.84	0	1	0.8*	2.23
Pseudo R-Square		0.44						0.74					

Note: * $p < .05$, ** $p < .01$, OR is the odds ratio.

Overall, our results show that environmental constraints, socio-demographics, planning regulations and built environment features all significantly (at least $p < .05$) affected VUD. Former land occupied with buildings was negatively associated with new low-rise house development, but not for development of the low-rise apartment and the medium- to high-rise apartment – the two types of VUD we define in this study. Elevation showed a positive effect on the medium- to high-rise apartment VUD. Distance to the nearest main road had a negative impact on the medium- to high-rise apartment VUD, while entropy had a positive impact on this VUD type. Medium-density and high-density residential zoning were positively associated with both VUD types, while upzoning was negatively associated with the low-rise apartment VUD. The population density and number of persons in employment both showed a positive relationship with medium- to high-rise apartment VUD. Specifically, the medium- to high-rise apartment VUD type was associated with higher elevation, more mixed land use, shorter distance to transportation, higher-density residential zoning, higher population density and more job opportunities. This result is verified by our observations that large-scale redevelopment (e.g. West Village, Riverside South precinct and Gasworks Plaza) all occurred in areas with mixed land use in residence, commerce, waterbody, easy-access transportation.

On the other hand, land parcel size and parcel change have a notable impact on VUD. Parcel size is a positive determinant for both VUD types, indicating that VUD is more likely to occur on larger parcels. In addition, parcel amalgamation is also a positive determinant for VUD. Specifically, the occurrences of low-rise apartments and medium- to high-rise apartments are 131.59 (OR= 131.59, 95% confidence interval = 52.71–328.51) and 721.55 (OR = 721.55, 95% confidence interval = 248.99–2090.96) times more likely to be located in parcels with amalgamation than those with no parcel change. Here, we present two examples of VUD that occurred on parcel amalgamation. One example is a low-rise apartment VUD located at 38 Prospect St, Fortitude Valley, where the previous four parcels (Figure 1(a)) were amalgamated into a larger 1017 m^2 site, with a new 2-storey apartment (6 Units) (Figure 1(a)). Another example is a medium- to high-rise apartment VUD that occurred at 23 Allenby St, Spring Hill, where two former parcels (Figure 1(b)) were combined to create a larger parcel of approximately 682 m^2 for a 5-storey multi-unit apartment (Figure 1(b)). In contrast, parcel subdivision is positively associated with a low-rise house. Using parcels with no change as the reference, parcels experienced subdivision were 254.97 times more likely to be built with a new low-rise house. An example of parcel subdivision for a low-rise house is found at 41 Lockhart Street, Woolloongabba. This site was previously a 708 m^2 parcel with a single-storey detached house (Figure 1(c)). In 2009, a development permit application was submitted for parcel subdivision. Upon approval, this parcel was subdivided into two parcels of 404 m^2 and 304m^2, each of which was developed into a 2-storey low-rise house in 2011 (Figure 1(c)).

Discussion

This study aimed to understand the driving factors of VUD at the parcel scale. We identified VUD that had occurred over a five-year period from 2009 to 2014 and examined the extent to which VUD was associated with a number of explanatory factors using a multinomial logistic regression model. Our results show that VUD accounts for around 32% (186 out of 580) of the new housing constructions in Brisbane inner-city areas, with the remaining being non-VUD (i.e. low-rise houses) over the study period.

Our results show that land parcel size and parcel change factors, environmental constraints, socio-demographics, planning regulations and built environment together significantly affected the occurrence of VUD, with the development of low-rise apartments and medium- to high-rise apartments likely to occur on larger-sized parcels or amalgamated parcels. This result is consistent with the economy of scale theory in residential construction (Ott et al., 2012). These two types of

VUD are also more likely to occur in medium-to-high density residential zoning areas, as is guided by the local urban planning policy (Brisbane City Council, 2000). On the other hand, certain factors also affect the two types of VUD differently to a certain extent. First, environmental constraints (i.e. high elevation), higher level of road accessibility and land use mix only constrain the development of medium- to high-rise apartments, but not with low-rise apartments. Higher elevation may lead to higher construction costs (Liu et al., 2016), and a higher level of road accessibility and land use mix will increase its land value and therefore the construction costs (Song and Knaap, 2004). Those added costs are more likely to be affordable for larger-scale development of medium- to high-rise apartments. Second, higher population density and job opportunities are likely to increase the likelihood of VUD; however, such a likelihood is only associated with medium- to high-rise apartments. This echoes the findings by where VUD is associated with higher concentration of population and easy access to job opportunities. Third, before taking into account the scale effect of land parcels, upzoning was positively associated with medium- to high-rise apartments development. However, this association became negative for low-rise apartments when the scale effect was taken into account. According to Greenaway-McGrevy et al., (2021), upzoning could result in increased land premiums and reduce the likelihood of VUD. In addition, the scale of the parcel size may impede the effect of upzoning on VUD. Upzoning increases new buildings' permissible floor area ratio and the corresponding minimum lot size requirement. The land size of the upzoned parcel may not meet this minimum size requirement, thus limiting the potential of VUD.

