Developers’ vertical price premium behavior in residential tall buildings

A study on vertical price premiums and their determinants for apartments in Rotterdam’s residential tall buildings

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Executive summary

Currently 55% of the global population is located in urban areas. The United Nations (2018) expect that in 2050, this portion will have grown to 68%. In line with global urbanization trends, The Netherlands has to deal with increasing population density in urban areas. In 2030, nearly three quarters of the expected growth of 950.000 Dutch citizens (compared to 2015) will locate in large municipalities of currently 100.000 or more inhabitants, with the largest growth in the G4 (Amsterdam, Rotterdam, Den Haag, Utrecht) cities (PBL/CBS, 2016). The research centers foresee a 15% growth in the municipalities' inhabitants compared to 2015. These cities need to develop a large number of residences. Cities are limited in their options to expand horizontally and are forced to vertical sprawl. This leads to the increase tall building developments in the Netherlands. These vertical objects have become more prominent in the urban fabric - especially of large cities – resulting in higher density urban areas, which can be considered to have environmental benefits, but also raise socio-economic concerns. These concerns are not limited to the contribution to density of an area, but also relate to the buildings themselves. The longevity of tall buildings should not be underestimated as most are observed to make up a permanent part of the urban fabric and claim a part in the spatial legacy of the concerning city (Ahlfeldt & McMillen, 2018).

Problem statement & research objective

Tall building economics remain understudied, despite the fact that both the number and size of tall building developments are increasing. However, recent studies found that the vertical dimension plays an important role in urban economics for the commercial sector (Ahlfeldt & McMillen, 2018; Koster, Rietveld, & van Ommeren, 2013; Liu, Rosenthal, & Strange, 2018; Nase, van Assendelft, & Remøy, 2018; van Assendelft, 2017). These recent studies spawned a new subtopic within tall building economics that concerns floor level premiums. This thesis defines floor level premiums as the premium to locate one floor higher, ceteris paribus. Literature on height premiums is growing but small and limited to observations on the demand side by Liu et al. (2018); Nase et al. (2018) for commercial real estate. Similar results were found for the residential sector in Switzerland by Danton and Himbert (2018) and for Hong Kong by Wong, Chau, Yau, and Cheung (2011). These results all point towards the importance of verticality in urban economics. However, these studies are demand-focused. As the studies signal that different aspects of height are valued differently by the demand side, particular aspects of height should be priced differently by the apartment supplier - the real estate developer. This thesis focusses on developer prices in order to fill the gap concerning developer vertical price premium behavior. The following research questions is placed centrally in this thesis.

How do real estate developers behave regarding vertical price premiums in residential tall buildings?

In order to answer the main research question, several sub research questions are formulated, aiming to answer a piece of the puzzle with each sub-question.

1. *What are the determinants of vertical price premiums?*
2. *How can a model be developed in order to measure the developers' vertical price premium behavior in residential tall buildings?*
3. *To what extent do different factors contribute to developers' vertical price premiums in residential tall buildings?*

Research scope

This research focusses on the Dutch residential market. In specific, residential tall buildings in the city of Rotterdam are studied. Elaboration on city selection is provided in section 3.2.1. In the Netherlands, it is customary for real estate developers to sell their products instead of renting them out and retaining ownership. As a result, more data should be available on listing prices of residential real estate that real estate developers placed on the market for sale than on rental rates of residential real estate that real estate developers placed on the rental market. Therefore, the research only considers initial asking prices for residential real estate placed on the sales market. Further scoping aspects include a minimum height for tallness of 70 meters together with restrictions on height-base ratios and building age. Detailed information on the framework used to select buildings to create the dataset for this research is provided in section 3.2.

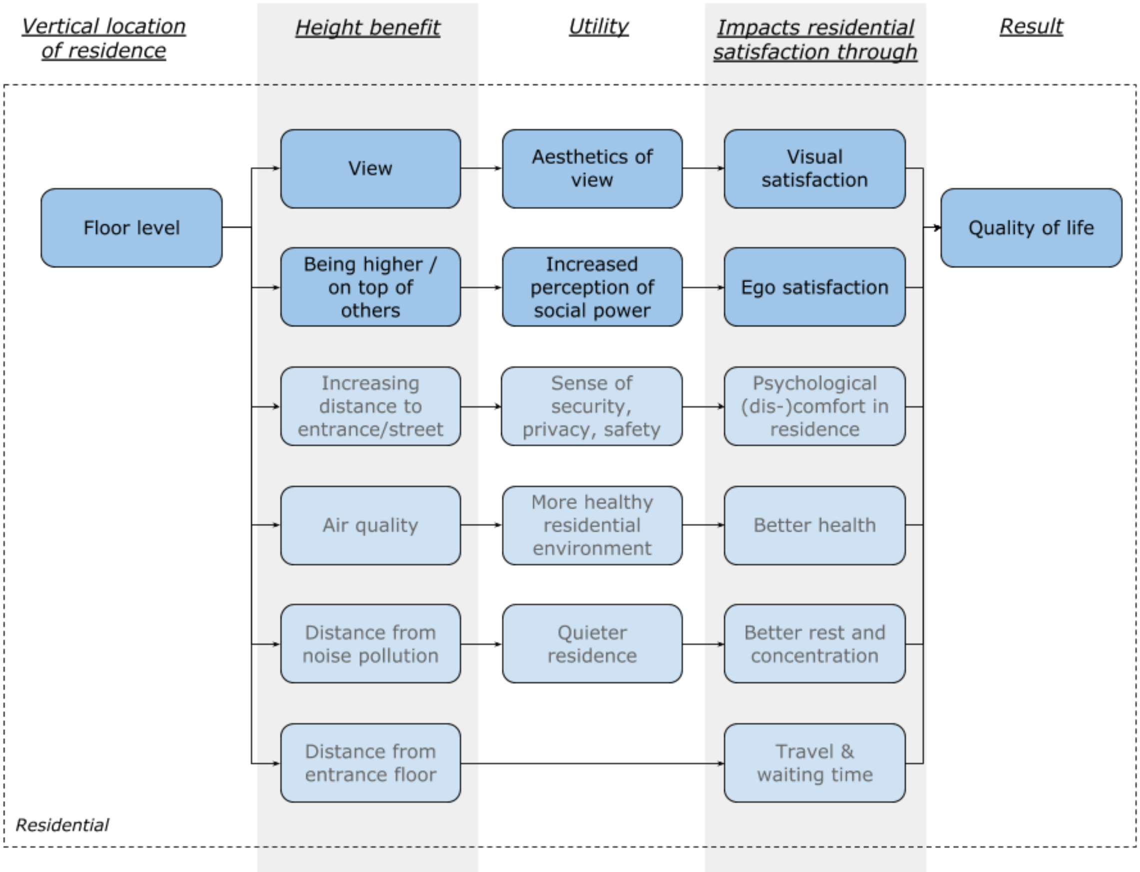
Relevance

On academic level, this research contributes to the small but growing body of knowledge on tall building economics. The research is especially relevant for the small field of height premiums, as - to the extent of my knowledge - no other studies have focused on the behavior of real estate developers regarding floor level premiums. However, there are clear signals that there is a demand for aspects of height and the vertical rent gradients found in previous studies indicate that developers act based upon a certain perception of consumer willingness-to-pay. The dynamics behind this behavior are currently unclear and this thesis contributes to filling the gap on the supply side point of view. New insights on the relation between height and views as well as status concepts are presented. Additionally, this thesis advances the body of tall building economics within the Netherlands and is the first to research floor level premiums in Rotterdam. Another contribution are the findings concerning premiums commanded for a view on the Erasmus bridge. Lastly, this thesis adds to the body of knowledge on several standard control variables, namely number of bathrooms, outside spaces, living room orientation and indoor floor area.

On a practical level, various parties can use the resulting knowledge to add more value. First of all, findings enable appraisals of apartments in residential tall buildings to be performed more accurately, but also earlier in development processes. This is beneficial to developers, valuers and other parties interested in price formation or apartment and building valuation. Secondly, findings will provide more transparency to the demand side of the housing market on apartment price formation, enabling stakeholders on the demand side to more effectively select an object or residence that matches their demands and interests. Thirdly, findings are of use to municipalities for estimating residual land values more accurately, which in turn may influence high-rise policies and regulations on maximum heights.

Theoretical underpinnings

Different theories on building height determinants exist, but for this thesis profit maximization theories and game-theoretic theories relating to status are most relevant. Recently various studies have reported findings on floor level premiums and it is evident that end-users are willing to pay premiums for particular benefits of height in the commercial real estate sector. This thesis focusses on the residential sector rather than the commercial sector, where views and status are important height-related determinants of residential satisfaction. Other benefits of height are left for future research as no data on the vertical dimension was obtained for those factors in this study.



Benefits of height for residential real estate: concepts and associations. Air quality, sense of security, privacy and safety and the aspect of luck are not included in the empirical research due to reasons elaborated upon in chapter 2.. Source: Own illustration, based on various sources discussed in chapter 2.

Since residential satisfaction leads to an increase in quality of life of the residents, this thesis theorizes that residents are willing to pay a premium to locate higher in a residential tall building. As the studies signal that these factors are valued by residents, these factors should be priced by the real estate developer. The quantitative analysis of this thesis puts this to the test. The vertical price premium determinants *view* and *perception of social power* are used to form hypotheses on top of a general hypothesis on vertical price premiums.

Hypothesis 1: developer unit prices & floor levels

Hypothesis 1 concerns floor level premiums. Based on other research (e.g. Danton and Himbert (2018), Wong et al. (2011), Coulson et al. (2018)), I expect to find a positive relationship between floor levels and developer units prices.

Hypothesis 2: developer units prices & views

Several studies found that higher floor levels are correlated with better views (Hasanah & Yudhistira, 2018; So et al., 1997; Yamagata et al., 2016; Yu et al., 2007). As height was found to have a positive impact on views, this thesis hypothesizes that developers raise unit prices to exploit homebuyers' willingness to pay for better views. I expect a positive relation between views, floor levels and developer unit prices. In order to test this hypothesis, the regression models include control variables for the number of view features that an apartment offers. View features are categorized as *city, Erasmus bridge, harbor, Maas, panorama and park,* based on the view features that are most marketed by developers in sale brochures. Many combinations are possible, but not enough observations are included in the dataset to adequately measure the effect of these combinations.

Instead, the number of view features are counted, resulting in three dummies: 1 view feature, 2 view features, 3 or more view features. Furthermore, a categorical variable is created for whether or not one of these view features is the Erasmus bridge. The Erasmus bridge is a prominent local icon and no previous studies have measured how developers exploit the view on the Erasmus bridge in apartment price formation. As the effect of views is expected to increase when locating higher due to increasing view quality, interaction terms between floor level and these view control variables are added throughout the models.

Hypothesis 3: developer unit prices & perception of social power

Vertical location in tall buildings was found to have a positive impact on the perception of social power (Dorfman et al., 2017). It is suggested that social power could be priced within the context of tall building developments. This thesis models three aspects which are believed to be a representation of social power. Firstly, this thesis considers the concept of *'prestige'* by creating dummy variables for whether or not the apartments is marketed as a penthouse. With this, I hypothesize that living in a penthouse is valued by homebuyers in search for status and that developers try to take advantage of this willingness to pay through a *'penthouse premium'*. Secondly, this thesis considers the extent to which a resident has *'the whole floor to him/herself'* by creating a variable for the number of neighbors and by investigating the relation between floor neighbors, floor level and developer unit prices. Thirdly, the extent to which a resident *'is on top of others'* is investigated by creating a squared relative floor level variable. This variable is created by taking the apartment's floor level, dividing it by the total number of floors in the building and squaring this number. This results in a gradient from zero to one with only higher floors achieving relatively higher scores.

Testing methodology & variables

To test our hypotheses, hedonic pricing analysis is performed, which is widely accepted as a suitable method for studying prices of property characteristics. The hedonic pricing analysis is a statistical method that assesses the relationship and its strength between a dependent variable and a (or multiple) independent variables (Rosen, 1974). This thesis uses regression modelling to test several of the formulated hypotheses. To determine which variables should be included in the analysis as independent variables, this thesis considers the variables that are required to test the hypotheses and supplements these with a set of control variables. The dependent variable, developer unit prices, is acquired by taking the listed apartment price, subtracting any costs included for parking places and then dividing by the indoor floor area. Prices are adjusted for inflation effects using CBS consumer price index data for the yearly quarter that the apartments prices were marketed. These prices are then transformed into a logarithmic form in the regression models. Table 2 in section 3.1.3. displays all variables that are included in the regression analysis, which dummy variables act as baseline dummies within the concerning categorical variable and also provides basic descriptive statistics. Appendix A provides an overview of data sources.

A high-level representation of the regression model is presented in the equation below. Bold glyphs are aggregated for hypothesis testing variables, control variables and for interaction term variables. Each bold glyph represents a matrix of variables and each coefficient represents a column vector corresponding to the neighboring matrix.

$$Ln(P) = \beta_0 + \beta_{i-n} X + \beta_{j-n} Y + \beta_{k-n} Z + \varepsilon_i$$

Dataset

Rotterdam is selected as urban area for data collection because it has the highest number of residential tall buildings in The Netherlands. Further scoping leads to a selection framework that only fits predominantly residential buildings developed after the year 2000 of at least 70 meters height and a height-dependent height-base ratio (<70m: 56 meters diagonally | >70m: 42 meters diagonally). Table 4 in section 3.2.2. provides an overview of all objects that fit into this framework, along with several characteristics. Note that towers with only rental apartments are also excluded.

Table 5 in section 3.3.1. provides an overview of the towers that are analyzed in the regression analysis. Note that in all cases, the developer was assisted by brokers and sometimes other advisors in apartment price formation. Nevertheless, developers ultimately decide prices and, therefore, prices gathered from lists are suitable for analyzing developer vertical price premium behavior. The final dataset consists of a total number of 1406 apartments divided over fifteen towers. With a total number of 54 independent variables and one dependent variable, this leaves 26 observations per independent variable. Of these 54, 43 variables are dummy variables, divided over eight categories. As only a single dummy variable of each category is applicable per apartment, a total of 16 independent variables are of influence on each apartment's developer unit prices in the regression model. These combinations are adequate enough to start analyzing the data and to test the formulated hypotheses (Field, 2009).

Regression model outcomes

The analysis considers real estate developer prices in the form of apartment prices divided by indoor floor area. All models employ these unit prices as dependent variable data and fifteen different regression models are constructed to test various hypotheses. Every model includes a different combination of variables in order to test effects of different apartment characteristics. The model architecture is defined in the table below.

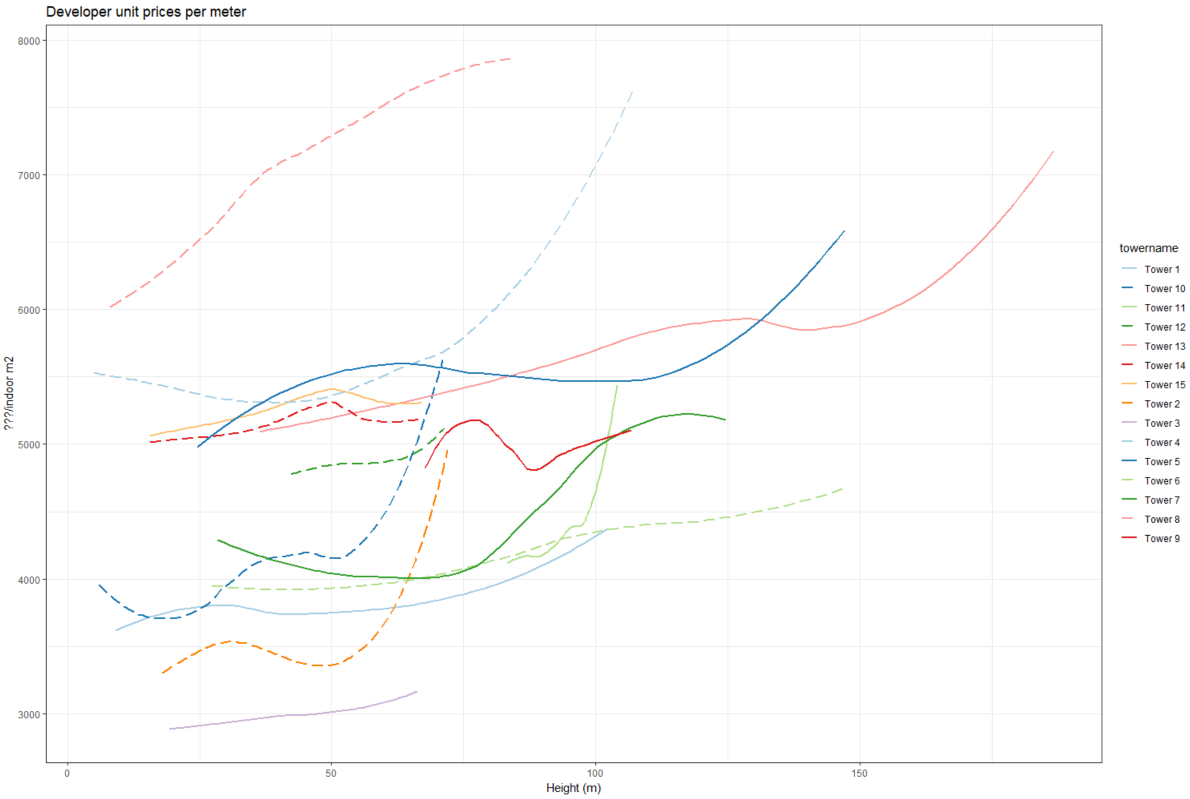
Regression model analysis architecture.

Model number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Floor level *(GFLPs)*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of views		Yes	Yes			Yes	Yes		Yes		Yes	Yes	Yes	Yes	Yes
Erasmus bridge view		Yes	Yes			Yes	Yes		Yes		Yes	Yes	Yes	Yes	Yes
Number of views * Floor level			Yes				Yes		Yes		Yes	Yes	Yes	Yes	Yes
Erasmus bridge view * Floor level			Yes				Yes		Yes		Yes	Yes	Yes	Yes	Yes
Penthouse				Yes	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes
Penthouse * Floor level *(PHFLPs)*					Yes		Yes			Yes	Yes	Yes	Yes	Yes	Yes
Building FE * Floor level *(TSFLPs)*								Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Neighbors * Floor level *(NFLPs)*												Yes	Yes	Yes	Yes
Building FE * Penthouse													Yes	Yes	Yes
Rel. floor level^2 *(GRFLPs)*														Yes	Yes
Building FE * Rel. floor level^2 *(TSRFLPs)*															Yes
Standard control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dataset	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full
Constant	8,237	8,279	8,252	8,253	8,256	8,294	8,270	8,279	8,292	8,294	8,309	8,371	8,345	8,339	8,323
Observations	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406
R^2	0,908	0,912	0,913	0,908	0,908	0,912	0,913	0,916	0,920	0,916	0,921	0,923	0,932	0,933	0,933
Adjusted R^2	0,905	0,909	0,910	0,905	0,905	0,909	0,910	0,912	0,917	0,913	0,917	0,919	0,929	0,930	0,929

Findings of preceding parts of this thesis indicate that developers are highly heterogenous and this is accounted for in the regression models by clustering standard errors at building level.

Floor level premiums

General floor level premiums (GFLPs) are consistently significant at the $p<0.01$ level for model 1 through 13. Model 1 displays a 0.51% increase in developer unit prices per when locating one floor level higher, *ceteris paribus*. Controlling for height-dependent view effects raises the floor level premium by ~25%. The figure on the next page shows that there are severe differences in unit price developments over floor levels, both inter-building and intra-building. The inter-building differences are considered a representation of developer heterogeneity in applying floor premiums during apartment price formation. This means that a *general* floor level premium may not accurately reflect floor level premiums for all towers in the employed dataset. In order to analyze the differences in floor level premiums between different towers, regression model 8 through 15 include an interaction term between building-fixed effects and floor levels. The addition of this interaction term results in a decrease in magnitude of the GFLP effect from 0.51% to 0.42% in model 8. Different towers display different floor level premiums, as is visible in the table on the next page.



Developer unit prices in relation to absolute height (without controlling for other effects).

One of the aspects that is deemed a representation of status is the extent to which a resident has to share the concerning floor with neighbors. Model 12 includes an interaction term for number of floor neighbors times floor level. The addition of this interaction term results in an increase of the GFLP from 0.53% to 0.58% (compared to model 11). The impact on TSFLPs is substantial, displaying both negative and positive effects of different sizes on the regression estimates. The discrepant effect of this variable is interpreted as a sign that it simulates more detailed approximation of the floor level premiums. Controlling for squared relative floor level effects in model 14 and 15 eliminates the significance of the general floor level premium.

Regression estimates are of a lower magnitude than those of other studies where transaction prices were employed as dependent variable data in their hedonic pricing analysis. One unit increase in floor level was found to impact transaction prices by 2.2% in San Diego (Conroy, Narwold, & Sandy, 2013).

A study on developers' supply functions in Singapore found a wide spectrum of floor level related premiums, ranging from -0,9% to 15,5% depending on time and place (Coulson et al., 2018). This strengthens the need to consider floor level premiums on a building level, as in the employed dataset apartments' 'time and place' is linked to the tower they are located in. Danton and Himbert (2018) report a 2% increase in unit rent levels after controlling for different factors and conclude that the floor level premiums are influenced by building height, view features and location. This thesis accounts for these effects by interacting the floor level variable with the tower dummy variables in all models and also by interacting the floor level variable with view variables. These interaction variables return statistical significance at the 5% level for several towers and indicate deviation from the general floor level premium for several others. This is interpreted as additional evidence for heterogeneity in developer behavior regarding the use of floor levels in apartment price formation. The difference in general floor level premiums compared to these studies is attributed to contextual differences.

The result of this heterogeneity is a wide range of floor level premiums, influenced by different determinants. An overview of the floor level premiums applicable for each regression model per observed tower is available in the following table, which is discussed in more detail in section 4.1.1.