This study also contributes to parcel-based land use planning policies that are targeted at more intensive urban land use. First, measures such as direct state-led government involvement are recommended to promote the land acquisition for VUD. While our study highlights the importance of parcel size on VUD, relatively smaller land parcels under fragmented ownership may hinder the acquirement of land in adequate size for VUD (Queensland Government, 2017). Second, it is

Figure 1. Examples of the parcel amalgamation for (a) low-rise apartments and (b) medium- to high-rise apartments, and parcel subdivision for (c) low-rise houses (Green lines denote parcel boundaries of 2009 and red lines denoted parcel boundaries of 2014. Base maps are satellite imagery of 2009 and 2014 from Google Earth).

necessary for policymakers to review the minimum parcel size requirement set in the relevant planning policies in order to promote VUD. Although governments propose upzoning with expectations for high-rise developments and higher-density housing, upzoning alone does not appear to be sufficient to drive VUD (Freemark, 2019; Greenaway-McGrevy et al., 2021). One possible explanation is that the increase of the minimum parcel size requirement from upzoning may increase the difficulty of acquiring parcels with sufficient size for further development. For example, in Brisbane, the minimum parcel size requirement for multi-unit development in a Low-Density Residential zone is 600 m^2 in the year 2000 zoning plan (Brisbane City Council, 2000). If a parcel is upzoned from a Low-Density Residential zone to a Medium-Density Residential zone, the permitted multi-unit dwelling form on this site could be changed from a duplex to a maximum of five-story apartment. With this increased allowable dwelling density, the minimum parcel size requirement would increase to 800 m^2 (Brisbane City Council, 2000, 2014). This would increase the difficulty of finding a parcel of sufficient size. Third, our findings show that transport accessibility is positively associated with low-rise apartment development. Early research by Searle (2007) and also McCrea and Walters (2012) also show that traffic congestion is an inevitable side-effect of VUD. As such, it is recommended that the provision and upgrading of transport infrastructures and amenities are necessary in order to avoid such advert effect on VUD.

There are some limitations in this current study. First, we quantified the socioeconomic and built environment factors using data at two time points – 2009 and 2014 – without considering the dynamic nature of change of these factors over time, and we used a one-time census data in 2011 as a proxy to approach the socio-demographic profile of the area over the five-year period. Second, we assigned area-based (SA1) socioeconomic data to land parcels and different land parcels within the same SA1 inherited identical socioeconomic characteristics. This study also did not consider certain human behaviour factors, such as those associated with real estate developers, or the housing preference of individuals and how to choose to live in what type of housing development. Given that most of these variables are not readily available, it is not within the scope of the current work but would need more research in the future.

Conclusion

This study explores the relationship between VUD and the driving factors by examining factors that influence the development of multi-story residential housing at the parcel scale. The findings from this study make several contributions to the current literature. First, unlike the usual grid-based VUD studies, our study analyses factors influencing VUD at the parcel scale, and contributes to the ongoing scholarship towards modelling VUD at the land parcel scale. Second, this study enriches our understanding of VUD process of different VUD types and the association by quantifying the scale effects from parcel size and its changes. Third, these findings contribute to developing practical parcel-based land use planning policies that are targeted at more intensive urban land use, avoiding the biased urban land allocation imposed by the parcel size.

There are two aspects of this work that can drive future research. First, from empirical perspectives, our study of factors driving VUD at the parcel scale could be applied in the simulation and prediction of future urban land use, which can guide the future allocation of urban land resources. The research framework developed in this study can also be extended to include other human factors, such as residents' housing preferences, to understand more comprehensively the driving forces of VUD, as such housing preferences affect not only the market demand of housing types, but also the location and extent of VUD. To this end, we call for further research that takes into account human behaviour factors as a promising analytical framework to enhance our understanding of vertical urban development.

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Author contributions

Yuanyuan Huang: Conceptualization, methodology, formal analysis, writing – original draft.
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Supplemental Material

Supplementary material for this article is available online.

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