	Regression model numbers	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Control overview	Standard control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	View control variables	-	Yes	Yes	-	-	Yes	Yes	-	Yes	-	Yes	Yes	Yes	Yes	Yes
	View * floor level IV	-	-	Yes	-	-	-	Yes	-	Yes	-	Yes	Yes	Yes	Yes	Yes
	Penthouse control var.	-	-	-	Yes	Yes	Yes	Yes	-	-	Yes	Yes	Yes	Yes	Yes	Yes
	Penthouse * floor level IV	-	-	-	-	Yes	-	Yes	-	-	Yes	Yes	Yes	Yes	Yes	Yes
	Building FE * floor level IV	-	-	-	-	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
	Neighbors * floor level IV	-	-	-	-	-	-	-	-	-	-	-	Yes	Yes	Yes	Yes
	Building FE * Penthouse IV	-	-	-	-	-	-	-	-	-	-	-	-	Yes	Yes	Yes
	Relative floor level^2	-	-	-	-	-	-	-	-	-	-	-	-	-	Yes	Yes
	Building FE * relative floor level^2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Yes
GFLPs	Floor level *(GFLP)*	*0.51%*	*0.50%*	*0.63%*	*0.50%*	*0.50%*	*0.50%*	*0.62%*	*0.42%*	*0.53%*	*0.42%*	*0.53%*	*0.58%*	*0.55%*	-	-
TSFLPs (add to GFLPs)	Tower 2	-	-	-	-	-	-	-	0.81%	0.80%	0.80%	0.79%	1.04%	1.14%	0.79%	-
	Tower 3	-	-	-	-	-	-	-	0.32%	-	0.32%	-	0.59%	0.69%	-	-
	Tower 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 5	-	-	-	-	-	-	-	-	-	-	-	-	0.48%	0.65%	-
	Tower 6	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33%	-
	Tower 7	-	-	-	-	-	-	-	0.49%	0.51%	0.49%	0.52%	0.52%	0.57%	0.67%	-
	Tower 8	-	-	-	-	-	-	-	0.82%	-	0.81%	-	-	0.67%	0.54%	-
	Tower 9	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.40%	-
	Tower 10	-	-	-	-	-	-	-	0.74%	0.80%	0.75%	0.81%	0.93%	0.86%	0.65%	-
	Tower 11	-	-	-	-	-	-	-	1.42%	1.23%	1.46%	1.27%	-	-	-	-
	Tower 12	-	-	-	-	-	-	-	-	-	-	-	0.62%	0.35%	-	-
	Tower 13	-	-	-	-	-	-	-	-	-	-	-	-	0.34%	0.53%	-
	Tower 14	-	-	-	-	-	-	-	-0.36%	0.38%	-	-	-	-	-	-
	Tower 15	-	-	-	-	-	-	-	-0.33%	0.34%	-	-	-	0.45%	-	-
Sign. Dets.	Views * floor level IVs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Penthouse * floor level IV *(PHFLP)*	-	-	-	-	-	-	-	-	-	-	-	-	*0.95%*	*0.86%*	*0.87%*
	Neighbors * floor level IV *(NFLP)*	-	-	-	-	-	-	-	-	-	-	-	*-0.07%*	*-0.08%*	*-0.08%*	*-0.07%*
GRFLPs	Relative floor level^2 *(GRFLP)*	-	-	-	-	-	-	-	-	-	-	-	-	-	*17.64% (8.65%)*	*6.99% (9.9%)*
TSRFLPs	Tower 2: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*19.85%*
	Tower 3: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 4: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 5: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*16.18%*
	Tower 6: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 7: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*24.65%*
	Tower 8: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*13.20%*
	Tower 9: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 10: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*16.25%*
	Tower 11: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 12: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 13: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*16.28%*
	Tower 14: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 15: `relative floor height2`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

The coefficients reported in the table above can be used to estimate floor level premiums (FLPs) for each apartment. By entering the coefficients found in a model in the equation on the next page, the floor level premium (FLP) for a specific apartment can be estimated. I argue that different models are more suitable to estimate premiums based on different determinants. Example: an apartment located on the top floors of a tower is likely to be more accurately estimated using the architecture of regression model 14. Model 15's architecture enables an even more accurate approximation of top-level apartments in towers that significantly deviate from the GRFLP. One of the main takeaways for this thesis is that the floor level premium is composed of different determinants and one should very carefully consider the quality of height-related characteristics of an apartment when applying floor premiums during price formation. Note that in the equation, the inclusion of interaction terms increases the amount of noise in the formula and diminishes the pureness of the FLP since the interaction terms partially include the value of other characteristics of an apartment (e.g. penthouse effect).

$$FLP_{apt} = flv_{apt} * (\beta_{GFLP} + \beta_{TSFLP} + \beta_{PHFLP} * (1 \vee 0) + \beta_{NFLP} * N_{flv} + \frac{flv_{apt}}{(flv_{max})^2} * (\beta_{GRFLP} + \beta_{TSRFLP}))$$

FLP_{apt} = floor level premium of the concerning apartment
flv_{apt} = floor level of the concerning apartment
β = coefficient reported by the regression models.
GFLP = general floor level premium
TSFLP = tower-specific floor level premium
PHFLP = penthouse floor level premium
NFLP = number of neighbors floor level premium
N_{flv} = number of neighboring apartments on the concerning floor level
flv_{max} = highest floor level of the concerning tower
GRFPL = general relative floor level premium
TSRFLP = tower-specific relative floor level premium

View effects

The regression models control for views in the form of umber of view features and whether or not an apartment provides a view on the Erasmus bridge. Model 2 reports a 4.23% increase in developer unit prices for having two view features instead of one. Three or more view features only add a marginal magnitude on top of this 4.23%, resulting in 4.64%. Since the effect of view is expected to increase when locating higher due to better views, interaction terms between the view control variables and floor level are added. These raise the number of view feature control variables to 7.26% and 6.59% respectively. Controlling for additional effects marginally decreases these estimates, indicating that those variables do not impact the effect of views on developer unit prices.

The second categorical variable in the context of view and height is whether or not one of the view features of an apartment is a view on the Erasmus bridge, a local icon. After adding interaction terms for tower-specific floor level effects in model 9, the regression estimate increases to 4.88% and raises its significance to the 5% level. The estimated developer unit price increase remains stable at ~5% at retains its significance when adding additional control variables in model 11 through 15.

As reported above and in section 4.1.1., the magnitude of the GFLP increases with ~25% when adding interaction terms between views and floor levels. Combined with the outcomes reported above, this is interpreted as corroborative evidence for the hypothesis that height-induced views offered by an apartment impact the magnitude of floor level premiums set by developers. However, the interaction terms do not return any significant estimates on the size of the impact on height-dependent view premiums. This is mainly attributed to the quality of data used in the regression analysis.

Perception of social power

The first aspect of perception of social power tested in this thesis is *prestige,* in the form of whether or not an apartment is marketed as a penthouse. Penthouses are often highly unique residences and vary significantly in their characteristics. This thesis does not pretend to have defined when an apartment is or is not a penthouse, but simply considers whether or not the developer has marketed the concerning apartment as a penthouse. Due to heterogenous developer behavior, some developers may apply a lower threshold to put the title of penthouse on an apartment than others and some may even use the title of penthouse as a marketing strategy. As a result, ‘Marketed as penthouse’ observations in our dataset may differ significantly in their characteristics. However, considering penthouse effects per tower (and, thus, per developer) instead of over the entire dataset provides regression estimates for groups of observations that are less heterogenous. Model 13 through 15 include interaction terms between building-fixed effects and the penthouse variable. In contrast to non-tower specific penthouse variables, an effect on the GFLP can be observed, decreasing the regression estimate from 0.58% to 0.55%. Furthermore, the penthouse variable as well as the floor level interaction variable become highly significant after the addition of this interaction term. This means that developers increase penthouse unit prices when they are on a greater vertical location, indicating that they seem to think that a penthouse offers more prestige when located higher. The models report an initial penthouse penalty on developer unit prices of ~20%, which are compensated by an additional 0.95%, 0.86% and 0.87% developer unit price increase per floor level. The outcome is then further adjusted according to the tower-specific penthouse premiums, some of which display significant deviation from the general penthouse effect.

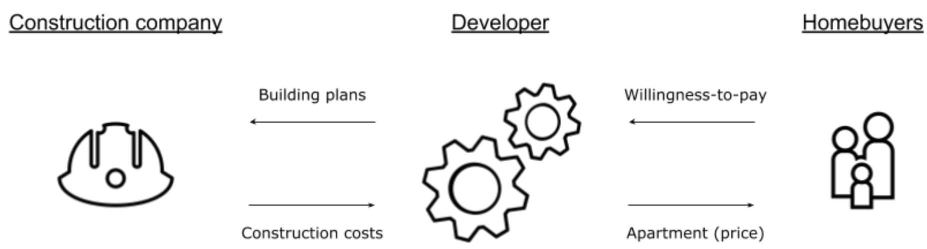
The second representation of perception of social power is measured by the number of neighbors, a variable that is employed as representation of the extent to which a resident '*has the entire floor for him-/herself*'. It is hypothesized that the effect size of the number of neighbors depends on the apartments' vertical location and the analysis introduces an interaction term between floor level and number of neighboring apartments on the concerning floor. The estimates are highly significant ($p<0.01$) and largely consistent throughout all models, ranging from -0.07% to -0.08% times the number of neighbors for each floor level. The effect on the GFLP is noticeable and significant, which is deemed as evidence for the hypothesis that the number of floor neighbors in relation to height plays a role in the composition of floor level premiums.

The last part of perception of social power that this thesis attempts to simulate is whether the resident is *'on top of others'*. The squared relative floor level variable is employed to model this effect in model 14 and 15. The variable absorbs most of the general floor level variable's predictive power, rendering it highly insignificant while achieving high significance for itself ($p<0.05$). Therefore, it can be inferred that the squared relative floor level variable is a strong variable in explaining the floor level premium. The estimated coefficient is reported as 0.1764 in model 14. This means that when an apartment is located on the top floor, it is assigned a 17.64% developer unit price premium compared to an apartment on the ground floor. Several towers display significant deviation from the GRFLP when adding TSRFLPs in model 15. The main takeaway from these outcomes is that those TSRFLPs that deviate sizably correspond to towers that are icons and break records for residential tall building heights in Rotterdam or the concerning Rotterdam neighborhood when they are completed, consistent with the implications of Koster et al. (2013). The concerning height record-breaking buildings are all constructed in boom times, which is consistent with the findings of Barr (2012). This thesis theorizes that from a certain floor level, the apartments in these towers provide the unique characteristic of living in an apartment located on a greater vertical location than apartments in other towers in the city or neighborhood. It can be inferred that the sizable deviation from the GRFLP displayed by these towers is a result of developers placing larger floor level premiums on apartments that possess this unique characteristic of being located higher than apartments in any other tower in the area. Floor level premiums in relation to height of surroundings and inter-building social power competition are out of the scope of this thesis and should be investigated in future research as they potentially play an important role in floor level premiums composition.

Floor level premiums in the context of costs

The overall 0.5% premium that is found in this thesis does not weigh up against the 0.8% increase in marginal costs per floor indicated by van Oss (2007). While it is unclear if the 0.8% cost premium per floor is applicable for the buildings included in our dataset, it may the case that 0.5% premiums in developer unit prices per floor is not enough to obtain profit for adding extra floors. One issue at hand is that if marginal costs per floor are larger than marginal revenues per floor, then marginal profits per floor are negative and tall building developments cannot be justified from a financial perspective. This thesis argues that marginal costs per floor and floor level premiums play different roles in the development process and apartment pricing process.

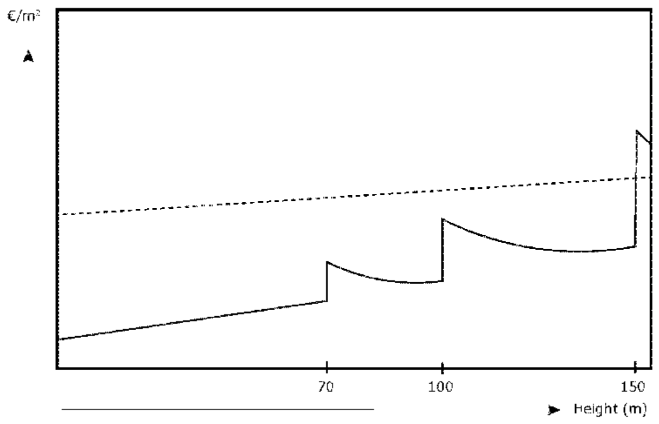
Developers monitor the costs side of the development by considering the costs/m^2 and total costs. With clear knowledge on total development costs/m^2, the developer is tasked with realizing a financially healthy business case. On the revenue side of the business case, it is important to realize that the developer does not sell single m^2 units, but apartments. As is evident from the performed regression analyses, apartments are priced according to their characteristics. This thesis proves that floor level is an apartment characteristic that plays a role in apartment price formation, as developers exploit homebuyers' willingness to pay for benefits of height. These dynamics are depicted in the figure below. As the figure shows, construction costs do not directly impact apartment prices. While the developer is tasked to set apartment prices to create a healthy business case - based on construction costs and other development costs - premiums for certain apartment characteristics are driven by homebuyers' willingness-to-pay. This supply and demand interaction for an apartment and its characteristics is leading in floor level premium formation. Ultimately, homebuyers never come in contact with the construction or development costs and are only willing to pay for what they do come in contact with: the apartment and its characteristics. This thesis concludes that vertical price premiums for apartments are, therefore, not impacted by increasing marginal floor costs. On the other hand, the overall apartments costs are indirectly influenced by marginal floor costs. This thesis provides an elaboration on those dynamics below.



Apartment price formation dynamic in the development process.

As visible in figure 26 in section 4.1.1., developers tend to develop residential tall buildings to certain heights: 70 meters, 100 meters and 150 meters. One explanation is the extremely nonlinear increase in costs/m^2 related to height, mainly originating from required fire safety measures and structural safety measures. Exceeding these heights means that these additional measures need to be accounted for in the costs section of the business case, leading to substantial effects on costs/m^2.

Since developers focus on costs/m^2, they try to spread out the sudden large investment over as much surface area as possible, aiming to minimize the overall costs/m^2. One of their options is to add as many additional floor levels as possible, thus adding a substantial amount of surface area. From an economic point of view, the costs are minimized when adding as much extra floors possible without breaking another height barrier that induces additional large investments. The figure below conceptually displays these dynamics. In the figure, a 150m building is economically optimal. This behavior is in line with profit maximization theories as discussed in chapter 2 and leads to the building heights of 70m, 100m and 150m (Barr, 2012; Clark & Kingston, 1930; Garza & Lizieri, 2016). Marginal costs and floor level premiums influence the slope of the lines as depicted in figure 29 and the absolute costs and absolute revenues determine the starting points on the y-axis of the lines. Both aspects together determine the break-even height. This leads to the conclusion that both marginal cost increase and floor level premiums, as well as absolute costs and revenues, play a role in determining optimal building height.



Marginal costs & revenues dynamics. The dashed line represents a linear (e.g. 0.5%/floor) increase in revenues/m^2 and the continuous line represents costs/m^2 (average 0.8% increase/floor).

Building heights were also found to be impacted by building height regulations. While building height regulations play a role in building height determination for some towers, the building height of the majority of the observed residential tall buildings is consistent with profit maximization theories.

Openings for further research

Limitations of the research include a lack of depth in the view data quality, which needs to be defined in further detail in order to enable results to determine to more accurately quantify the extent to which view quality induced by height is priced by developers. The findings of Benson et al. (1998); Rodriguez and Sirmans (1994) may provide a basis for this next step. Further qualitative findings indicate that height premiums sharply increase starting from the floor where views are no longer blocked by a neighboring building. This calls for further research on the height of surroundings, as this can simulate whether or not a view is blocked. This is also a key step in investigating inter-building social power competition - indicating whether an apartment is *king of the hill*, which would be an interesting expansion on studies relating to status, height and vertical price premiums.

Recommendations & limitations

The results of the research are highly relevant for real estate actors involved in pricing strategies. They provide evidence that floor level premiums are applied by various developers and additional research in the concerning apartments' time on market would provide valuable insights in the success potential of the applied premiums. The foundation of the findings of this thesis can applied broadly by using the notion that floor level premiums are impacted by views and status related aspects. Even though the outcomes may be different, this thesis proves that these mechanics are important determinants in the behavior of developers when it comes to vertical price premiums. An example: the uniqueness of living in a high vertical location is likely to be lower in other cities in the Netherlands due to a lower number of residential tall buildings and developers may apply greater vertical price premiums for apartments in other cities to exploit this situation. However, the high level of developer heterogeneity regarding vertical price premiums found in the analysis of this thesis proves that resulting price premium strategies differ from tower to tower. This corroborates the notion that further research is desired on other building types and cities.

Nevertheless, the findings of this thesis can be used as a reference point for pricing strategies in new developments. This is not only useful for developers, but also for real estate appraisers and advisors. Additionally, homebuyers can use the findings to gain more detailed insights in the price for locating higher – ceteris paribus – when hunting for a new home. Lastly, policy makers should interpret the findings as evidence for the existence of floor level premiums. These floor level premiums contribute to the developers’ business case and, therefore, also positively impact residual land values. Consequently, the findings may provide incentive to municipalities to stimulate tall building developments in their urban planning policies.

Preface

This document contains my graduation thesis, a report of my research within the topic of Real Estate Economics of the master track Management in the Built Environment of the Delft University of Technology. It is the manifestation of the closing act of my study career at the Delft University of Technology and required to obtain the Master of Science degree.

The research contributes to a topic in the larger field of urban economics. Within this field, I address the topic of tall building economics, where a small body of knowledge on height premiums has emerged. These recent studies are focused on the demand side and result in findings on vertical rent gradients and willingness to pay for certain benefits of height. As the studies signal that different aspects of height are valued differently by the demand side, particular aspects of height should be priced differently by the supplier - the real estate developer. Currently there is a gap in the literature and body of knowledge on the behavior of real estate developers regarding the value of height in tall buildings. This thesis contributes to filling this gap.

Researching this topic presented me with an opportunity to address two themes that I am passionate about: tall buildings and development. The first has long been an interest of mine. Through the years I learned that I feel particularly attracted to contributing to pioneering and unique endeavors. Tall buildings fit this frame well because they stand out from the crowd and emit a certain grandeur and prestige, which is - unsurprisingly - also an important aspect in the theme of tall building economics and height premiums in particular. Secondly, this research allowed me to take a peek into the realm of development of tall buildings, which I consider to be an interesting career path as development matches my enthusiasm for the commercial and organizational side of real estate business. A third feature of this research that also matches one of my interests is the actual analysis of the study. Having a natural interest and dexterity in mathematics, I have always felt disappointed during my studies within the Faculty of Architecture & the Built Environment in the low quality and quantity of mathematical challenges. As this research requires statistical analyses, it presented me with a chance to catch a glimpse of the world of real estate econometrics.

I am very glad that I have chosen and performed this research. Contrary to most of my fellow students, I have been able to keep a relatively high level of motivation throughout the entire journey due to the opportunities the research presented me as discussed above. Even though the journey has been a rocky road on the personal side of life, I look back on a successful year and am proud of what I have accomplished. Of course, many people have supported me throughout the year. Ilir Nase in the first place, from the start of the journey your enthusiasm inspired me and infected me with the same excitement. Luckily Peter de Jong was present as well to aid me in the more qualitative sense of the research and provide insights in the context of Rotterdam’s tall buildings. I would also like to thank Fakton, my graduation company, and Léon van der Wal in particular for the assistance and more practical perspective on the research. And last, but certainly not least, I thank all friends and family for the good times and helping me through the no-so-good times during this journey.

In case you are reading this and would like to know more about my research, feel free to contact me using the contact information presented in the first section of this document.

Sincerely,

Nathan Westerhuis

Abstract

Even though both the number and the size of tall building developments are increasing, tall building economics remain understudied. The goal of the research is to study developer behavior regarding height premiums in residential tall buildings. Literature offers little knowledge on developers' behavior when it comes to height premiums in the residential sector. Previous findings on the demand side of height premiums indicate that willingness to pay for height benefits depends user preferences, but all signal that higher floors offer characteristics that can be priced by developers. Contextually relevant height benefits in the residential sector are categorized as views and perception of social power. This research employs data from fifteen residential tall buildings in Rotterdam and analyzes the relation between developer unit prices, floor levels and height benefits. Results display a 0.5% increase in developer unit prices per floor level, ceteris paribus. However, a deeper analysis shows that height premiums display inter-building and intra-building differences, which is interpreted as evidence for heterogenous vertical price premium behavior amongst developers. The floor level premiums were found to be substantially impacted by height-induced view effects. The results further show that developers place a price on status aspects related to height. Penthouses premiums were found to be larger when placed on a greater vertical location and some developers seem to put a price label on the concept of being located on top of others. These novel insights can help various stakeholders to better understand developer vertical price premium behavior.

Table of Contents

1. Introduction

This chapter introduces the research context, topic scope, questions and describes the relevance of the research. The chapter concludes with a readers' guide for the rest of the thesis.

1.1. Introduction to tall buildings

One of the first tall buildings in the world was the Great Pyramid of Giza. This is not the first structure that comes to mind when someone says 'skyscraper'. Neither do the cathedrals that were built in the middle-ages. The goal to reach a height of significance within these developments was not to house a greater amount of people or to allow for greater profits, but to be the tallest structure in the area - and thereby the closest to God (Helsley & Strange, 2008). These structures were constructed using masonry as its structural building blocks. The innovation of using steel of a building material for large structures began with the English gardener Joseph Paxton, who chose metal frame structures as a skeleton for greenhouses. It turned out as inexpensive and effective and, combined with the rising demand for office space in America's business districts, led to the development of the Home Insurance Building in Chicago more than a decade later. This building is considered as the first skyscraper (Ali & Al-Kodmany, 2012).

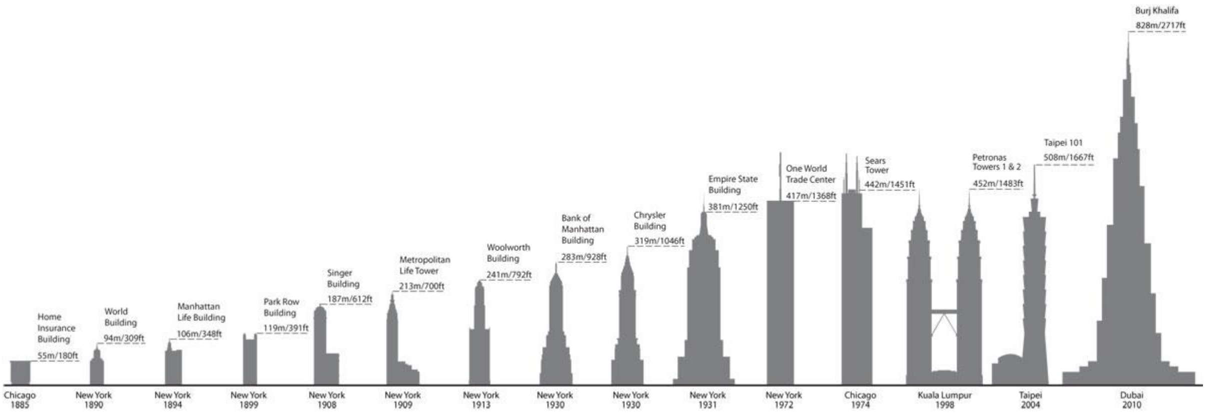


Figure 1. History and Progression of the "World's Tallest" building. Source: Council on Tall Buildings and Urban Habitat (2010)

The technology of using steel and elevators in buildings rapidly gained popularity and was adopted and improved by many. These innovations removed the limitations on building tall of having to build massive thick lower walls and the intolerance of human beings of having to climb stairs in order to move between floors (Glaeser, 2011). Tall buildings became objects that were able to facilitate human habitation to extreme density levels and society started developing tall buildings for economic purposes, rather than purely symbolic ones. Yet, the ego of many stakeholders, from developers to companies and even to countries, drove tall buildings to be developed taller and taller - aspiring to acquire the title of having built the 'tallest building' (Helsley & Strange, 2008). Figure 1 depicts history's tallest buildings, with the Burj Khalifa as the current champion. Not only have buildings become taller, they are also developed more frequently. Figure 2 provides an overview of (global) tall building completions (starting from 200 meters or taller) throughout the last 60 years. Note that in this thesis, buildings are defined as 'tall' when exceeding 70 meters that the numbers depicted in figure 2 are substantially higher when applying this height as a threshold.

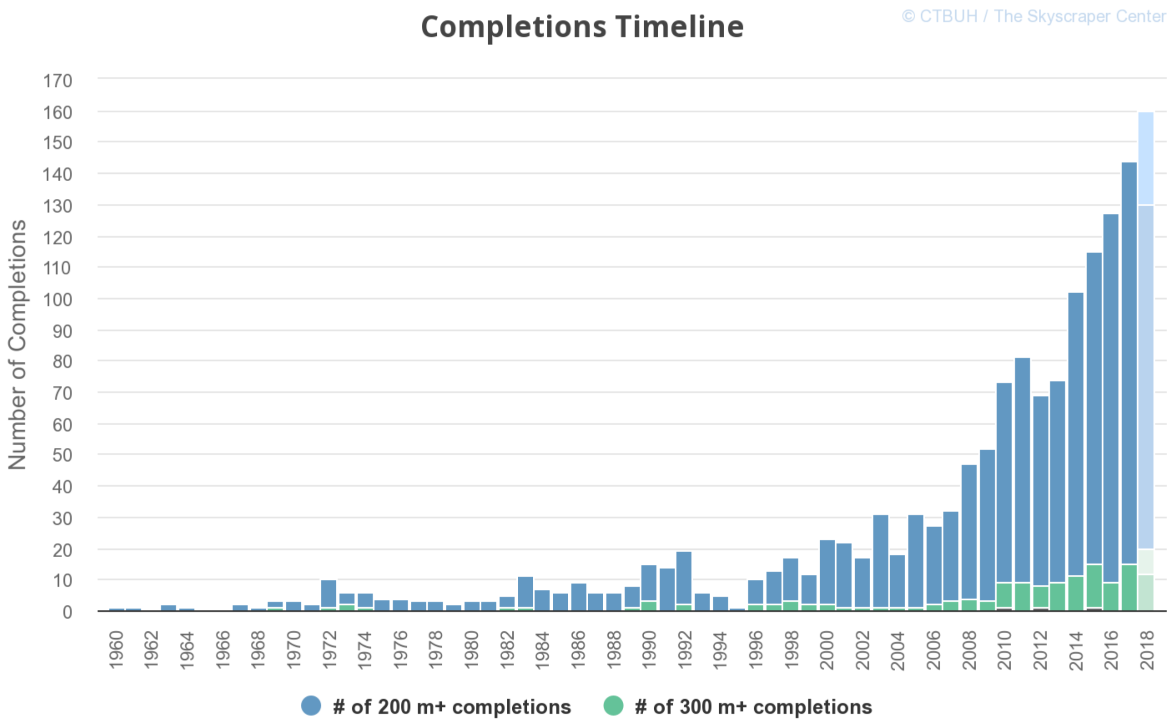


Figure 2. Completions of tall buildings (200m +), 1960-now. Source: Council on Tall Buildings and Urban Habitat (2018)

There are various factors that contribute to the success of tall buildings, of which Ali and Al-Kodmany (2012) argue that the rapid increase in growth of urban populations as a result of rural-to-urban migration (urbanization) and increasing world population is most significant. Currently 55% of the global population is located in urban areas. The United Nations (2018) expect that in 2050, this portion will have grown to 68%. Other contributors to the success of tall buildings are the instrumentality of tall buildings in creating an image of prosperity, status and power, the need for more space in a specific place, land prices, urban regeneration goals, agglomeration effects, environmental benefits, infrastructural and mobility aspects and technological advancements (Ali & Al-Kodmany, 2012).

In line with global urbanization trends, The Netherlands has to deal with increasing population density in urban areas. In 2030, nearly three quarters of the expected growth of 950.000 Dutch citizens (compared to 2015) will locate in large municipalities of currently 100.000 or more inhabitants, with the largest growth in the G4 (Amsterdam, Rotterdam, Den Haag, Utrecht) cities (PBL/CBS, 2016). The research centers foresee a 15% growth in the municipalities' inhabitants compared to 2015. Together, the G4 cities will account for 30% of the Dutch population in 2030, while some smaller municipalities outside of the Randstad will have to deal with a decline in population numbers and some retain current population numbers. All these statement lead to the fact that these cities need to develop a large number of residences. It will come as no surprise that in the Netherlands, tall buildings have also gained more popularity and have become more prominent in the urban fabric - especially of large cities. Of the currently 25 completed tallest buildings of the Netherlands, 22 were completed this century. Six projects tall enough for joining the top 25 tallest (depicted in table 1) buildings are currently being developed, all of which are either fully or partly residential. When considering residential-only tall buildings, the thirteen tallest buildings were completed after 2004 and only three out of the 30 tallest were completed before the year 2000 (Skyscrapercenter, 2019).

Table 1. Overview of the top 25 tallest buildings of the Netherlands (including in those in development). Source: Skyscrapercenter (2019).

Building List — Netherlands, All Companies, All Heights, 1885-No Max. Year

Completed | Architecturally Topped Out | Structurally Topped Out | Under Construction | On Hold | Never Completed | Proposed | Vision | Demolished

#	Building Name	City	Height (m)	Height (ft)	Floors	Completion	Material	Use
1	De Zalmhaven	Rotterdam	212	696	58	2021	concrete	residential / office
2	The Grace Tower 1	The Hague	180	591	55	-		residential
3	Maastoren	Rotterdam	164.8	541	44	2010	concrete	office
4	New Orleans	Rotterdam	158.4	520	46	2010	concrete	residential
5	District E Tower 1	Eindhoven	158	518	-	2022		residential
6	Montevideo	Rotterdam	152.3	500	43	2005	composite	residential
7	Gebouw Delftse Poort 1	Rotterdam	151.4	497	41	1991		office
8	De Rotterdam	Rotterdam	151.3	496	45	2013	concrete	office / residential / hotel
9	Havana & Philadelphia	Rotterdam	150	492	51	2022		residential
10	Cooltoren	Rotterdam	150	492	50	2021	concrete	residential
11	Baan Tower	Rotterdam	150	492	47	-		residential
12	The Grace Tower 2	The Hague	150	492	46	-		residential
13	Postkantoor	Rotterdam	150	492	43	-		residential / hotel
14	Rembrandt Tower	Amsterdam	150	492	35	1995	composite	office
15	Millennium Tower	Rotterdam	149	489	34	2000		hotel / office
16	Ministerie van Binnenlandse Zaken	The Hague	146	479	37	2012		office
16	Ministerie van Justitie	The Hague	146	479	37	2012		office
18	Hoftoren	The Hague	141.9	465	29	2003		office
19	New Babylon City Tower	The Hague	141.8	465	45	2013	concrete	residential
20	Westpoint	Tilburg	141.6	465	48	2004		residential
21	World Port Center	Rotterdam	133.6	438	38	2001		office
22	Het Strijkijzer	The Hague	131.6	432	41	2008	precast	residential
23	De Kroon	The Hague	131.2	430	41	2011		residential
24	First Rotterdam	Rotterdam	128.2	421	32	2015		office
25	The Red Apple	Rotterdam	123.5	405	38	2008		residential

These figures, tables and numbers make it evident that height is becoming increasingly more important in urban areas. Knowledge on economics of tall buildings can contribute to effective city planning regarding verticality in urban landscapes, but also aid stakeholders in development processes.

1.2. Problem statement

Tall building economics remain understudied, despite the fact that both the number and size of tall building developments are increasing. At the very base of tall building economics is the greater discipline of urban economics. The Alonso (1964); Mills (1967); Muth (1969) model, or monocentric city model, is at the center of urban economics. The model dictates that the price per area unit of housing, land rent per unit of land area, structural and population density all decrease as the distance to the CBD increases, while housing size increases as distance to the CBD increases. These predictions are all broadly consistent with general empirical observations (Brueckner, 1987). The theoretic field of urban economics is well developed and builds mostly on the monocentric city model (Duranton & Puga, 2015). Following the model, variations in heights in urban landscapes have long been considered a consequence of variations in land prices (Mills, 1967). As a result, cities have been treated as flat and most principles of urban economics are developed on a horizontal dimension, largely ignoring vertical characteristics of urban areas.

However, recent studies found that the vertical dimension plays an important role in urban economics for the commercial sector (Ahlfeldt & McMillen, 2018; Koster, Rietveld, & van Ommeren, 2013; Liu, Rosenthal, & Strange, 2018; Nase, van Assendelft, & Remøy, 2018; van Assendelft, 2017). These recent studies spawned a new subtopic within tall building economics that concerns floor level premiums.

This thesis defines floor level premiums as the premium to locate one floor higher, ceteris paribus[1]. Literature on height premiums is growing but small and limited to observations on the demand side by Liu et al. (2018); Nase et al. (2018) for commercial real estate. Similar results were found for the residential sector in Switzerland by Danton and Himbert (2018) and for Hong Kong by Wong, Chau, Yau, and Cheung (2011). These results all point towards the importance of verticality in urban economics. However, these studies are demand-focused. As the studies signal that different aspects of height are valued differently by the demand side, particular aspects of height should be priced differently by the apartment supplier - the real estate developer. Currently there is a gap in the literature and body of knowledge on real estate developers' vertical price premium behavior in residential tall buildings. It is important to study this topic in order to achieve a greater understanding of the economic dynamics of tall buildings, an understanding which can be used to steer future developments of tall buildings, aid development stakeholders and impact urban landscapes.

1.3. Research proposal

Prior studies on height premiums analyze transaction prices of residences. The transactions of rents or purchase sums represent the price tenants and owners (demand side) are willing to pay for property. After the transaction, the property is taken off the market. Similarly, the supply side can be represented by the price for which property is put *on* the market. The initial price for which the property is put on the market reflects developer behavior. This thesis focusses on these developer prices in order to fill the gap concerning developer vertical price premium behavior.

1.3.1. Research objective

The main objective of this research is to provide an in-depth contribution to the body of knowledge on developer vertical price premium behavior in the field of tall building economics. The field of tall building economics has been neglected for a long time and especially the field of height premiums is small. This research contributes to these disciplines and advances on previous studies and results within the topic of height premiums that were delivered by Coulson, Dong, and Sing (2018); Danton and Himbert (2018); Liu et al. (2018); Wong et al. (2011) and Nase et al. (2018). Compared to these studies, the main contribution to literature is the consideration of the supply side of height premiums for tall buildings, rather than the demand side. Additionally, the research uses data from tall buildings in Rotterdam. While Koster et al. (2013) used Rotterdam data for building height premiums, no research has been done before on floor level premiums in this city. Furthermore, this thesis provides novel insights on how developers price certain apartment characteristics related to status.

1.3.2. Research questions

The problem statement and main objective of this research lead to the following research question:

How do real estate developers behave regarding vertical price premiums in residential tall buildings?

In order to answer the main research question, several sub research questions are formulated, aiming to answer a piece of the puzzle with each sub-question.

4. *What are the determinants of vertical price premiums?*
5. *How can a model be developed in order to measure the developers' vertical price premium behavior in residential tall buildings?*

[1] The terms *height premium, vertical price premium* and *floor level premium* are used interchangeably in this thesis.

6. *To what extent do different factors contribute to developers' vertical price premiums in residential tall buildings?*

1.3.3. Research scope

This research focusses on the Dutch residential market. In specific, residential tall buildings in the city of Rotterdam are studied. Elaboration on city selection is provided in section 3.2.1. In the Netherlands, it is customary for real estate developers to sell their products instead of renting them out and retaining ownership. As a result, more data should be available on listing prices of residential real estate that real estate developers placed on the market for sale than on rental rates of residential real estate that real estate developers placed on the rental market. Therefore, the research only considers initial asking prices for residential real estate placed on the sales market. Further scoping aspects include a minimum height for tallness of 70 meters together with restrictions on height-base ratios and building age. Detailed information on the framework used to select buildings to create the dataset for this research is provided in section 3.2.

1.3.4. Relevance

Growth of urban populations force cities to expand. Options for horizontal expansion are in many cases limited, contributing to the decision to opt for vertical expansion. In the Netherlands, increasingly more municipalities are providing room for real estate developers to build taller structures as an instrument to battle the shortage of housing supply. This results in higher density urban areas, which can be considered to have environmental benefits, but also raise socio-economic concerns. These concerns are not limited to the contribution to density of an area, but also relate to the buildings themselves. The longevity of tall buildings should not be underestimated as most are observed to make up a permanent part of the urban fabric and claim a part in the spatial legacy of the concerning city (Ahlfeldt & McMillen, 2018). With these structures having an impact of such great caliber on various societal aspects, the gap in the literature on the vertical dimension in urban economics is dissatisfying. This research provides novel insights on the dynamics of verticality within urban economics, which benefit stakeholders involved in the developments of residential tall buildings and enable them to add more value on societal level in various ways.

On academic level, this research contributes to the small but growing body of knowledge on tall building economics. The research is especially relevant for the small field of height premiums, as - to the extent of my knowledge - no other studies have focused on the behavior of real estate developers regarding floor level premiums. However, there are clear signals that there is a demand for aspects of height and the vertical rent gradients found in previous studies indicate that developers act based upon a certain perception of consumer willingness-to-pay. The dynamics behind this behavior are currently unclear and this thesis contributes to filling the gap on the supply side point of view. New insights on the relation between height and views as well as status concepts are presented. Additionally, this thesis advances the body of tall building economics within the Netherlands and is the first to research floor level premiums in Rotterdam. Another contribution are the findings concerning premiums commanded for a view on the Erasmus bridge. Lastly, this thesis adds to the body of knowledge on several standard control variables, namely number of bathrooms, outside spaces, living room orientation and indoor floor area.

On a practical level, various parties can use the resulting knowledge to add more value. First of all, findings enable appraisals of apartments in residential tall buildings to be performed more accurately, but also earlier in development processes. This is beneficial to developers, valuers and other parties interested in price formation or apartment and building valuation. Secondly, findings will provide more transparency to the demand side of the housing market on apartment price formation, enabling stakeholders on the demand side to more effectively select an object or residence that matches their demands and interests. Thirdly, findings are of use to municipalities for estimating residual land values more accurately, which in turn may influence high-rise policies and regulations on maximum heights.

1.4. Thesis structure

This first chapter introduces the research context, thesis subject and presents the formulated research objectives, research questions and relevance. The research questions are addressed in different chapters as specified in the thesis structure depicted in figure 3. Chapter 2 provides the theoretical underpinnings that form the foundation of and input for the empirical analysis. Chapter 3 elaborates on the methodology of how this thesis applies a model to measure developers' vertical price premium behavior in residential tall buildings. Here you will also find the urban area selection framework, building selection framework, data acquisition strategies and constructed dataset description. Chapter 4 presents the empirical analysis and results and places these in a broader context. Chapter 5 presents the conclusions of this thesis, its limitations, generalizability and recommendations for practice and further research. References are found after chapter 5.

Research phase	Chapter	Content of chapter	Relevant research question
Introducing the research	1. Introduction	This chapter introduces the research topic and provides context. The problem definition is presented and the research proposal and scope are elaborated upon, followed by the research questions and relevance.	Research questions, context and scope are presented.
Theoretical framework	2. Theoretical underpinnings	The theoretical underpinnings analyse the existing body of knowledge on the research topic. The takeaways from this chapter are the determinants of height premiums in residential tall buildings, which form the basis for the quantitative analysis.	1. What are the determinants of height premiums?
Input and methods of analysis	3. Methodology & data	This chapter described the methods that are used in the empirical analysis in order to acquire answers on the formulated research questions. Furthermore, it elaborates on the framework set for data selection and acquisition and on the constructed dataset.	2. How can a model be developed in order to measure the developers' vertical price premium behavior in residential tall buildings?
Empirical analysis & discussion	4. Empirical analysis results & evaluation	The empirical analysis and the findings are presented in this chapter. Firstly, the regression models' architecture is discussed. Then, the regression model outcomes are disserted, results are discussed and placed in a broader context.	3. To what extent do different factors contribute to developers' vertical price premiums in residential tall buildings?
Synthesis	5. Conclusion	This final chapter places the findings of previous chapters in the broaders context of this thesis and its research objective. The chapter also discusses limitations and provides recommendations for practice and for future research.	How do real estate developers behave regarding vertical price premiums in residential tall buildings?

Figure 3. Thesis structure.

2. Theoretical underpinnings

This chapter provides more depth into the concept of verticality in the field of urban economics. Firstly, the core of urban economics, the monocentric city model, is presented. Then, studies on the effect of the vertical dimension in urban economics are analyzed for both the commercial as well as the residential sector. Furthermore, benefits of heights in real estate are studied. Section 2.2. considers real estate developer behavior on the topics of building height determination, time-on-market and risk hedging and lastly on residential property pricing behavior. Section 2.3. provides a summary of the chapter, connecting various concepts and relating these to the first sub-question of this thesis.

2.1. Verticality in urban economics

At the core of urban economics is the monocentric city model, which combines housing, construction, transport, location choice and household consumption. It dictates that the price per area unit of housing, land rent per unit of land area, structural and population density all decrease as the distance to the CBD increases, while housing size increases as distance to CBD increases (Alonso, 1964; Mills, 1967; Muth, 1969). These predications are all broadly consistent with general empirical observations (Brueckner, 1987). However, while the predictive performance of the model is great on this general level - making it a natural starting point to understand theories on economic forces within urban landscapes - the model is limited in its level of realism due to the assumptions that are made in the model's design (Kraus, 2003). These assumptions include the existence of only one place of employment (the CBD), homogeneous citizens, the non-existence of urban zoning and regulations, continuous and perfectly symmetric cities, the exclusion of characteristics of housing - except for density, rent per area unit and area per house - and that the activities of labor and living are the only citizen activities (Brueckner, 1987; Duranton & Puga, 2015; Waddell, Berry, & Hoch, 1993). Many studies have addressed the topic of the last assumption (e.g. Brueckner, Thisse, and Zenou (1999)), concluding that next to working there are many other important activities for consumers. As this thesis focusses on the residential sector instead of the commercial sector, the value of theories on centrality here is mainly related to proximity to residential amenities (e.g. restaurants, theater, etcetera).

Theories in urban economics have long followed the monocentric city model, considering variations in building heights in urban landscapes as a consequence of variations in land prices (Mills, 1967). As a result, most principles on urban economics have been on the horizontal dimension, treating cities as flat. However, cities are increasingly more expanding in the vertical dimension and recent studies found that this vertical dimension plays an important role in urban economics for the commercial sector.

2.1.1. Height premiums in rental transactions

Two effects on value caused by the vertical dimension can be distinguished for commercial real estate. The first is the effect of building height, which was found to have a positive effect on commercial building values (Colwell, Munneke, & Trefzger, 1998; Shilton & Zaccaria, 1994). A study on building height in The Netherlands found that commercial rents increased 4.2% for every 10-meter increase in total height of the building (Koster et al., 2013). The authors provide three determinants that together explain the willingness to pay these rent premiums to locate in taller buildings. The first determinant is within-building agglomeration economies, which derive from the sheer number of workers that are located in high density, tall office buildings. The density of workers enable firms to gain internal returns of scale when they hire multiple floors within the building to locate their workers (Gold, 1981).

Additionally, the firm may not be the only tenant in the building. As workers of various companies are present in the same building, contact between these workers may occur more rapidly than in more traditional single-tenant office settings. These interactions may lead to knowledge spill-overs and innovation (Jacobs, 1969; Marshall, 1890; Storper & Venables, 2004). The second determinant dictates that, next to within-building agglomerations, rent premiums are driven by a landmark effect. It is not unusual for tall buildings become subjects of local, regional or even (inter-)national news. As the building is discussed through various media, they are likely to receive a certain landmark or even iconic status - which in turn drives renters to be willing to pay a premium on rent. This effect is likely to be strongest for buildings that are competing to be tallest in certain geographical markets (Helsley & Strange, 2008). However, building aesthetics also contribute to landmark effects and may grant tenants with a certain amount of prestige, which in turn enables the concerning firms to attract clients, workforce talent and even to drive up business fees (Klein & Leffler, 1981; Roberts, 1986). The third determinant for willingness to pay to locate in a taller building is that firms and visitors may allocate value to views that tall buildings provide - especially on higher floors (Koster et al., 2013). This leads to the conclusion that, contrary to the monocentric city model, other forces than only the price of land must be of importance for determining building heights. Additionally, they conclude that the marginal effect intrabuilding agglomeration benefits is constant and estimate the sum of view effects and landmark effects to be 2.8-5.5% for buildings that achieve five times the mean height of the corresponding area. Also, the authors argue that it is unlikely that the effect is a sole consequence of views, suggesting that the landmark effect is present. Translating these conclusions to a residential context could imply that apartments in taller residential buildings may be listed for higher prices than apartments in less tall residential buildings, since they provide more stunning views and more significant landmark or iconic effects. These implications are important for interpreting tower-specific relative floor level effects in this thesis' empirical analysis.

Zooming back out, the second effect on the vertical dimension impacting commercial real estate values does not consider the building as a whole, but concerns intra-building differences per floor level. A study employing a combination of three large datasets on commercial real estate in the USA found that rents increase 0.58% to 0.87% per floor level starting from the third floor and increased stronger when approaching the highest floor levels (Liu et al., 2018). However, the ground floor level rents were characterized by a significant premium as well. These findings provide evidence for a strong tension between access-oriented and amenity-oriented tenants. The willingness-to-pay for access fits retail tenants and willingness-to-pay for amenities fits office tenants. In this thesis' empirical analysis, only the residential sector is investigated. Liu et al. (2018) argue that the tenants' willingness-to-pay is driven by floor-level related benefits that equalize higher commercial rents by either increased revenues or reduced operating costs. The three benefits that are referred to as amenities that accompany locating on a higher floor level are views, status and signaling productivity to potential clients. The authors argue that the extent to which these amenities achieve these results differs per industry, leading to vertical sorting in commercial tall buildings and corroborating the notion of heterogeneity amongst tenants. Their results do indeed prove that certain tenants, mainly highly-productive office occupiers, locate higher up and less productive offices locate lower.

For the Netherlands, a similar vertical rent gradient was found in the research of van Assendelft (2017), which amounted to 0.7% to 1.0% for commercial real estate in Amsterdam. In this particular research, the higher rent is attributed to amenities in the form of panoramic view potential, prestige and exclusivity of locating in one of the tallest buildings in buildings in the local market. van Assendelft

(2017) does not find significant evidence for vertical sorting, but attributes this to limitations in the dataset. Nase et al. (2018) extend this research with three goals. The first was to decompose the vertical rent gradient for commercial real estate in Amsterdam. The authors find that, after controlling for view factors, approximately 70% of vertical rent premiums can be attributed to firm-level signaling and other aspects. They find that the view effect accounts for approximately 27% of vertical rent premium and the leftover 3% of the vertical rent premiums is attributed to industry level variations. Secondly, they research if higher wages of certain industries are capitalized into office rents. This was found to be true for 'Law firms' and 'Consultancy and management firms' compared 'Other sectors', but only 'Law firms' were found to locate on higher floors for higher rents, suggesting that not all industries are willing to pay more rent for amenities that accompany locating on a higher floor level. Thirdly, they research the existence and nature of vertical sorting for commercial tall buildings in Amsterdam. Vertical sorting was only found to be evident for 'Law firms' and the authors argued that different industries value the amenities that accompany height differently (e.g. status versus view). This further strengthens the idea that consumers of space should not be assumed to be of homogenous nature, which is also limiting in the potential of the monocentric city model (Brueckner, 1987; Duranton & Puga, 2015; Waddell et al., 1993). The studies prove that in the commercial real estate market, consumers are heterogenous and value different amenities that accompany height differently. Similarly, developers may set height premiums differently for different residential tall building projects as they aim for different market segments. This further complicates the quantification of various factors that together determine height premiums for residential tall buildings. The benefits of height as discussed in the studies above are summarized in figure 4.

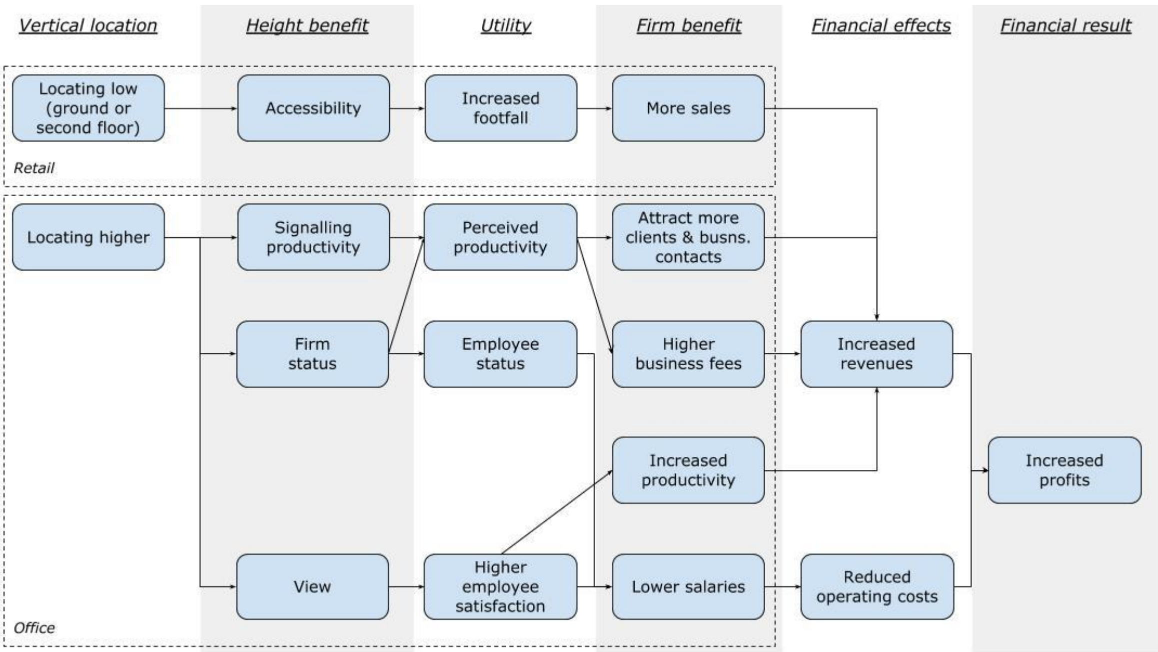


Figure 4. Benefits of height for commercial real estate: concepts and associations. Source: Own illustration, based on Liu et al. (2018); Nase et al. (2018); Basu (1989); Cable and Turban (2003); Klein and Leffler (1981); Roberts (1986); Dorfman, Ben-Shahar, and Heller (2017).

Figure 4 shows how the amenities that accompany height translate into value for the commercial sector. In this figure I add to the studies above by rationalizing the willingness-to-pay for status in an economical sense. It is not unreasonable that individuals are in search of this recognition and are willing to accept lower wages if compensated with perceived higher status as a result of their association with the status of their employer (Basu, 1989; Cable & Turban, 2003). Furthermore, status was suggested to enable firms to drive up business fees (Klein & Leffler, 1981; Roberts, 1986), also leading to increased profits. Furthermore, this thesis links firm status with perceived productivity based on the findings of Dorfman et al. (2017). These findings are discussed in more detail in section 2.1.2. The associations between the concepts depicted in figure 4 are important for this thesis as they reveal the dynamics of the willingness to pay for certain height benefits. Different industries have different business dynamics and consequently benefits of height have different impacts on profits, leading to varying willingness to pay to locate higher, which in turn leads to the observed vertical tenant sorting. Understanding that real estate users are heterogeneous and have different preferences and willingness to pay for height benefits is crucial in this research on height premiums for residential real estate as residential real estate users are more highly heterogenous. Nevertheless, similar to profits for commercial real estate, locating higher should contribute to a core interest of the user for residential real estate. The different concepts depicted in figure 4 are translated from the commercial sector to the residential sector in the next section while placing residents' core interest centrally.

2.1.2. Benefits of height in residential real estate

Vertical rent gradients were also found to be present for the residential sector in Switzerland in the research of Danton and Himbert (2018). After controlling for various factors that affect the steepness of the vertical rent gradient, they found the elasticity of rental price per m^2 in relation to floor level to be approximately 1.1% to 2.5%. Availability of a view, neighborhood dwelling density and the commercial nature of a building were found to have a positive effect on the elasticity. Also, they found that a view as well as the height of the concerning building being greater than the average building height within a 100m radius both increased the elasticity by 0.4 percentage points, while a combined effect was estimated at 0.6 percentage points. Furthermore, the authors find that building age and density of dwellings within the building negatively impact the elasticity of rental price per m^2 in relation to floor level. These aspects are accounted for in this thesis' regression analysis by including building-fixed effects in the models. Danton and Himbert (2018) argue that the urban resident in their research is willing to pay for higher vertical locations, accompanied by higher rents, as long as they are compensated by an increased level of amenity values. As observed in the commercial real estate sector and as mentioned as a critical feature missing in the monocentric city model, different consumers have different preferences, resulting in differences in willingness to pay for benefits of height. In reply to the last argument of Danton and Himbert (2018), heterogenous urban residents can be expected to value different benefits of height differently.

It should be noted that the research of Danton and Himbert (2018) is based on a dataset that includes a large amount of rental objects from Zurich, Geneva, Basel, Lausanne and Bern, but does not specifically consider tall buildings. Therefore, this thesis considers their research as valuable evidence for the existence of vertical rent gradients in residential buildings of standard height, which provides further motivation for the analysis of height premiums in residential tall buildings. The contrast between rental and sale objects further strengthens the need for the analysis of premiums in the non-rental sector. A study on supply functions for residential real estate attributes investigates 63.235 condominium transactions in Singapore covering a 14-year period up to March 2009 and advances on the topic by reporting a wide range of floor level premiums, varying from -0.9% to 15.5% (Coulson et al., 2018). The main takeaway for this thesis is that premiums are highly dependent on time and place, which is accounted for by including building-fixed effects and also investing building-fixed floor level premiums. As the authors conclude that time and place are highly important for floor level premiums, prior findings cannot simply be extrapolated to the Rotterdam context. Nevertheless, these studies all point towards the importance of verticality in urban economics and provide evidence of the existence of vertical rent premiums, which means that there is a demand for particular amenities that accompany height.

The demand for particular amenities that accompany height was observed to be different for different end-users, providing evidence for the heterogenous willingness-to-pay of users. Different end-users need real estate for different purposes and require different characteristics. For commercial office firms, real estate enables employees to be productive, ultimately resulting in the added value of profit for the firm - which is considered as commercial office firms' core business. As seen in figure 4, real estate may also be used as an instrument to decrease operational costs. For the residential sector, the end-user (resident) does not aim to use the space to generate profit. If this were the case, the end-user is considered as an asset manager instead of a resident. Properties of the residence (including benefits of height) are determinants of residential satisfaction, which in turn is of significant influence on individuals' quality of life (Lu, 1999). Nevertheless, decreasing operational costs is beneficial to the resident as it enables the resident to spent savings on other activities that contribute to the individual's quality of life. However, I have found no literature on aspects of height that decrease operational costs for the end-user of residential tall buildings. Prevailing literature on benefits that are associated with height can be split into four categories. The four benefits are followed by a negative aspect of height.

The first benefit is that of views. Apartments on higher levels of tall building tend to offer more impressive views (So, Tse, & Ganesan, 1997). Views are determined by viewsheds and line of sight, but also by the observer's horizontal location and vertical location. Viewsheds represent what is visible from an observer point of view and line of sight represents what is obstructed or not. Numerous studies found that views impact real estate values, with differences in views having significant impact on the intensity of the premiums (for example; Benson, Hansen, Schwartz, and Smersh (1998); Rodriguez and Sirmans (1994); Bishop, Lange, and Mahbubul (2004)). Different studies were carried out in different geographical locations and yielded varying results concerning the values of views in similar categories. For this thesis, these results are interpreted as a message that views are highly heterogenous and should be treated as such in this investigation on floor level premiums set by developers. Furthermore, various studies have found that height has a positive impact on the values on views (for example; Hasanah and Yudhistira (2018); Yamagata et al. (2016); (So et al., 1997); Yu, Han, and Chai (2007)). In the study of Nase et al. (2018), 27% of the observed vertical rent premiums were attributed to view effects. Liu et al. (2018) and Nase et al. (2018) both argue that end-users of commercial real estate are willing to pay vertical rent premiums for better view because the utility ultimately leads to higher profits. However, the amenity value of view capitalizes into value differently for end-users of residential real estate because residents do not use residential space for generating profits. Instead, views are valued for their utility in the form of aesthetics resulting in visual satisfaction (Bourassa, Hoesli, & Sun, 2004). Other interpretations of the utility of view relate to the biological tendency of human beings to be able to see as much as possible, without being visible themselves. This is a strategic survival tendency as this enables the observer to spot predators from great distances and, thus, increases the sense of security. This utility of view is rejected in this thesis as it does not match the purpose of residential real estate in the modern societal context of the Netherlands.

The second benefit of height residential real estate is status. Even though status is a relatively intangible concept, status is seen as an amenity of height that can be capitalized upon (Barr, 2012). Additionally, prior studies suggested status to be in demand for - at least partly - its utility in the commercial sector (Liu et al., 2018; Nase et al., 2018). It can be expected to be in significant demand for its utility in the form of ego satisfaction in the residential sector as well, considering extreme prices that are paid for top level penthouses - a price increase that cannot be properly explained by other amenities that accompany height as their effects do not accelerate proportionately. This theory is supported by a recent study on a similar topic showed that being located higher in a building is associated with a perception of more social power[2], suggesting it could be considered as a significant economic good (Dorfman et al., 2017). However, the results imply that other individuals than the resident perceive the owner of the concerning residence as having more social power, meaning that locating higher radiates a certain image. The study also suggest that locating higher up also boosts the residents' own perception of social power (identity, rather than image) as a result of others perceiving them as powerful - ultimately echoing into a vicious circle (Dorfman et al., 2017). Researching the willingness-to-pay for status would require household-specific data on income. As this thesis focuses on the supply side rather than the demand side, this remains out of the scope of this research. However, this thesis does investigate if developers try to capitalize on the amenity of status (identity-wise and image-wise combined) that accompany higher level apartments by examining three concepts related to status. These concepts are elaborated upon in the following chapters.

The third benefit that accompanies height in residential real estate is an increased sense of security and privacy (for example; Li (2013); Sullivan (1991). However numerous studies argue that these benefits translate into a negative aspect for some users, as they experience a lower sense of safety e.g. fire safety, falling from a balcony, elevator failure, etcetera (Li, 2013). Furthermore, some studies report that the increased sense of privacy ultimately results in a negative feeling of anonymity. However, the sense of security, privacy and safety as a result of height is considered as an amenity of a highly intangible and subjective nature on the demand side of tall buildings. As this thesis focusses on the supply side, these factors are excluded from the analysis.

The fourth benefit of height is the benefit of 'escaping' street-level sound and air pollution (Choy, Mak, & Ho, 2007; Ferlan, Bastic, & Psunder, 2017). This is a natural consequence of height as the pollution sources are located at street level and their effects are diminishing in relation to distance, not excluding the vertical dimension (Yuen et al., 2006). Air pollution was found to be of impact on residential property value (Shaaf & Rod Erfani, 1996). No data was acquired on the vertical level to analyze these topics in this thesis. Additionally, while it is a prominent topic in megacities (e.g. Beijing and Hong Kong), it is assumed not to be of influence on height premiums in the Netherlands as it is not a factor that was observed to be of impact on residential property value in the Netherlands. Furthermore, the Dutch Building Code prescribes a minimum level of acoustic insulation for residential real estate, which is expected to result in the negation of any noise pollution and, in turn, any impact on floor level premiums for apartments in residential tall buildings.

Lastly, an aspect of height that many experience as negative rather than positive. Consider Alonso's model (Alonso, 1964) in which there is a tension between transportation costs (to central objects) and costs for housing. One could say that in the vertical dimension, apartments that are located higher are

[2] The terms *perception of social power* and *status* are used interchangeable in this thesis.

charged with additional travel time to the central objects and, thus, should be compensated with lower cost for housing for the increased 'commuting' time. Following this theory of centrality, I interpret this as that the vertical travel and waiting time should converted to a height discount. The negative effect on vertical travel and waiting time on quality of life can be diminished by optimizing the means of vertical travel: number of elevators, speed of elevators, etcetera. Aside from the number of elevators per tower, no data on transportation matters was obtained for the empirical analysis. Therefore, this aspect is excluded from the empirical analysis.

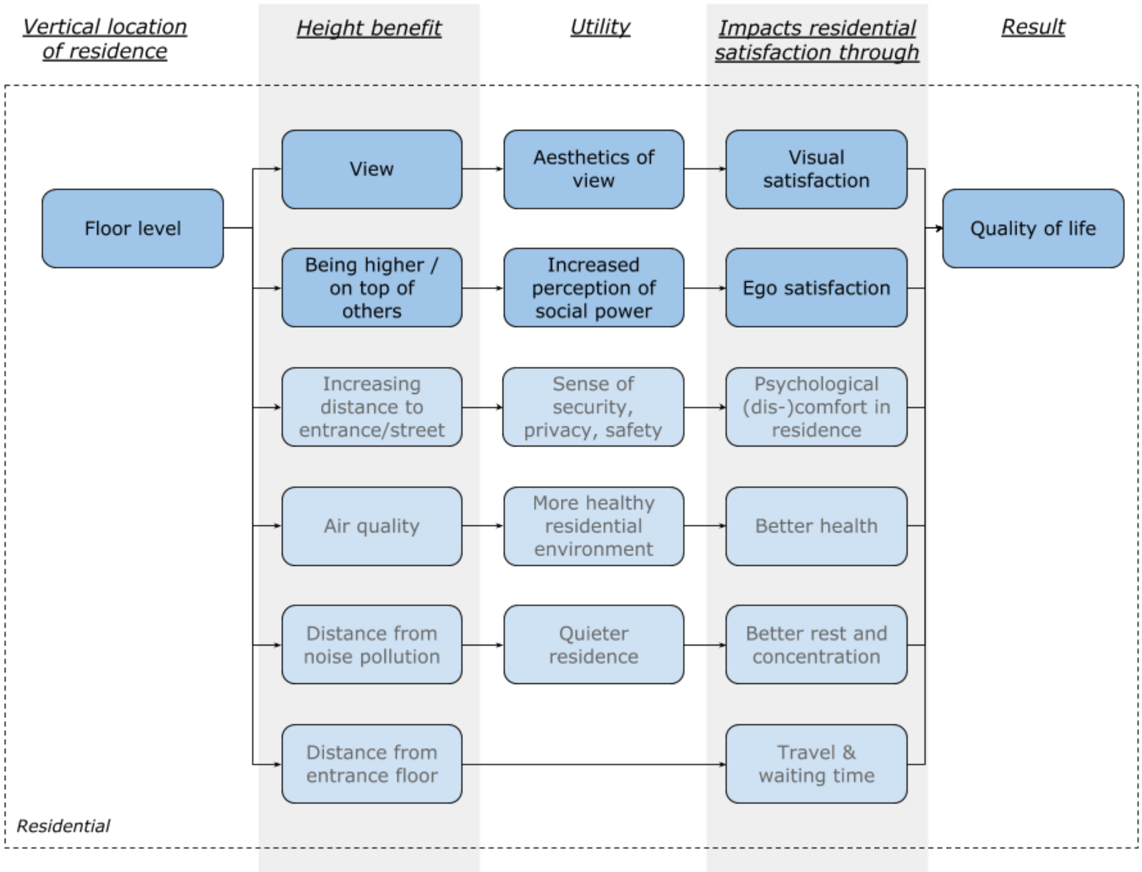


Figure 5. Benefits of height for residential real estate: concepts and associations. Air quality, sense of security, privacy and safety and the aspect of luck are not included in the empirical research. Source: Own illustration, based on various sources discussed in this section.

Literature on the effect of heterogeneity of residents on preference for different values of height are limited, but observations on gender differences resulted in women being more attracted to height induced view benefits and men being more attracted to 'the feeling of height' (Haber, 1977), which is interpreted as 'status' in this thesis. Furthermore, the market segments of YPS, DINKY, empty nesters and high-earners were found to be inclined towards residential tall buildings (Yuen et al., 2006). These results are partly dated and may not be applicable to the Dutch context due to, but not limited to, cultural and demographic differences. Nevertheless, the findings reinforce the conclusions on the need to be considerate of the heterogeneity of residents. For developers, these findings indicate that the residential environments should be tailored to the residents' preferences and, vice versa, the proper market segments should be targeted as they will ultimately gain more quality of life from particular benefits of height. This could enhance the potential revenues to be gained from capitalizing on the willingness to pay for certain height benefits, as the height benefits are expected to be more valuable to certain market segments. It should be noted that, if successful in matching particular market segments with particular benefits of height, vertical segregation will be unavoidable. Further research is needed to shed better light on the match between particular height benefits and the different groups that demand them.

The studies analyzed above are demand-focused. Yet these conclusions should also provide a signal to real estate developers (supply side) that there is a demand driven by heterogenous users which means that particular aspects of height can be capitalized upon and should be priced to match the targeted market segment. However, there is a literature gap on supply-focused studies and the extent to which developers behave as suggested remains unclear.

2.2. Determinants of building height

This section reviews existing studies on real estate developer behavior. In particular, studies on building heights are reviewed because they align with the content and context of the empirical analysis.

One of the first studies on this topic dates back to early 20th century and analyzed the relation between height of tall buildings and their economic performance, looking at land costs, construction costs and rent levels. The authors argued that extreme heights were consistent with profit maximization (Clark & Kingston, 1930). Since then, different theories the determinants of height have been developed. Garza and Lizieri (2016) divided the theories into four categories: traditional microeconomic models, game-theoretic approaches, business cycle behavioral models and global city theories.

In the first category, traditional microeconomic models, the urban economics' monocentric city model is used as a basis to explain building heights. As distance to the CBD increases, rent levels decrease, but transportation costs increase. This results in a tension between higher transportation costs or higher real estate costs for firms as well as households, creating a competition for scarce land nearby the CBD. Consequently, the competition follows the principles of demand and supply dynamics and is responsible for higher prices nearby the CBD. Having to bid more for land requires the developer to create more revenues to offset extra land costs. Extra revenues are achieved by developing more sellable or rentable area. As the plot of land remains the same, the developer must expand vertically rather than horizontally, thus resulting in additional floors. Consistent with Clark and Kingston (1930), this increases building height. However, cities are becoming increasingly more polycentric (Kraus, 2003) and many cities exhibit significant variations in building height when moving away from the CBD (Duranton & Puga, 2015). These variations in building height may be the result of polycentricity, but many researchers argue that many other factors are of influence on building height as well. One example is that of the artificial manipulation of building heights (regulations), for example to prevent the disturbance of the urban landscape formed by heritage and monuments. Various studies report that its impact on population, housing prices, dwelling sizes, density and land prices is severe (Ding, 2013; Kulish, Richards, & Gillitzer, 2012). The subject of building height limitations is further discussed for the case of Rotterdam in section 3.2.1.

Ahlfeldt and McMillen (2018) report that the elasticity of construction cost in relation to height starts at 25% for relatively small objects but increases up to 170% for super-tall buildings. Construction costs was also found to be important in explaining intercity building height differences, together with the availability of developable land (Barr, 2013). The relation between construction costs and height was researched within the context of the Netherlands by van Oss (2007), who also found significant cost premiums as the number of floor levels increased. Cost increases are attributed to three main aspects:

logistics (of an immense amount of people and objects in the vertical dimension), structure (significantly higher wind loads than for non-tall buildings) and foundation (significantly higher loads per area units and the influence of wind). These three aspects have several effects on financial aspects of the building (Ali & Al-Kodmany, 2012; de Jong, van Oss, & Wamelink, 2007; van Oss, 2007). As the total number of floors increases, more surface area per floor will have to be attributed to structural objects and vertical transportation elements. This negatively impacts the GFA/LFA ratio (Langdon & Watts, 2002). This topic is also discussed in further detail for Rotterdam in section 3.2.1.

Important for the context of the Netherlands is that tall building developments also require additional financial means in order to achieve levels of fire safety required to obtain a building permit. Building regulations prescribe additional fire safety measures as building height increases. This includes (additional) elevators for the fire fighters, additional demands for fire compartmenting, additional demands for stairways and doorways, additional demands for structure fireproofing and additional demands for sprinkler systems. Next to fire safety, additional height also results in additional requirements for structural safety. Different techniques are viable and some are considered more viable for particular heights (van Oss, 2007). However, in every case, the increased loads are compensated by constructing structural elements that have bigger dimensions or increasing the number of structural elements. In both cases, this impacts the GFA/LFA ratio and costs for structural elements rise. The same is applicable for vertical transportation, especially elevators. The number of elevators required increases as building height increases. Furthermore, additional installation capacity is also required when building taller in order to facilitate long-term use of human beings. Heavy regulations that aim to ensure healthy and comfortable environments, sometimes supplemented by additional measures to increase productivity or acquire sustainability and quality labels, translate into large demand for the capacity of HVAC and other installations. In turn, this results into increased space use and costs. Costs for façades also marginally increase with height, mainly because of increased construction difficulty. This effect is also present for roofing. Furthermore, increased building height also leads to a more complex construction site configuration and more expensive construction equipment (e.g. more heavy-duty cranes).

The abovementioned measures are required when breaking certain height barriers. Consequently, development costs sharply increase when exceeding the concerning heights, raising the overall development costs/m^2 as well. This results in the need to build quite a bit taller than that particular height, in order to be able to spread out these costs over additional surface area and to reacquire a healthy business case. In the thesis of van Oss (2007), an 8% increase in marginal building costs per ten extra floors was found for pre-2008 office buildings. Ahlfeldt and McMillen (2018) found the cost of height to be greater for residential tall buildings than for commercial tall buildings, which is attributed to the difference in design of floor plans and greater marginal loss of floor space (per higher floor level) for residential floor plans than for office floor plans. de Jong and Wamelink (2008) expand on this topic and argue that tall building feasibility is heavily impacted by the efficiency of floors plans, measured in the GFA/LFA ratio. In turn, the GFA/LFA ratio is heavily impacted by the number of floors (Langdon & Watts, 2002). The relation between the number of floors, GFA/floor and GFA/LFA ratio is depicted in figure 6. The figure shows that as the GFA per floor decreases, the GFA/LFA ratio decreases as well, in an increasing rate when building taller - the reasons for which are discussed above. This means that delivering a feasible project is more difficult with smaller floors. However, regulations on e.g. daylight requirements force building designs to smaller floors rather than large ones (de Jong et al., 2007).

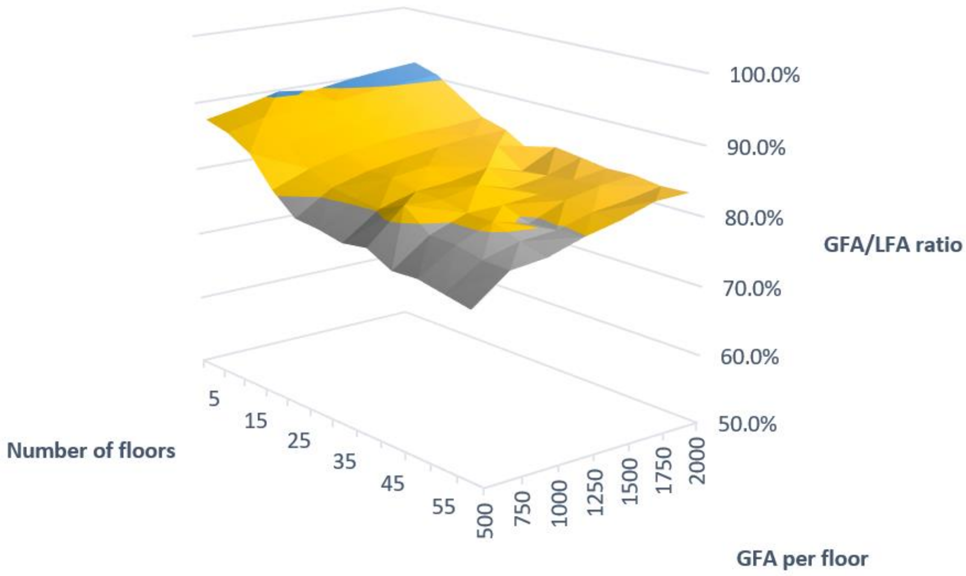


Figure 6. Relation between number of floors, GFA per floor and GFA/LFA ratio. Source: van Oss (2007)

Even though the studies discussed above are not purely focused on residential real estate, the findings above show that building height is a result of economic and regulatory forces. Real estate developers compete for a plot of land, resulting in higher land prices. These higher land prices must be offset by higher revenues in order to achieve the required profit margin. In order to increase revenues, more sellable surface area is developed, which can only be added by expanding in the vertical dimension when the land parcel remains the same. This results in additional floors and, thus, additional height. However, additional floors are found to have increasingly higher marginal costs and revenues decrease as a result of unfavorably changing GFA/LFA ratios. Consequently, these additional costs per floor can, at some height, equal or exceed the additional revenues created. Barr (2010) found that tall building developments in Manhattan (analyzing objects developed between 1895 and 2004) were consistent with this profit maximizing theory, which was also the case for tall buildings in Hong Kong (Chau, Wong, Yau, & Yeung, 2007). Since the designated function of the floor level impacts the lay-out and, thus, GFA/LFA ratio, the designated function theoretically further impacts the optimal building height. The cost of height was found to be greater for residential use (Ahlfeldt & McMillen, 2018), therefore indicating that the optimal building height should be lower for residential tall buildings than for commercial tall buildings, *ceteris paribus*. This is consistent with the early research the on influence of designated use on economically optimal building height (Sullivan, 1991). These findings all points towards the importance of economic viability as a determinant of height.

However, the second category of building height determinants advocates that ego plays an important role in determining building heights. These game-theoretic theories argue that building heights serve to satisfy the developer's ego and that economic viability may come second place. In the game-theoretic model of Helsley and Strange (2008), two developers are rival skyscraper developers and compete to make plans for development. The incentive to build tall is associated with the prestige of being tallest, a non-financial reward that offset the additional costs to build taller than economically optimal. The height that is acquired by matching the profits + non-financial reward of prestige with the building costs for achieving economically optimal heights + extra height costs, is called the preemption height. As the prestige is only awarded when the development succeeds in becoming the tallest, scenarios exist where the developer invests in the extra height costs but is not rewarded with compensating prestige as a rival skyscraper developer chose to build even taller. This rivalry leads to insecurity of compensation and, therefore, developers are inclined to overbuild in order to make sure their skyscraper height exceeds the height of the rival skyscraper and that they will obtain the prestige of being the tallest. This results in dissipation. Developers were found to primarily compete with buildings in the close vicinity that were completed in the short-term past (Barr, 2012). The same study concluded that developers were found to more easily engage in height rivalry during times of economic prosperity as the costs for non-profitable height were relatively low compared to the non-financial reward of prestige.

Thirdly, the abovementioned developer behavior has led to theories on the relation between business cycles and skyscraper height. Record-breaking heights were argued to be related to large-scale economic crises, reflecting a large-scale misallocation of funds and being an effective indicator of bubbles (Lawrence, Hsu, Luo, & Chan, 2012). The authors argue that skyscraper booms tare the manifestation of warning signs of imminent economic corrections. These theories are tested on their statistical validity and the testers conclude that these theories are incorrect and that skyscraper height cannot be used as an instrument to predict business cycle movements (Barr, Mizrach, & Mundra, 2014). The testers add that the relation between business cycles and skyscraper height is more likely to be a response to increase in incomes. These macroeconomic factors are categorized as the third height determinant by Garza and Lizieri (2016).

Lastly, theories on global cities address the relation between buildings heights and global connectivity of cities. When global connectivity of a city is larger, there are more opportunities to attract global resources that enable developments of larger scale, also resulting in taller buildings (Garza & Lizieri, 2016). As global connectivity increases, larger numbers of highly-skilled workforces will need to be accommodated. These opportunities can be seized by both internal as well as external parties. Traditional economic models do not consider external forces of this nature. Yet, tall buildings were found to be the popular form of real estate to accommodate these large numbers of highly-skilled workforces. When developed by external parties, dynamics of traditional economic models are less likely to be limiting in the development options since these external parties do not solely operate in the context of the concerning development. This implies that foreign forces can be of determining nature when it comes to building heights.

These theories provide us with the insights that multiple factors are of influence on building height. The uneven vertical distribution of costs for tall building development could be a factor that drives developers to set height premiums, as it is an obvious method to make end-users of each floor bear their fair share of total costs. Furthermore, the aspect of ego in tall building development leads to adding floor levels that are economically unfeasible. As ego is a character trait, this implies that height is impacted by heterogeneity in developer behavior. This could possibly be reflected in floor level premiums set by developers, as their high interest for status drives them to highly value status related aspects that accompany height. This suggests that the relation between status and floor level is nonlinear and gains strength on the 'prestigious' floor levels. Findings show that the opportunity costs of exceeding economically optimal heights are lower during times of economic prosperity, implying that the effect proposed in the statement above should be more easily detectable in buildings originating from boom times rather than those originating from economically disadvantageous times. In section 4.1.3. the manifestation of this effect is discussed.

2.3. Summary

Tall building economics have long been neglected in the research field of urban economics. Different theories on building height determinants exist, but for this thesis profit maximization theories and game-theoretic theories relating to status are most relevant. Recently various studies have reported novel findings on floor level premiums and it is evident that end-users are willing to pay premiums for particular benefits of height in the commercial real estate sector. This thesis focusses on the residential sector rather than the commercial sector, where views and status are important height-related determinants of residential satisfaction. Other benefits of height are left for future research as no data on the vertical dimension was obtained for those factors in this study.

Since residential satisfaction leads to an increase in quality of life of the residents, this thesis theorizes that residents are willing to pay a premium to locate higher in a residential tall building. As the studies signal that these factors are valued by residents, these factors should be priced by the real estate developer. However, it remains unclear to what extent developers exploit the willingness to pay for these height benefits during apartment price formation. Views and status function as key input for the next chapter, where hypotheses on developer behavior regarding floor level premiums are formulated.

3. Methodology & data

This chapter provides an elaboration on the different methods applied in order to answer the formulated research question and sub-questions. Figure 7 depicts the steps that are taken in the research process for this thesis.

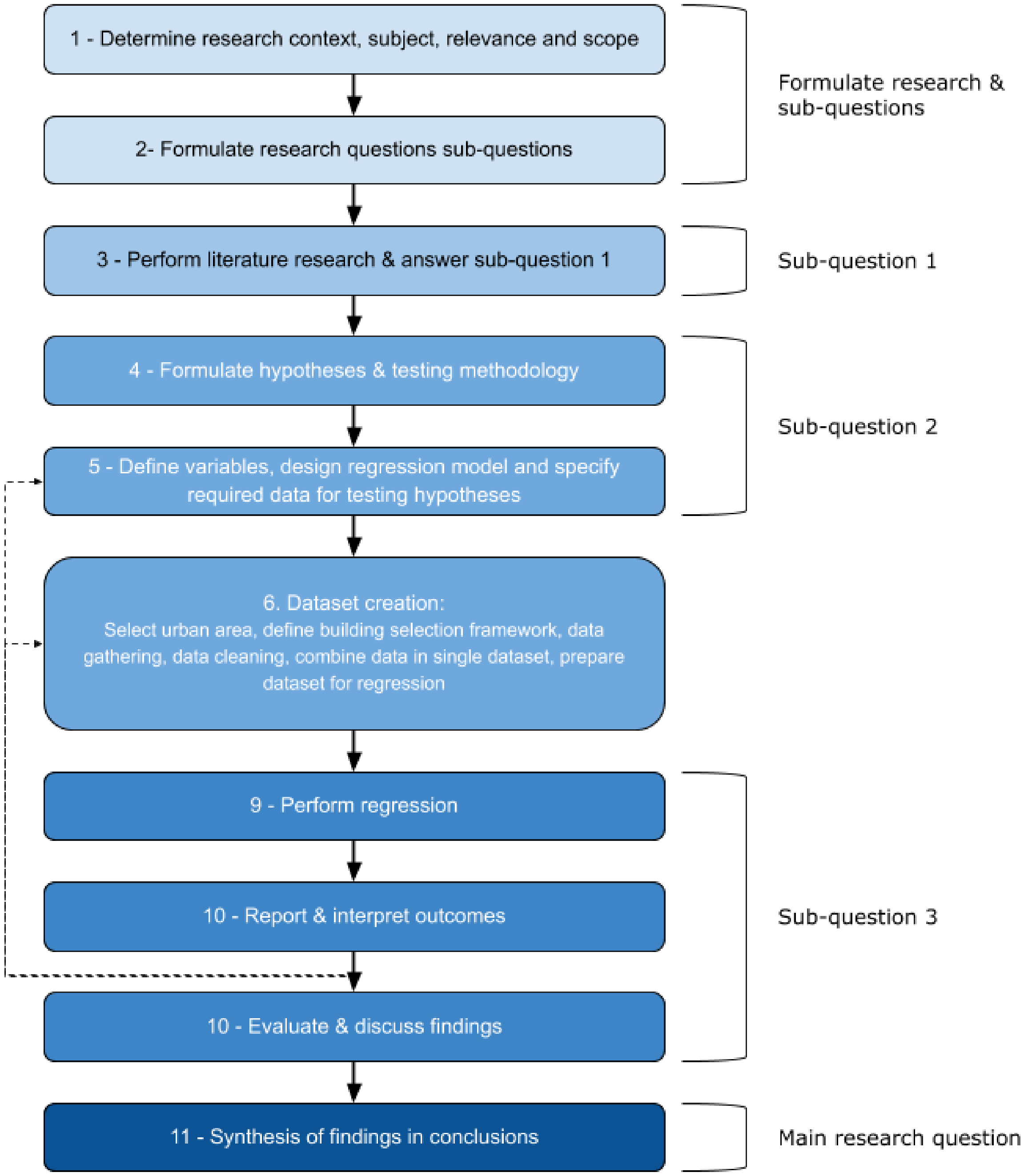


Figure 7. Research design. Dashed lines represent feedback loops. Darkening colors of the text boxes represent the chronological chapters (1-5) of this thesis. The right hand side of the figure indicates which part of the thesis is answered by the research steps.

Step 1 and 2 are addressed in chapter 1. Extensive research on height premiums is conducted in order to lay the foundations for this quantitative research, resulting in the theoretical underpinnings provided in chapter 2. Figure 7 represents these actions in step 3. Step 4, 5, and 6 are discussed in this chapter and step 4 and 5 provide this thesis' answer on sub-question 2. Section 3.1. presents a detailed description of the methodology applied. Section 3.2. provides the framework that was used for data collection and section 3.3. presents various characteristics of the constructed dataset. Step 8, 9 and 10 of the figure are elaborated upon in chapter 4, where this thesis' answer on the third sub-question is obtained. Step 11 is reported in chapter 5 and presents the key findings of this thesis, therewith answering the main research question.

3.1. Research design

The main objective of this thesis is to analyze the supply side of residential tall buildings in order to answer how real estate developers behave regarding vertical price premiums in this sector. This section describes the research strategy that is employed within this thesis to complete the objective.

Three sub-questions are formulated in order to The first sub-question is addressed in chapter 2. This chapter researches various aspects that are of influence on height premiums in residential tall buildings and the key findings are used as input for the rest of the thesis, starting in this chapter. The second sub-question concerns how a model can developed to measure developers' vertical price premium behavior in residential tall buildings. The model that this thesis uses to do so is elaborated upon in this chapter.

The third sub-question looks into the extent to which different factors contribute to real estate developers' vertical price premiums in residential tall buildings. These different factors are provided by the answer to the first sub-question in chapter 2 and this chapter explains how these factors are measured in this thesis. The first step taken is to translate the found influential factors into hypotheses. As mentioned in the previous chapter, some of the determinants are left for future research as no data on the vertical dimension was available for those determinants. Sub-question three is answered by quantifying the extent to which the remaining different hypothesized height premium determinants are of influence developer unit prices. The third sub-question is answered by conducting a quantitative empirical analysis in the form of a hedonic pricing analysis.

3.1.1. Hypotheses

Answering the third sub-question is done in a quantitative manner. Three main hypotheses are presented below.

Hypothesis 1: developer unit prices & floor levels

Hypothesis 1 concerns floor level premiums. Based on other research (e.g. Danton and Himbert (2018), Wong et al. (2011), Coulson et al. (2018)), I expect to find a positive relationship between floor levels and developer units prices.

Hypothesis 2: developer units prices & views

A study in Fairfax County, Virginia, USA, found that 'good views' increased the value of housing by 5%-8% (Rodriguez & Sirmans, 1994). Ferlan et al. (2017) found that 'good views' increased residential property value by 12%, while a sea view was found to increase residential property value by 40%. Benson et al. (1998) researched the impact of different view types and qualities on residential values in Bellingham, Washington, USA through the use of hedonic price estimations, implicating that using a generic view variable of 'good' and 'bad' is not appropriate for real estate valuations when views vary by type or quality. Several studies found that higher floor levels are correlated with better views (Hasanah & Yudhistira, 2018; So et al., 1997; Yamagata et al., 2016; Yu et al., 2007). As height was found to have a positive impact on views, this thesis hypothesizes that developers raise unit prices to exploit homebuyers' willingness to pay for better views. I expect a positive relation between views, floor levels and developer prices. In order to test this hypotheses, the regression models include control variables for the number of view features that an apartment offers. View features are categorized as *city, Erasmus bridge, harbor, Maas, panorama and park,* based on the view features that are most marketed by developers in sale brochures. Many combinations are possible, but not enough observations are included in the dataset to adequately measure the effect of these combinations. Instead, the number of view features are counted, resulting in three dummies: 1 view feature, 2 view features*,* 3 or more view features. Furthermore, a categorical variable is created for whether or not one of these view features is the Erasmus bridge. The Erasmus bridge is a prominent local icon and no previous studies have measured how developers exploit the view on the Erasmus bridge in apartment price formation. As the effect of views is expected to increase when locating higher due to increasing view quality, interaction terms between floor level and these view control variables are added throughout the models.

Hypothesis 3: developer unit prices & perception of social power

Vertical location in tall buildings was found to have a positive impact on the perception of social power (Dorfman et al., 2017). It is suggested that social power could be priced within the context of tall building developments. This thesis models three aspects which are believed to be a representation of social power. Firstly, this thesis considers the concept of 'prestige' by creating dummy variables for whether or not the apartments is marketed as a penthouse. With this, I hypothesize that living in a penthouse is valued by homebuyers in search for status and that developers try to take advantage of this willingness to pay through a 'penthouse premium'.

Secondly, this thesis considers the extent to which a resident has 'the whole floor to him/herself' by creating a variable for the number of neighbors and by investigating the relation between floor neighbors, floor level and developer unit prices.

Thirdly, the extent to which a resident 'is on top of others' is investigated by creating a squared relative floor level variable. This variable is created by taking the apartment's floor level, dividing it by the total number of floors in the building and squaring this number. This results in a gradient from zero to one with only higher floors achieving relatively higher scores.

This thesis does not investigate the relation between developer unit prices and noise levels or travel time due to a lack of adequate data at the vertical level. The effects are left to be controlled for by building fixed effects. Only a single building had partial data available on apartment costs, which enables an approximation of relative floor level costs. No such data was acquired for other towers. van Oss (2007) thesis provides a twelve-year-old model for approximating office building developments costs. The model is limited to buildings constructed with concrete, is not specified to circumstances of a single urban area, does not take into account innovations that have been adopted since its publication (e.g. new climate control, environmental sustainability measures, double facades) or the impact of construction market fluctuations on costs. This research is not focused on office building developments, does not limit the building selection to buildings constructed with concrete, is specified to a single urban area, includes buildings that are recent and include modern technologies and other innovations and considers buildings that are impacted by market fluctuations. Therefore, the van Oss (2007)model is considered as an inappropriate method to model buildings costs for the buildings that are included in the dataset. No other method for modeling relative costs per floor was discovered. Nevertheless, this thesis acknowledges the fact that additional floors are accompanied with increasing marginal costs. Section 4.2. provides a qualitative discussion on the findings concerning developer unit prices and floor levels in the context of marginal costs of adding floor levels.

3.1.2. Testing methodology

To test our hypotheses, hedonic pricing analysis is performed, which is widely accepted as a suitable method for studying prices of property characteristics. The hedonic pricing analysis is a statistical method that assesses the relationship and its strength between a dependent variable and a (or multiple) independent variables (Rosen, 1974). This thesis uses regression modelling to test several of the formulated hypotheses. The concept of regression modelling is as follows:

$$\text{Outcome}_i = \text{Model}_i + \text{error}_i \quad (1)$$

The most basic form of the population regression function, *the simple linear regression*, is provided below. Only one independent variable is included.

$$y_i = \beta_0 + \beta_1 X_i + \varepsilon_i \quad (2)$$

with

y_i = the dependent variable (e.g. price).

β_0 = the intercept, or value for that is left after $\beta_1 X_i = 0$.

β_1= the strength of the relation between the dependent and independent variable, also known as a coefficient.

X_i = the value of the independent variable (e.g. floor level).

ε_i = every unit that is predicted by the population regression function has some theoretical distance to values predicted by the regressed relation. This error term itself cannot be predicted, but it does exist in theory. Note that it is different from 'e', as that is the observed error (or distance to the population regression function) from an observation that has actually happened, rather than one that is only modelled.

Apartment prices are influenced by many aspects and cannot be properly explained by a single independent variable. Literature offers numerous variables that impact price levels, which are further discussed in section 3.1.3. The simple linear regression can be extended to include multiple variables, resulting in a *multiple regression model*.

$$y_i = (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n) + \varepsilon_i \quad (3)$$

Theoretically, the number of independent variables that can be added to the regression model is infinite. However, adding too many variables can diminish the predicting power of the model, as some variables may only provide negligible contributions and may be correlated to each other. On the other hand, including too few variables results in a biased model. Field (2009) advises to include at least 10 to 15 observations per independent variable. The value of R^2 explains how much of the dependent variable is explained by the independent variables in the model. The value of the *adjusted* R^2 also shows how much of the outcome is predicted by the model but takes into account the number of independent variables that are included in the model. The adjusted R^2 value can be used to compare predictive power between different models.

All regression models in this thesis employ developer unit prices in the form of apartment prices divided by indoor floor area as the dependent variable. The dependent variable is transformed into logarithmic variables. As a result, an increase in one unit of an independent variable will no longer add the magnitude of the coefficient to the dependent value in absolute value, but as a percentage.

The multiple regression model considers all apartments and their characteristics to be independent and randomly distributed. However, each building was built by a different development team and in a different time and time, factors which were found to be highly influential on price formation (see chapter 2). This means that the relation between the different independent variables and the dependent variable differs per tower, which results in residual error clustering for each specific tower. The multiple regression model combines all these clustered variations to return the relations of the dependent and independent variables for the model as a whole on a single level. This thesis accounts for this issue by clustering standard errors at building level. Additionally, some models investigate tower-specific effects.

To perform the regression analysis, the programming software 'R' (version 3.5.2.) is used. RStudio (version 1.1.463.) is used as a programing environment. Code used for building the regression models is available in appendix C.

3.1.3. Variables

To determine which variables should be included in the analysis as independent variables, this thesis considers the variables that are required to test the hypotheses and supplements these with a set of control variables. The dependent variable, developer unit prices, is acquired by taking the listed apartment price, subtracting any costs included for parking places and then dividing by the indoor floor area. Prices are adjusted for inflation effects using CBS consumer price index data for the yearly quarter that the apartments prices were marketed. These prices are then transformed into a logarithmic form in the regression models. Indoor floor area and outdoor floor area are also transformed into log forms. Table 2 in this section displays all variables that are included in the regression analysis, which dummy variables act as baseline dummies within the concerning category and also provides basic descriptive statistics. Appendix A provides an overview of data sources.

A well-established body of knowledge is available on aspects that were observed to affect residential property prices. These aspects are segregated to a regional level, area level, building level and apartment level. On a regional level, this includes local construction costs and availability of developable land (Manning, 1989), demographic differences - again corroborating statements on heterogeneity of homebuyers - (Fortura & Kushner, 1986; Ozanne & Thibodeau, 1983), local development controls e.g. zoning and regulations (Ding, 2013; Elliott, 1981; Kulish et al., 2012) and economic uncertainty (Choudhry, 2018). These variables are taken into account by investigating apartments in only a single city and by adjusting prices for consumer price inflation.

Observations on area level include, but are not limited to, proximity to water bodies (Cohen, Cromley, & Banach, 2015; Goetgeluk, Kauko, Priemus, & Straub, 2005; Rouwendal, Levkovich, & Marwijk, 2017), green areas (Asabere & Huffman, 2009), sport and entertainment facilities (Ferlan et al., 2017; Mok, Chan, & Cho, 1995), and available parking places (Ferlan et al., 2017). Other area-specific amenities and the proximity to those amenities that were observed to be of influence on residential value are universities and their ranking (Shen & Turner, 2018; Wickramaarachchi, 2016; Zahirovic-Herbert & Turnbull, 2008), houses of worship (Brandt, Maennig, & Richter, 2014; Carroll, Clauretie, & Jensen, 1996), subway stations and other public transport nodes (Choy et al., 2007; Li, Yang, Qin, & Chonabayashi, 2016) and street layout (Matthews & Turnbull, 2007). For Rotterdam, den Dekker (2009) concludes that walking distance from urban amenities are an important factor in the decision-making of purchasers, providing the following ranking order: grocery shops (run-shopping), fashion stores and other fun-shopping stores, leisure. Significant variables on building level include building age (Brueckner & Rosenthal, 2009; Mok et al., 1995; Sirmans, MacDonald, Macpherson, & Zietz, 2006), visual uniqueness (Moon et al., 2010), 'green' (sustainability) measures and expected effect on maintenance costs (Yoshida & Sugiura, 2015) and many others. This thesis does not address these aspects for each apartment unit specifically in the empirical analysis because these aspects are not important for real estate in the vertical dimension. Prices of apartments in the same tower are not expected to differ as a result of these aspects, thus having no impact on height premiums. The effects on area and building level as described, but certainly not limited to, above are controlled for by including building fixed effects in the regression analysis, reflecting area-, building-, but also time-induced effects.

On apartment level, time-on-market was found to impact price levels (Choi, Rasmussen, & Davison, 2012; Edelstein, Liu, & Wu, 2012; Li & Chau, 2018). Therefore, apartments that were placed on the market for sale in a later stage than other apartments of the same tower cannot be directly compared to each other to determine height premiums. Their heterogeneous nature in terms of market entry time influences their prices because the developer has had an opportunity to recalibrate prices according the demand for the apartments that were placed on market during the first phase. Therefore, their vertical difference is no longer the sole factor of influence on their price difference. Apartments located in one of the towers used in this thesis' dataset are subject to this condition. In response to this issue, this thesis adopts variables on time between opening of sale and start of construction as well as completion of construction.

The regression analysis is applied to a dataset that includes buildings with often multiple apartments per floor. Unless vertically stacked apartments are identical, which is not always the case, vertical price differences may be influenced by differences in apartment characteristics rather than being a pure consequence of greater vertical location. Numerous studies found that indoor surface area, number of bedrooms and number of bathrooms impact residential property prices (Sirmans et al., 2006). These variables are included in the regression models as control variables, supplemented by control variables for total number of rooms, number of toilets and living room orientation. In the thesis of den Dekker (2009), a personal outside space was considered a must-have for many homebuyers in Rotterdam, preferably a loggia and otherwise a balcony. Therefore, dummies for number of and type of outside spaces are also included as independent variables in the regression. Additionally, a continuous variable for outside surface area is included. Both indoor and outdoor surface area are transformed into logarithmic variables. Regression outcomes for these variables represent unit price elasticities as surface area changes.

This bring us to the following regression equation. Bold glyphs are aggregated for hypothesis testing variables, control variables and for interaction term variables. Each bold glyph represents a matrix of variables and each coefficient represents a column vector corresponding to the neighboring matrix.

$$Ln(P) = \beta_0 + \beta_{i-n} X + \beta_{j-n} Y + \beta_{k-n} Z + \varepsilon_i \quad (4)$$

Table 2. Descriptive statistics of analyzed variables. DV = Dependent variable. FL = floor level variable. CV = Control variable. S = Status variable. V = view variable.

Variable	Description	Category	Mean	Std. dev.	Min.	Max.
Log(epm2int)	Developer unit prices (€/indoor m2), log transformed	DV	4827.06	1049.28	2379.44	9177.56
floorlv	Floor level of concerning apartment	FL	21.61	12.05	1.00	56.00
quarterstostart	Number of quarters to start of construction	CV	-3.84	7.07	-20.00	3.00
quarterstodelivery	Number of quarters to end of construction	CV	8.68	5.44	0.00	15.00
Log(areaext)	m2 outdoor floor area, log transformed	CV	15.54	19.28	0.00	261.00
Log(areaint)	m2 indoor floor area, log transformed	CV	111.98	55.60	39.00	728.00
floorneighbors	Number of floor neighbors	S	4.61	2.22	0.00	14.00
nrooms	Number of rooms	CV	3.26	0.94	1.00	8.00
nbathrooms	Number of bathrooms	CV	1.12	0.37	1.00	6.00
ntoilets	Number of toilets	CV	0.36	0.50	0.00	2.00
nbedrooms	Number of bedrooms	CV	2.21	0.88	0.00	8.00
relative floor height2	Relative floor height ((floor level/total floors)^2)	S	0.42	0.29	0.00	1.00
dTower 4	Tower 4 tower dummy	CV	0.08	0.27	0.00	1.00
dTower 5	Tower 5 tower dummy	CV	0.16	0.36	0.00	1.00
dTower 13	Tower 13 tower dummy	CV	0.11	0.31	0.00	1.00
dTower 14	Tower 14 tower dummy	CV	0.04	0.19	0.00	1.00
dTower 15	Tower 15 tower dummy	CV	0.04	0.19	0.00	1.00
dTower 12	Tower 12 tower dummy	CV	0.03	0.17	0.00	1.00
dTower 11	Tower 11 tower dummy	CV	0.02	0.14	0.00	1.00
dTower 9	Tower 9 tower dummy	CV	0.06	0.23	0.00	1.00
dTower 6	Tower 6 tower dummy	CV	0.13	0.34	0.00	1.00
dTower 10	Tower 10 tower dummy	CV	0.07	0.25	0.00	1.00
dTower 2	Tower 2 tower dummy	CV	0.04	0.21	0.00	1.00
dTower 1	*Tower 1 tower dummy → baseline dummy*	CV	0.11	0.31	0.00	1.00
dTower 3	Tower 3 A tower dummy	CV	0.06	0.24	0.00	1.00
dTower 7	Tower 7 tower dummy	CV	0.03	0.18	0.00	1.00
dTower 8	Tower 8 tower dummy	CV	0.03	0.18	0.00	1.00
dmarketedpenthouse	Marketed as penthouse dummy	S	0.05	0.22	0.00	1.00
dnotpenthouse	*Not marketed as penthouse dummy → baseline dummy*	S	0.95	0.22	0.00	1.00
dnw	Northwest living room orientation dummy	CV	0.11	0.31	0.00	1.00
dn	*North living room orientation dummy → baseline dummy*	CV	0.13	0.34	0.00	1.00
dno	Northeast living room orientation dummy	CV	0.09	0.28	0.00	1.00
do	East living room orientation dummy	CV	0.08	0.26	0.00	1.00
dzo	Southeast living room orientation dummy	CV	0.19	0.39	0.00	1.00
dz	South living room orientation dummy	CV	0.17	0.38	0.00	1.00
dzw	Southwest living room orientation dummy	CV	0.13	0.34	0.00	1.00
dw	West living room orientation dummy	CV	0.10	0.30	0.00	1.00
d360	360 degrees living room orientation dummy	CV	0.00	0.07	0.00	1.00
d1view	*1 view feature dummy → baseline dummy*	V	0.21	0.40	0.00	1.00
d2view	2 view features dummy	V	0.63	0.48	0.00	1.00
d3+view	3 or more view features dummy	V	0.16	0.38	0.00	1.00
dbridge	Erasmus bridge view dummy	V	0.12	0.32	0.00	1.00
dnobridge	*No view on Erasmus bridge dummy → baseline dummy*	V	0.88	0.32	0.00	1.00
dexpansion	Expansion dummy	CV	0.70	0.46	0.00	1.00
dcontraction	*Contraction dummy → baseline dummy*	CV	0.30	0.46	0.00	1.00
dext0	*No outdoor space dummy → baseline dummy*	CV	0.11	0.32	0.00	1.00
dext1	1 outdoor space dummy	CV	0.68	0.47	0.00	1.00
dext2	2 outdoor spaces dummy	CV	0.19	0.39	0.00	1.00
dext>2	>2 outdoor spaces dummy	CV	0.02	0.12	0.00	1.00
dbalcony	Balcony dummy	CV	0.46	0.50	0.00	1.00
dterrace	Terrace dummy	CV	0.18	0.38	0.00	1.00
dloggia	Loggia dummy	CV	0.28	0.45	0.00	1.00
dsunspace	Sunspace dummy	CV	0.02	0.15	0.00	1.00
dcornered balcony	Cornered balcony dummy	CV	0.02	0.13	0.00	1.00
dnooutside	*No outside space dummy → baseline dummy*	CV	0.05	0.22	0.00	1.00

3.2. Data collection

Data is required to fill the regression model and perform the actual analysis. This section describes how the city of Rotterdam was selected for analysis in this thesis. Furthermore, this section describes the framework that was used to determine which buildings can be included in the analysis. The data gathering and structuring methods are addressed as well.

3.2.1. Selection of urban area: Rotterdam

Previous sections already mentioned that Rotterdam is selected as the city from which buildings are selected to create this thesis' dataset. The section below provides the justification of this selection.

The Netherlands is a compact country, with most people living in cities. The largest cities in the Netherlands are:

Table 3. Inhabitants, households and residential tall buildings per city in 2018. Source: Centraal Bureau voor de Statistiek (2019).

Name	Inhabitants	Households
Amsterdam	854.047	467.606
Rotterdam	638.712	321.691
The Hague	532.561	260.887
Utrecht	347.483	178.186
Eindhoven	229.126	118.269

Looking at the columns of 'Inhabitants' and 'Households, one would think that Amsterdam is the preferred city to use for this study as more observation may be acquired for the quantitative analysis. However, Rotterdam has significantly more residential tall buildings (Council on Tall Buildings and Urban Habitat, 2019a, 2019b). Therefore, Rotterdam has the potential to provide more observations to the dataset. On May 14th 1940, Rotterdam was heavily hit by aerial bombings that eradicated nearly the complete city center (Gemeente Rotterdam, n.d.). This resulted in a *tabula rasa*, an opportunity to rebuild the city in a new way. Amsterdam protects its city image and cultural and architectonic heritage by limiting tall building developments. Rotterdam was not bound by these factors in its urban (re-)development policies and has been the Netherlands' pioneering star when it comes to tall buildings. Additionally, Amsterdam needs to set certain height restriction for the continuous operations of the nearby airport Schiphol. Rotterdam also has a nearby airfield (Rotterdam-The Hague Airport), but it is not nearly as heavily influential on height regulations as Schiphol for Amsterdam. Due to the greater number of residential tall buildings, Rotterdam is selected as city for this research.

The high-rise policy of the municipality of Rotterdam dictates that building between 70m and 150m are categorized as tall buildings. Buildings taller than 150m are categorized as *supertall*s. The policy appoints areas where no tall buildings can be developed, where tall buildings can be developed and where supertalls can be developed. This means that the policy is an important determinant for building heights in certain areas. Figure 9 displays a map of Rotterdam with the appointed zone for tall buildings as well as the area that was eradicated during WWII. Figure 10 provides the municipalities zoning plan for tall buildings and supertalls.

Figure 8. Rotterdam tall building zones A. Source: Gemeente Rotterdam (2011)

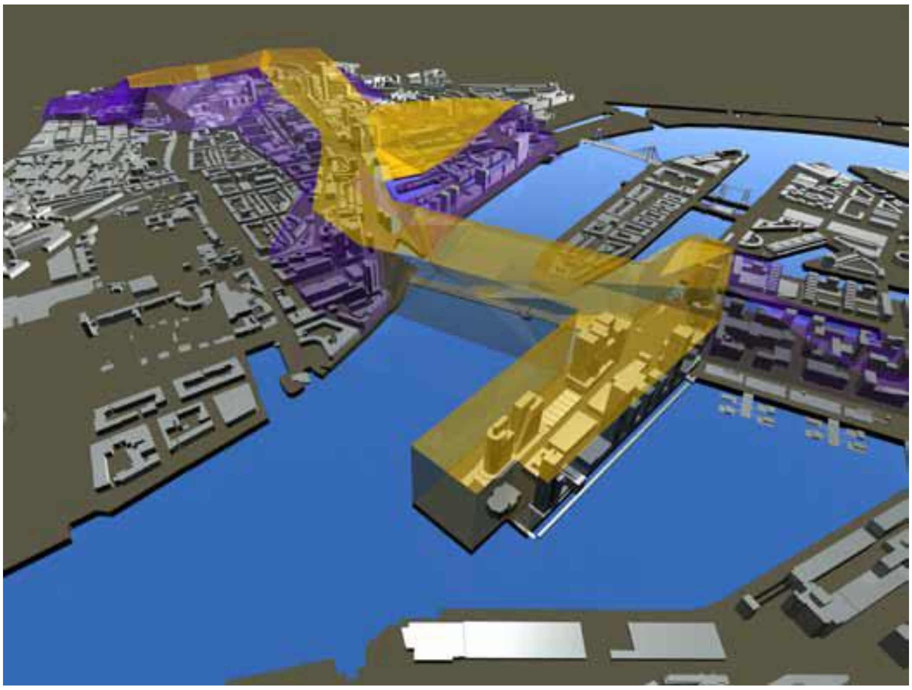


Figure 9. Zoning plan for tall buildings and supertalls in Rotterdam. Yellow zones represent supertalls (>150m), purple zones represent tall buildings (70m < h < 150m). Source: Gemeente Rotterdam (2011)

3.2.2. Selection of tall buildings

Within the city of Rotterdam, there are numerous residential tall buildings to be researched. Further scoping is required to determine which tall buildings are eligible to include in the dataset. The initial step to do this is to further explore the history and context of tall buildings in Rotterdam. The first residential tower project to break the 100-meter barrier is De Hoge Heren. During development it was a controversial project because tall buildings were not favored to reside in by citizens due to an unattractive image. The project proved that tall buildings could be successful and made them more appealing to Rotterdam's citizens. Also, the project provided evidence that there was enough willingness among the citizens of Rotterdam to live in 'the niche market' of residential tall buildings, acting as a gamechanger for tall building developments in Rotterdam and contributing to the initiation more residential tall building developments. Therefore, De Hoge Heren is considered a starting point for the development of tall buildings in Rotterdam and De Hoge Heren is also taken as a starting point regarding age for the data selection framework in this thesis. All residential tall buildings with apartments to be sold from that point on (the year 2000) are considered potential cases to include in the dataset. Argumentation to only consider apartments that were or are to be sold (instead of rented) is provided in section 1.3.4.

The next step in scoping is considering the term *residential tall buildings*. The first deciding part in this term is 'residential'. Only tall buildings that are predominantly residential are included, strongly mixed buildings are not. The word predominantly is used as it is not unusual for residential tall buildings to house different functions on or close to street level floors (e.g. retail, public restaurants, etcetera), but also on higher levels (e.g. hotel in The Sax, observation deck in Tower 13). This thesis considers these tall buildings to be equally suitable to analyze for height premiums. The second deciding part in the term 'residential tall buildings' is 'tall'. Gemeente Rotterdam (2011) defines buildings as 'tall' when their height is exceeds 70 meters and this same threshold is adopted in this thesis' building selection framework. Furthermore, the municipality or Rotterdam sets a maximum length for floor plate diagonals of 56 meters (40x40m) for floors under 70 meters and a maximum length for floor plate diagonals of 42 meters (30x30m) above 70 meters. Figure 11 provides a schematic representation of this policy.

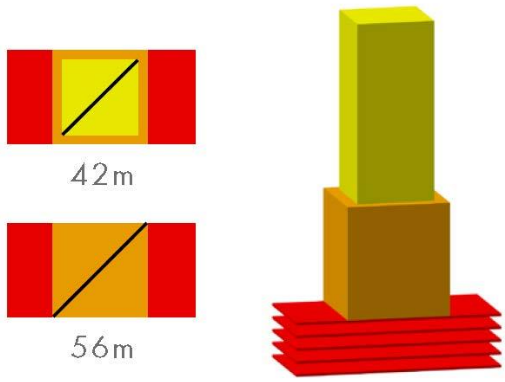


Figure 10. Tower typology and diagonal length limits. Source: Gemeente Rotterdam (2011)

The municipality's reason for this policy is to stimulate developments of tower typology buildings. This thesis uses the same height-base ratios in this thesis in order to only include buildings of a tower typology. These measures result in the selection framework that only accepts predominantly residential buildings developed after the year 2000 of at least 70 meters height and a height-dependent height-base ratio (<70m: 56 meters diagonally | >70m: 42 meters diagonally). Table 4 provides an overview of all objects that fit into this framework, along with several characteristics. Note that towers with only rental apartments were also left out.

Table 4. Pool of potential buildings for analysis.

#	Name	Completion	Height	Floors	Apts total
1	Zalmhaven I	2021	215	59	257
2	Zalmhaven II	2021	70	22	90
3	Zalmhaven III	2021	70	22	90
4	CasaNova	2022	110	35	115
5	CoolTower	2021	153	50	280
6	The Muse	2019	74	23	96
7	Terraced Tower	2019	104	32	340
8	Boston	2018	70	23	110
9	BaanTower	2022	150	47	145
10	UP:town	2019	107	34	178
11	The Sax: Havana	2023	150	43	432
12	The Sax: Philadelphia	2023	70	22	(part of 432)
13	100Hoog	2013	106	31	150
14	New Orleans	2010	158	44	234
15	Montevideo	2005	140	43	192
16	De Rotterdam	2013	151	44	240
17	The Red Apple	2009	124	40	231
18	Waterstadtoren	2004	109	36	168
19	Coopvaert	2006	106	30	124
20	Hoge Heren I	2000	102	34	285
21	Hoogmonde	2011	90	27	153
22	Scheepmakerstoren	2008	88	26	45
23	Harbor Village I	2002	85	29	187
24	Harbor Village II	2001	70	24	82
25	Koninginnnetoren	2001	79	26	82
26	De Admiraal	2003	78	19	82
27	Parktoren	2009	76	23	80
28	Westerlaantoren	2012	75	19	46
29	Lloydtoren	2010	74	24	100
30	De Statendam	2009	73	22	124
31	Hoge Maas	2001	73	24	109
32	Calypso A	2013	71	22	86
33	Wijnhaeve	2008	70	25	63
-	**Total**			**1021**	**4869**

3.2.3. Data gathering

The first step in gathering data on the towers listed above was contacting the towers' real estate developers and apartment sale brokers. This yielded ten lists of apartments, developer prices, floor levels and varying other characteristics. Two similar lists were found online, and two lists were acquired by visiting sale opening festivities. These lists and brochures provide all data on developer prices, floor levels, whether or not the apartment is marketed as a penthouse and price marketing dates. Price marketing dates in combination with published expected or empirical construction start and completion dates are used to create data for the variables of *'Quarters to construction start'* and *'Quarters to construction finish'*. However, lists obtained from developers and brokers may be stamped with a 'last modified' date, rather than the sale opening date. The variables are employed to control for price recalibrations effects in Tower 5 and their effects are further discussed in section 4.1.

Squared relative internal floor level data is constructed by dividing the floor level variable by the total number of floors in the concerning building and squaring this number. Data on number of different rooms, neighbors, external spaces and orientations is acquired through extensive tower and floor plan analysis. These plans were acquired via desk research (Google), field research (Stadsarchief Rotterdam and Mecanoo archives) or by visiting the sale opening festivities. Indoor and outdoor surface area is in some cases obtained from brochures and in some cases through floor plan analysis. Data on views was created by using view simulations (drone images and/or renders) on tower websites when available. For all other cases, Google Maps 3D satellite view was used. For each tower, I considered whether or not large surroundings were present during the time of sale. This enables the thesis to determine if a view was obstructed or unobstructed during the point of sale and to determine the number of view features that were applicable at that point in time. Further information on data sources is available in appendix A.

3.3. Dataset

The dataset is comprised of fifteen different residential tall buildings in Rotterdam. This section provides detailed information and statistics on the data that was acquired, which together form the dataset that is used in the regression analysis.

3.3.1. Dataset description

Table 5 provides an overview of the towers that are analyzed in the regression analysis. Note that in all cases, the developer was assisted by brokers and sometimes other advisors in apartment price formation. Nevertheless, developers ultimately decide prices and, therefore, prices gathered from lists are suitable for analyzing developer vertical price premium behavior.

Table 5. Overview of towers and apartments included in the dataset.

#	Name	Completion	Price marketing date	Floors	Number of apts
1	Tower 1	2013	2011 Q3	30 (31)	150 (150)
2	Tower 2	2018	2015 Q3	11 (23)	62 (110)
3	Tower 3	2013	2012 Q4	17 (22)	86 (86)
4	Tower 4	2022	2018 Q4	33 (35)	115 (115)
5	Tower 5	2021	2018 Q4, 2018 Q2	42 (50)	219 (280)
6	Tower 6	2013	2013 Q4	38 (44)	186 (240)
7	Tower 7	2005	2005 Q4	29 (43)	46 (192)
8	Tower 8	2008	2008 Q4	25 (26)	45 (45)
9	Tower 9	2019	2017 Q4	13 (32)	82 (340)
10	Tower 10	2019	2016 Q4	23 (23)	94 (96)
11	Tower 11	2019	2016 Q2	8 (34)	28 (178)
12	Tower 12	2012	2010 Q2	9 (19)	41 (46)
13	Tower 13	2021	2018 Q4	41 (59)	152 (257)
14	Tower 14	2021	2018 Q4	11 (22)	50 (90)
15	Tower 15	2021	2018 Q4	11 (22)	50 (90)
	Total			341	1406

For floors, the numbers in parentheses represent the total number floors in the building. The numbers before the parentheses represent the number of floors on which the various apartments included in the analysis are located. Likewise, the numbers in parentheses for *'Number of apts'* represent the total number of apartments in the building, while the numbers before the parentheses represent the number of apartments included in the analysis. Other apartments do not meet the criteria to be included in the analysis, which can generally be summarized to being rental apartments. Excluded floors either fully consist of rental apartments or other functions e.g. parking garage floors or lobbies.

Figure 13 provides an overview of the geographical distribution of the towers included in this thesis' dataset, indicated by the corresponding numbers from table 5. Note that Tower 5, has two price marketing dates. This is because the apartments were placed on the market in two phases and we have acquired access only to the two separate price listings. Phased sale opening implies that the project team may have adjusted prices after the first sale (possibly altering the relation with the various aspects that this research analyzes). The 'quarters to construction' variable is employed to control for this.

Figure 11. Map of all analyzed towers. Numbers correspond with table 5. Based on images of Google Maps (2019).

Hypothesis 1: developer unit prices & floor levels

For this hypothesis, the directly relevant data is data on floor level per apartment, prices per apartment and internal surface area per apartment, which is discussed in further section of this paragraph. Figure 14 shows the distribution of number of apartments per floor level for the entire dataset. The gap in apartments per floor level beneath floor level 13 can be explained by the fact that some towers in the dataset only have sale apartments on higher floor levels and have rental apartments or other functions (e.g. parking) on lower floor levels. Figure 15 shows the price levels per floor using boxplots. The width of the boxplots represents the quantity of data that functions as input for the graphical representation. As visible, the higher floor levels are less heavily represented in the dataset. This is no surprise, as the number of residential tall buildings in Rotterdam approximating or superseding 100 meters is limited. The red circles represent outliers per floor level. The most distant outliers are quickly recognized as penthouses. The regression analysis will provide further information on the true influence of each variable on price levels. In any case, the figure suggests that an overall increase in price levels per floor exists.

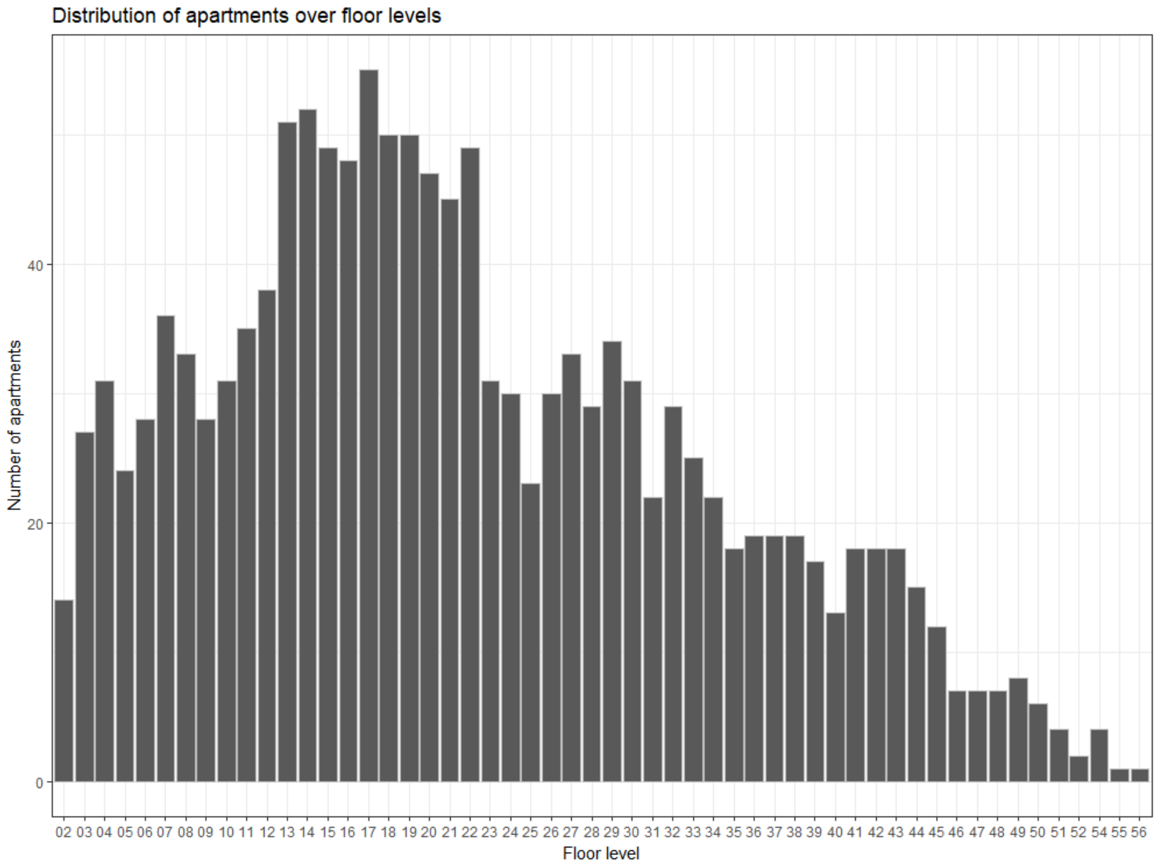


Figure 12. Distribution of apartments for each floor level.

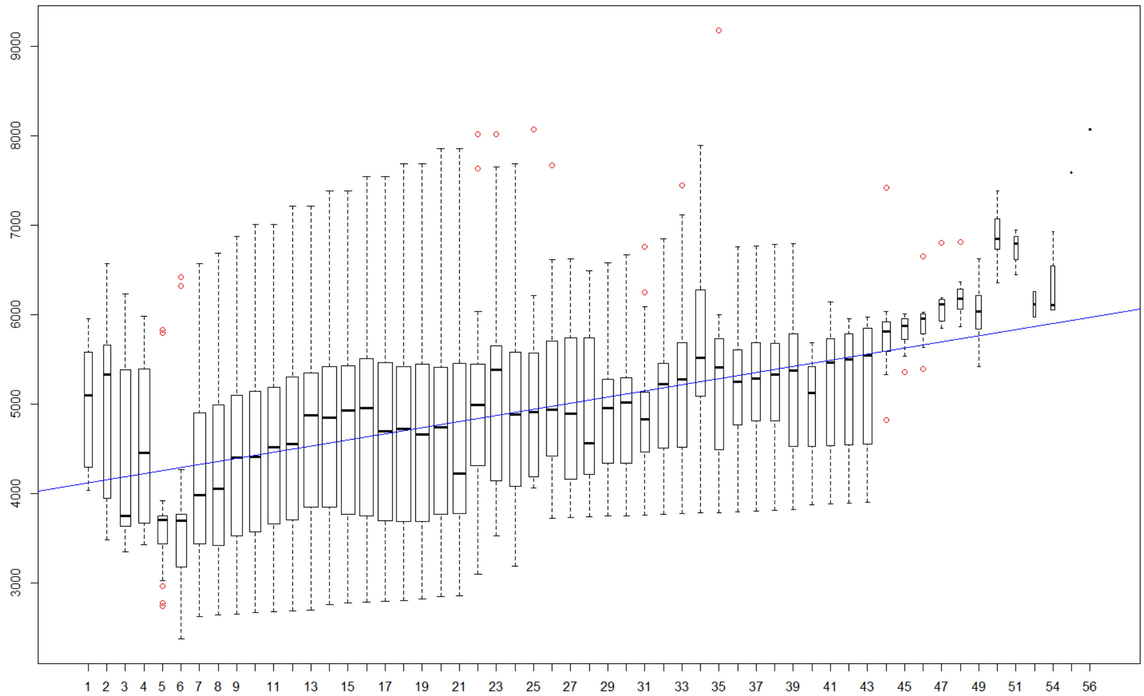


Figure 13. Boxplots of price per m² per floor. The width of the boxplots represents the quantity of data that functions as input for the graphical representation. The blue line is the estimate for floor levels regressed on unit prices.

Hypothesis 2: developer unit prices & views

Views that were found on lists and in brochures of the analyzed buildings include *City, Erasmus bridge, Harbor, Maas, Panorama and Park*. In this thesis, these options and variants that include multiple of these view features are employed to model views for each apartment. Each apartment is assigned one, two or three and more of these view features based on what is visible from the living room, using the living room orientation variables as a basis. Analyzing the different view features yields no significant results due to a large number of possible view feature combinations in relation to the number of observations in the dataset. Instead, the number of view features (as dummy variables) are used in the regression analysis. The panorama view feature is considered as providing three or more view features. The distributions of apartments for each option is depicted in figure 16 and the distribution for the number of apartments that do and do not provide an Erasmus bridge view is depicted in figure 17.

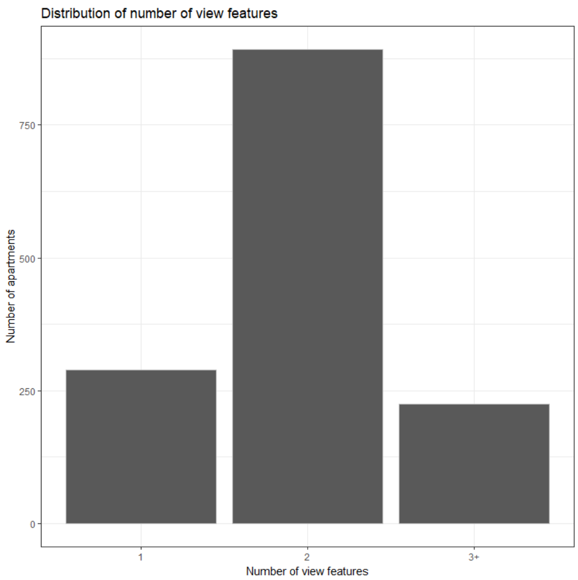


Figure 14. Number of apartments per view category.

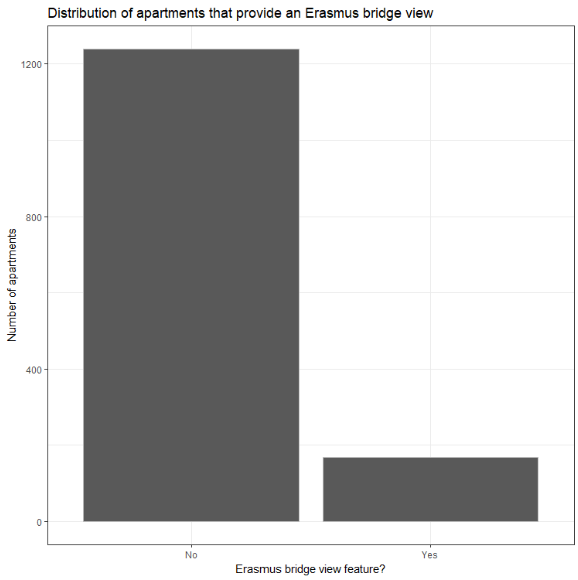


Figure 15. Distribution of apartments for the Erasmus bridge view feature dummy variables

Hypothesis 3: IAPS & perception of social power

Three concepts are used in the regression analysis to represent different aspects of perception of social power:

1. *'Prestige', in the form of whether the residence is marketed as a penthouse.*
2. *The extent to which a resident has the entire floor to him-/herself, using floor neighbors as a variable.*
3. *The extent to which a resident is on top of others, using squared relative floor level as a variable.*

Figure 18 shows that the number of neighbors decreases when locating higher in a building. The figure shows that the number of neighbors in the analyzed towers decreases from 8 to 4 in the lower third of the tower. This sharp decline is attributed to tower forms in Rotterdam, where the municipality requires the bottom 18 to 25 meters of a tall building to contribute to city dynamics and continuity of the urban identity (Gemeente Rotterdam, 2011). Often, this results in large 'podia', with large floor plans consisting of a relatively large number of apartments. On top of these podia, the actual towers are placed. Also, the figure shows that the number of neighbors further declines when approaching the top of the towers. All of this means that the extent to which a resident has the entire floor to him-/herself increases when locating higher. In the regression analysis, an interaction term of floor level times number of neighbors is used to add nuance to the general floor level premiums.

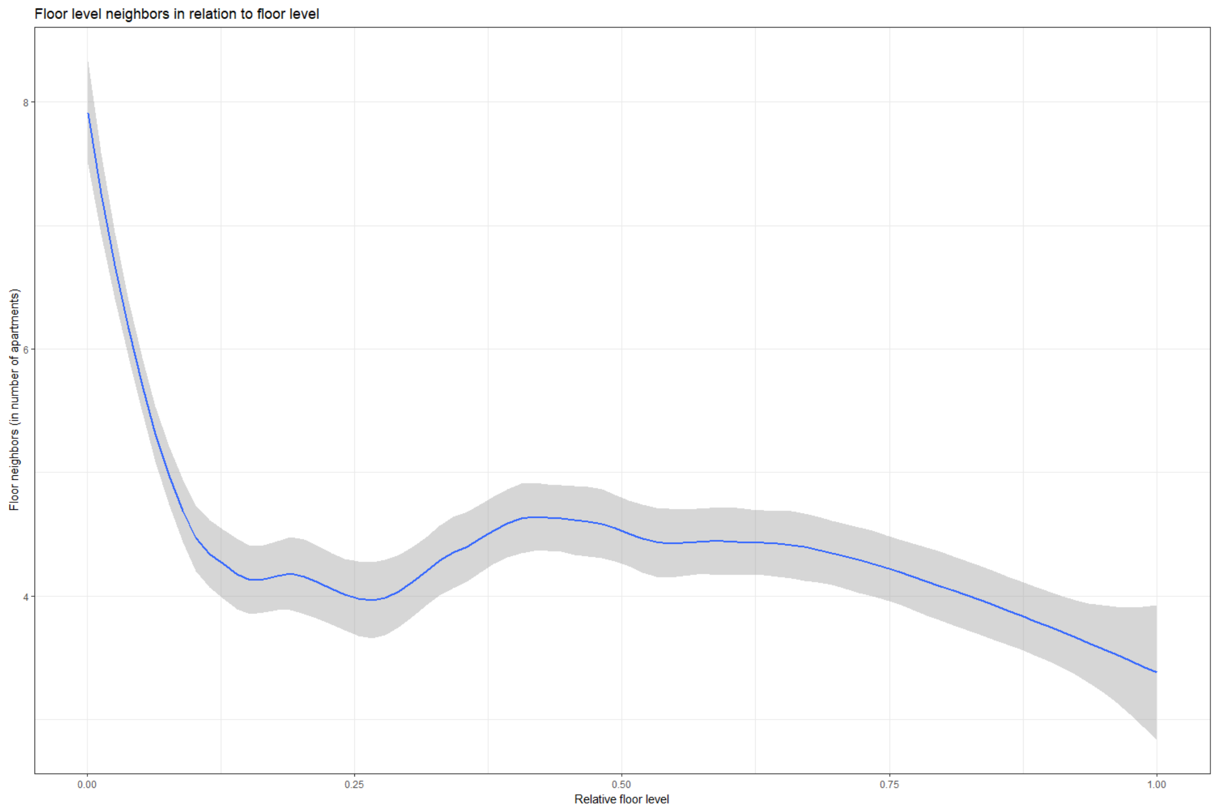


Figure 16. Number of neighbors in relation to floor levels. Blue = estimate, grey = 95% CI.

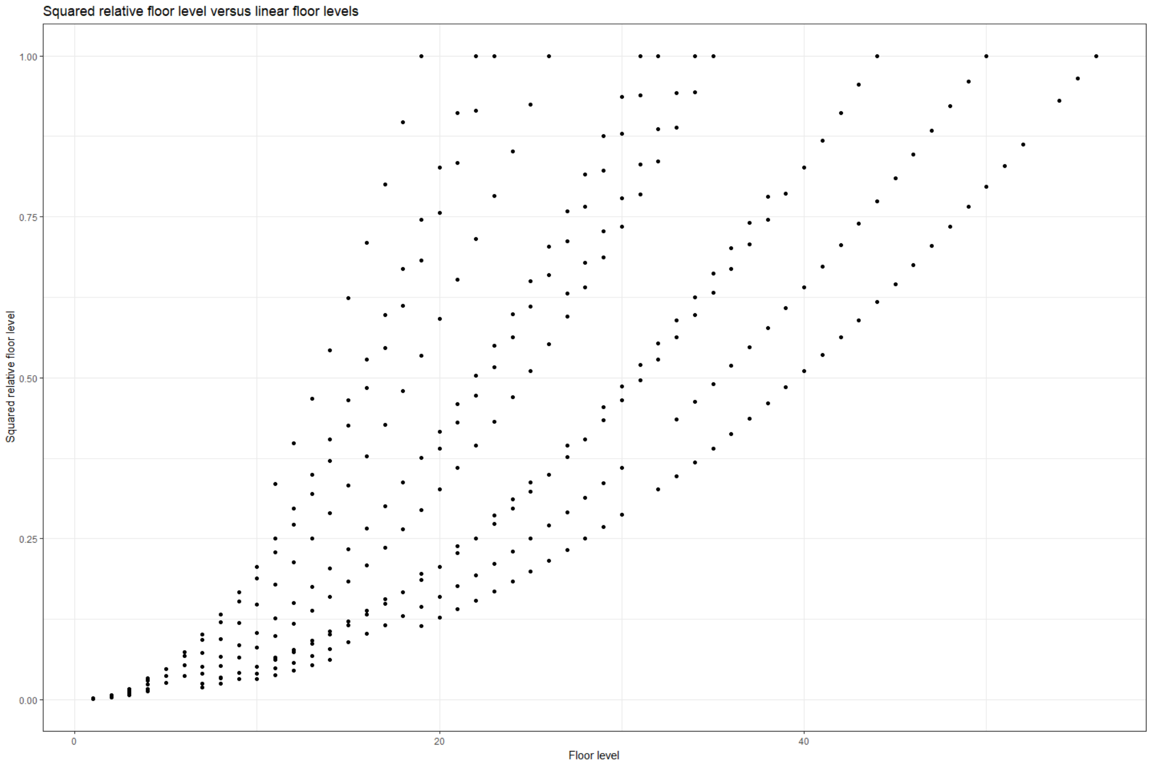


Figure 17. Floor levels in relation to squared relative floor level.

Figure 19 depicts the relation between floor levels and squared relative floor level. The squared function simulates the concept that apartments that are on a higher relative floor level obtain higher scores, which models the idea of being on top of others.

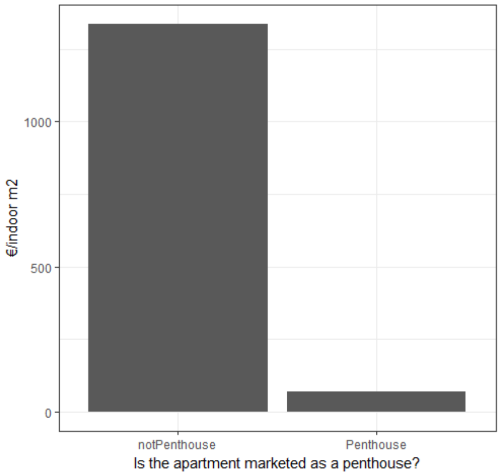


Figure 18. Distribution of Penthouse marketing dummy variables.

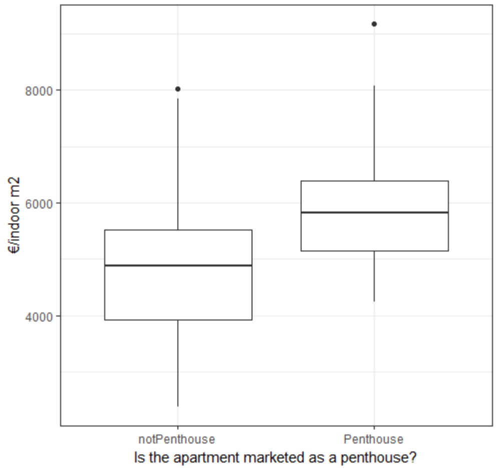


Figure 19. Boxplots of developer unit prices for penthouses and non-penthouses.

Figure 20 depicts the distribution of apartments that are and are not marketed as a penthouse. The total number of penthouses is the dataset amounts to 70. Figure 21 displays that developer unit prices for penthouses are higher than those for non-penthouses, which implies that this is an important variable to control for. The dots in figure 21 represent outliers.

Other control variables

Aside from variables that are linked to hypotheses, the models include many variables that are of influence on developer unit prices. Figure 22 displays an overview of when a number of apartments were put on the market for sale. Each column is accompanied by five numbers, with the first four representing the year of sale and the last number representing the quarter of the concerning year. Sale timing of each apartment is inherently linked to the tower each apartment is in. The regression models in this thesis include building fixed effects. Therefore, time fixed effects are already accounted for[3]. The takeaway from this figure is that there is not a continuous distribution of apartments over time in our dataset.

The dependent variable in the regression models is developer unit prices. The dependent variable is constructed using two pieces of data: total apartment price - minus parking place and kitchen costs - which is then divided by the indoor floor area of the apartment. Figure 23 provides the distribution of indoor floor meterage for the apartments in the employed dataset. Every column represents a bandwidth of 10m^2, with most of the apartments providing 75-85 m^2, 85-95 m^2 or 95-105m^2 indoor floor area. The largest residences provide over 700m^2 of indoor floor area.

Figure 20. Distribution of apartment price publication over time. Each bar represents a year (first four numbers) and a quarter (last number).

Figure 24 displays the number of apartments per cardinal orientation of living room. This distribution is well balanced, except for the '360 degrees' option, which is only applicable for a certain number of penthouses. Various apartments are designed with living rooms that are not bound to a single orientation but are oriented towards multiple cardinal direction. Furthermore, many apartments provide more than one living room (or reception room). For the analysis' sake, the orientation that the largest living room is oriented towards most centrally, is selected.

[3] With the exception of the CoolTower. The *Quarters to start construction* and *Quarters to delivery* control for possible price recalibration effects.

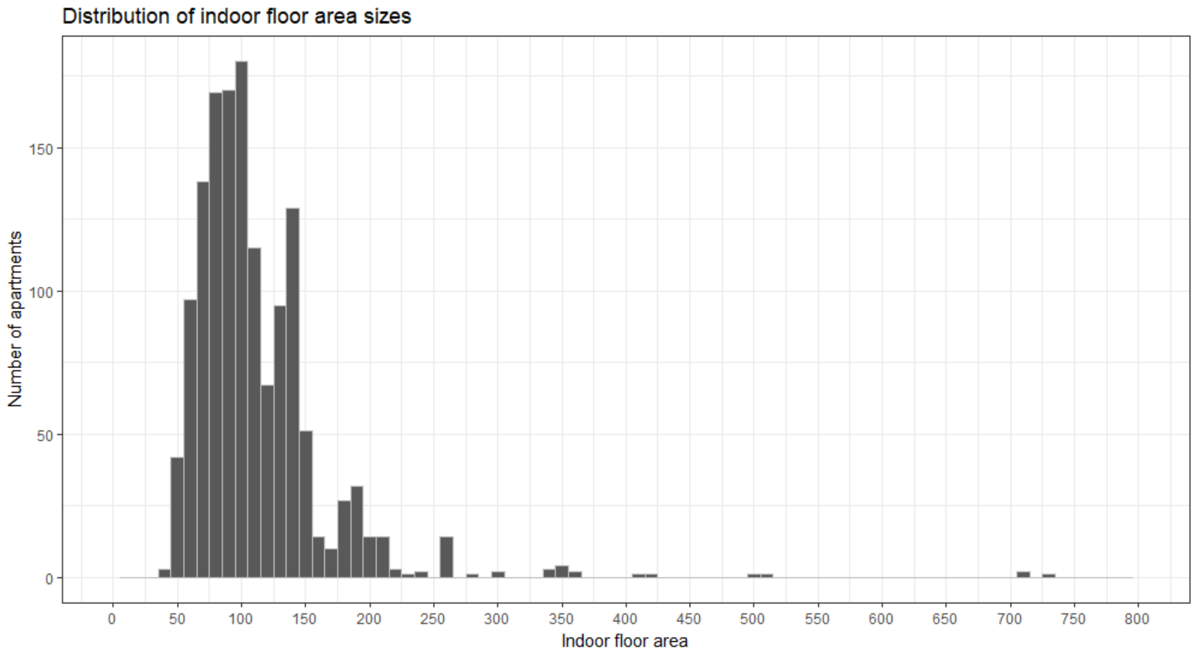


Figure 21. Distribution of indoor floor area. Each column represents a 10m² increase.

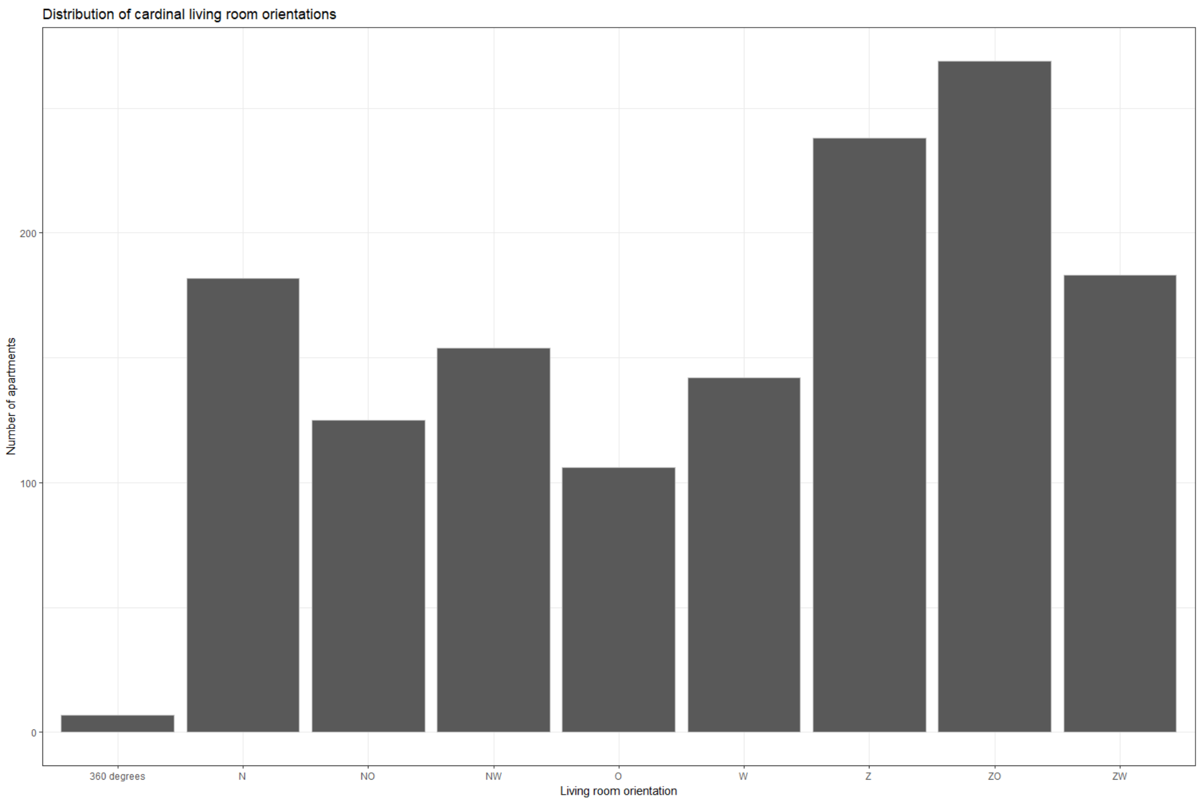


Figure 22. Distribution of living room orientations.

3.3.2. Research suitability and risks

The final dataset consists of a total number of 1406 apartments divided over fifteen towers. With a total number of 54 independent variables and one dependent variable, this leaves 26 observations per independent variable. Of these 54, 43 variables are dummy variables, divided over eight categories. As only a single dummy variable of each category is applicable per apartment, a total of 16 independent variables are of influence on each apartment's developer unit prices in the regression model. These combinations are adequate enough to start analyzing the data and to test the formulated hypotheses (Field, 2009).

Views are represented by the number of view features in the regression analysis. The data on these views does not provide information on view obstructions, on quality of the view features or other aspects. This thesis does not pretend that findings on the constructed view variables allow for any deeper inference on views than the number of view features that an apartment provides from its living room and its relation to height by including a floor level interaction term. Furthermore, while this thesis makes an effort to analyze the views based on the year of completion of the building, developers may have commanded premiums for view features that we do not account for due to missing information in Google Maps. Additionally, this thesis seizes the chance to analyze the premium developers command for a view on the Erasmus bridge, which may also have been different during the time of sale of the concerning apartments.

Perception of social power is split into three aspects that we test in this thesis: 'prestige', the extent to which a resident owns the entire floor and lastly the extent to which the resident is on top of others. Respectively, testing these concepts is done by analyzing the effect of three variables on developer unit prices: whether or not the apartment is marketed as a penthouse by the developer, floor levels times floor neighbors and lastly squared relative floor level. However, it remains questionable to what extent these variables actually represent the concept of status and perception of power, as the concept is rather abstract and difficult to quantify. The thesis does not claim to have exhausted all concepts that relate to perception of social power and further research is recommended to further explore the effect of concepts that relate to perception of social power on apartment prices, as becomes clear in section 4.1.3.

4. Empirical analysis

Chapter 4 provides an elaborate description of the quantitative empirical analysis of this thesis. Section 4.1. discusses regression model architecture, their internal dynamics and the regression model outcomes. Section 4.2. places the outcomes in a broader context.

4.1. Regression outcomes

The analysis considers real estate developer prices in the form of apartment prices divided by indoor floor area[4]. All models employ these unit prices as dependent variable data and fifteen different regression models are constructed to test various hypotheses. Every model includes a different combination of variables in order to test effects of different apartment characteristics. The model architecture is defined in table 6 below.

Table 6. Regression analysis architecture.

Model number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Floor level *(GFLPs)*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of views		Yes	Yes			Yes	Yes		Yes		Yes	Yes	Yes	Yes	Yes
Erasmus bridge view		Yes	Yes			Yes	Yes		Yes		Yes	Yes	Yes	Yes	Yes
Number of views * Floor level			Yes				Yes		Yes		Yes	Yes	Yes	Yes	Yes
Erasmus bridge view * Floor level			Yes				Yes		Yes		Yes	Yes	Yes	Yes	Yes
Penthouse				Yes	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes
Penthouse * Floor level *(PHFLPs)*					Yes		Yes			Yes	Yes	Yes	Yes	Yes	Yes
Building FE * Floor level *(TSFLPs)*								Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Neighbors * Floor level *(NFLPs)*												Yes	Yes	Yes	Yes
Building FE * Penthouse													Yes	Yes	Yes
Rel. floor level^2 (*GRFLPs*)														Yes	Yes
Building FE * Rel. floor level^2 *(TSRFLPs)*															Yes
Standard control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dataset	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full
Constant	8,237	8,279	8,252	8,253	8,256	8,294	8,270	8,279	8,292	8,294	8,309	8,371	8,345	8,339	8,323
Observations	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406	1.406
R^2	0,908	0,912	0,913	0,908	0,908	0,912	0,913	0,916	0,920	0,916	0,921	0,923	0,932	0,933	0,933
Adjusted R^2	0,905	0,909	0,910	0,905	0,905	0,909	0,910	0,912	0,917	0,913	0,917	0,919	0,929	0,930	0,929

Findings of preceding parts of this thesis indicate that developers are highly heterogenous and this is accounted for in the regression models by clustering standard errors at building level. Compared to trial models that do not account for heteroskedasticity by clustering standard errors, the explanatory effects of some variables significantly diminish. This strengthens the notion that pricing strategies differ per tower and developer. Unless otherwise specified, only effects that are significant at the 5% level are discussed.

Every model employs a set of standard control variables consisting of 9 continuous variables and 36 dummies divided over 5 categorical variables. The models report, among others, an intercept and a coefficient for the linear relation between each independent variable and the dependent variable. Numeric variables are continuous and simply add the value of their coefficient times the number of units that the variable represent for a certain apartment, e.g. the number of floor levels times the

[4] The term 'developer unit prices' is mainly used to refer to the dependent variable.

coefficient. Dummy variables are not engineered in the same fashion in the employed regression models, since these are not continuous. The characteristic of a dummy variable is either present, or not. However, one characteristic must always be present, e.g. an apartment is always located in one of the fifteen towers and, thus, must score positive for one of the dummy variables for one of the towers. The coefficient represents the difference between a variable being present (1) and the variable being absent (0). Where coefficients of numeric variables represent the increase in dependent variable value when increasing the concerning independent variable by one unit compared to one unit less, we cannot compare the increase of one unit of dummy variable to itself but one value lower as it is not continuous. Instead, the model compares the value of having a specific dummy variable instead of another. This requires a 'baseline' dummy. In the employed regression models, one dummy variable is not reported for each categorical variable. Instead, each baseline dummy is represented in the intercept value. Thus, the intercepts reported in table 7 represent a logarithmic value for developer unit prices of an apartment with the properties of all baseline dummies and a value of zero for all numeric variables. Table 2 in section 3.1.3. below provides an overview of the baseline dummies per categorical variable.

Table 7. Outcomes of regression models .

Regression model outcomes															
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
floorlv	0.0051***	0.0050***	0.0063***	0.0050***	0.0050***	0.0050***	0.0062***	0.0042***	0.0053***	0.0042***	0.0053***	0.0093***	0.0084***	0.0023	0.0061
	(0.0009)	(0.0009)	(0.0015)	(0.0008)	(0.0009)	(0.0008)	(0.0015)	(0.0005)	(0.0016)	(0.0005)	(0.0015)	(0.0028)	(0.0026)	(0.0039)	(0.0041)
factor(towername)Tower 10	0.1499***	0.1595***	0.1715***	0.1481***	0.1492***	0.1578***	0.1713***	0.0943***	0.1065***	0.0884**	0.1004***	0.1348***	0.1514***	0.1347***	0.1450***
	(0.0297)	(0.0307)	(0.0355)	(0.0293)	(0.0297)	(0.0302)	(0.0341)	(0.0343)	(0.0301)	(0.0359)	(0.0320)	(0.0388)	(0.0342)	(0.0336)	(0.0385)
factor(towername)Tower 11	0.1670***	0.1780***	0.1815***	0.1651***	0.1671***	0.1762***	0.1822***	-0.2075**	-0.1429	-0.2265**	-0.1619	0.0493	0.3004**	0.3656***	0.2302***
	(0.0552)	(0.0566)	(0.0598)	(0.0559)	(0.0566)	(0.0572)	(0.0605)	(0.0959)	(0.1088)	(0.1011)	(0.1097)	(0.1499)	(0.1229)	(0.1223)	(0.0690)
factor(towername)Tower 12	0.1439**	0.1333**	0.1142*	0.1460***	0.1460***	0.1352**	0.1163**	0.1033	0.0653	0.1016	0.0628	0.0765	0.1028*	0.1579***	0.1568***
	(0.0564)	(0.0577)	(0.0597)	(0.0557)	(0.0559)	(0.0570)	(0.0592)	(0.0737)	(0.0683)	(0.0800)	(0.0725)	(0.0860)	(0.0590)	(0.0570)	(0.0473)
factor(towername)Tower 13	0.2700***	0.2684***	0.2618***	0.2719***	0.2705***	0.2702***	0.2615***	0.2830***	0.2668***	0.2943***	0.2786***	0.3060***	0.2848***	0.2927***	0.3418***
	(0.0607)	(0.0573)	(0.0540)	(0.0609)	(0.0614)	(0.0576)	(0.0542)	(0.0543)	(0.0422)	(0.0505)	(0.0406)	(0.0638)	(0.0583)	(0.0533)	(0.0472)
factor(towername)Tower 14	0.3018***	0.2894***	0.2808***	0.3001***	0.3019***	0.2879***	0.2814***	0.3624***	0.3441***	0.3575***	0.3377***	0.3515***	0.3052***	0.3072***	0.3297***
	(0.0377)	(0.0413)	(0.0420)	(0.0385)	(0.0390)	(0.0421)	(0.0441)	(0.0532)	(0.0538)	(0.0573)	(0.0541)	(0.0537)	(0.0510)	(0.0481)	(0.0408)
factor(towername)Tower 15	0.3178***	0.3058***	0.2972***	0.3162***	0.3179***	0.3043***	0.2979***	0.3725***	0.3532***	0.3680***	0.3471***	0.3710***	0.3012***	0.2976***	0.3286***
	(0.0352)	(0.0389)	(0.0394)	(0.0359)	(0.0364)	(0.0396)	(0.0414)	(0.0496)	(0.0473)	(0.0547)	(0.0488)	(0.0599)	(0.0513)	(0.0480)	(0.0374)
factor(towername)Tower 2	-0.2480***	-0.2462***	-0.2697***	-0.2447***	-0.2452***	-0.2431***	-0.2668***	-0.4133***	-0.4259***	-0.3980***	-0.4105***	-0.3954***	-0.4166***	-0.4050***	-0.3081***
	(0.0688)	(0.0655)	(0.0688)	(0.0677)	(0.0666)	(0.0648)	(0.0658)	(0.0727)	(0.0668)	(0.0772)	(0.0715)	(0.0986)	(0.0836)	(0.0804)	(0.0845)
factor(towername)Tower 3	-0.7893***	-0.7665***	-0.8273***	-0.7814***	-0.7855***	-0.7591***	-0.8238***	-0.9720***	-0.9707***	-0.9359***	-0.9337***	-0.9385***	-1.0123***	-0.9622***	-0.7647***
	(0.2002)	(0.2068)	(0.2145)	(0.1992)	(0.1973)	(0.2068)	(0.2080)	(0.2487)	(0.2473)	(0.2676)	(0.2665)	(0.2777)	(0.2419)	(0.2346)	(0.2618)
factor(towername)Tower 4	0.4087***	0.4196***	0.4231***	0.4077***	0.4085***	0.4185***	0.4233***	0.4179***	0.4376***	0.4192***	0.4386***	0.4438***	0.4591***	0.4434***	0.4380***
	(0.0227)	(0.0191)	(0.0189)	(0.0228)	(0.0234)	(0.0188)	(0.0186)	(0.0312)	(0.0273)	(0.0323)	(0.0275)	(0.0363)	(0.0353)	(0.0355)	(0.0273)
factor(towername)Tower 5	0.2526***	0.2593***	0.2477***	0.2535***	0.2532***	0.2601***	0.2486***	0.2127***	0.2155***	0.2257***	0.2285***	0.2370**	0.2221***	0.2251***	0.3072***
	(0.0453)	(0.0417)	(0.0404)	(0.0453)	(0.0448)	(0.0418)	(0.0394)	(0.0755)	(0.0760)	(0.0787)	(0.0794)	(0.0951)	(0.0804)	(0.0773)	(0.0670)
factor(towername)Tower 6	-0.5789**	-0.5735**	-0.6451***	-0.5673**	-0.5709**	-0.5626**	-0.6372***	-0.7030**	-0.7418***	-0.6574**	-0.6967**	-0.6756**	-0.7525***	-0.7161***	-0.4978*
	(0.2343)	(0.2304)	(0.2411)	(0.2324)	(0.2294)	(0.2297)	(0.2331)	(0.2855)	(0.2626)	(0.3090)	(0.2873)	(0.3033)	(0.2476)	(0.2410)	(0.2835)
factor(towername)Tower 7	-0.3837**	-0.3656**	-0.4210**	-0.3701**	-0.3730**	-0.3530**	-0.4110**	-0.6245***	-0.6578***	-0.5928**	-0.6259***	-0.5663**	-0.6151***	-0.6015***	-0.4140*
	(0.1809)	(0.1750)	(0.1828)	(0.1808)	(0.1784)	(0.1766)	(0.1789)	(0.2368)	(0.2186)	(0.2542)	(0.2368)	(0.2604)	(0.2278)	(0.2180)	(0.2342)
factor(towername)Tower 8	-0.1926	-0.1549	-0.2396	-0.1816	-0.1867	-0.1445	-0.2336	-0.4941	-0.4698	-0.4416	-0.4158	-0.3683	-0.4918	-0.4793	-0.1744
	(0.2723)	(0.2819)	(0.2917)	(0.2715)	(0.2684)	(0.2823)	(0.2832)	(0.3498)	(0.3471)	(0.3839)	(0.3805)	(0.4096)	(0.3616)	(0.3555)	(0.3786)
factor(towername)Tower 9	0.2035***	0.2307***	0.2270***	0.2010***	0.2025***	0.2284***	0.2270***	0.2327***	0.2861***	0.2374***	0.2920***	0.3572***	0.3952***	0.4609***	0.3741***
	(0.0286)	(0.0317)	(0.0302)	(0.0279)	(0.0289)	(0.0307)	(0.0296)	(0.0443)	(0.0640)	(0.0474)	(0.0635)	(0.0760)	(0.0735)	(0.0717)	(0.0497)
factor(lrorientationfactor2)NO	-0.0224	-0.0333	-0.0257	-0.0213	-0.0214	-0.0324	-0.0252	-0.0308	-0.0343	-0.0304	-0.0340	-0.0350	-0.0350	-0.0355	-0.0338
	(0.0183)	(0.0227)	(0.0211)	(0.0183)	(0.0183)	(0.0230)	(0.0215)	(0.0189)	(0.0215)	(0.0188)	(0.0221)	(0.0225)	(0.0219)	(0.0218)	(0.0221)
factor(lrorientationfactor2)O	0.0265	0.0062	0.0132	0.0266	0.0262	0.0062	0.0122	0.0280	0.0139	0.0272	0.0125	0.0154	0.0133	0.0153	0.0159
	(0.0254)	(0.0233)	(0.0227)	(0.0252)	(0.0255)	(0.0230)	(0.0227)	(0.0235)	(0.0207)	(0.0237)	(0.0206)	(0.0194)	(0.0203)	(0.0206)	(0.0209)
factor(lrorientationfactor2)ZO	0.0114	-0.0118	-0.0094	0.0128	0.0121	-0.0104	-0.0094	0.0079	-0.0134	0.0077	-0.0138	-0.0099	-0.0151	-0.0134	-0.0137
	(0.0299)	(0.0249)	(0.0248)	(0.0301)	(0.0306)	(0.0252)	(0.0256)	(0.0309)	(0.0248)	(0.0310)	(0.0251)	(0.0239)	(0.0229)	(0.0231)	(0.0243)
factor(lrorientationfactor2)Z	0.0677*	0.0480	0.0501	0.0679*	0.0676*	0.0481	0.0498	0.0632	0.0456	0.0634	0.0458	0.0435	0.0342	0.0335	0.0350
	(0.0405)	(0.0332)	(0.0318)	(0.0404)	(0.0408)	(0.0331)	(0.0318)	(0.0422)	(0.0326)	(0.0425)	(0.0323)	(0.0322)	(0.0323)	(0.0321)	(0.0320)
factor(lrorientationfactor2)ZW	0.0360	0.0203	0.0256	0.0374	0.0373	0.0215	0.0261	0.0325	0.0231	0.0333	0.0236	0.0250	0.0232	0.0239	0.0227
	(0.0312)	(0.0260)	(0.0252)	(0.0312)	(0.0314)	(0.0259)	(0.0251)	(0.0298)	(0.0236)	(0.0297)	(0.0235)	(0.0232)	(0.0233)	(0.0238)	(0.0240)
factor(lrorientationfactor2)W	0.0686***	0.0568**	0.0600***	0.0695***	0.0690**	0.0575**	0.0600***	0.0652**	0.0573**	0.0652**	0.0573**	0.0591**	0.0560**	0.0564**	0.0562**
	(0.0265)	(0.0233)	(0.0221)	(0.0266)	(0.0270)	(0.0234)	(0.0224)	(0.0278)	(0.0231)	(0.0281)	(0.0233)	(0.0232)	(0.0239)	(0.0239)	(0.0234)
factor(lrorientationfactor2)NW	0.0021	0.0011	0.0034	0.0028	0.0024	0.0016	0.0036	0.0008	0.0026	0.0006	0.0026	-0.0006	-0.0077	-0.0064	-0.0057
	(0.0285)	(0.0246)	(0.0258)	(0.0284)	(0.0288)	(0.0247)	(0.0259)	(0.0291)	(0.0262)	(0.0293)	(0.0263)	(0.0254)	(0.0239)	(0.0241)	(0.0240)
factor(lrorientationfactor2)360 degrees	0.0333	0.0234	0.0252	0.0313	0.0256	0.0213	0.0166	0.0150	0.0024	0.0051	-0.0064	-0.0320	-0.0494	-0.0442	-0.0367
	(0.0539)	(0.0592)	(0.0572)	(0.0527)	(0.0573)	(0.0582)	(0.0610)	(0.0580)	(0.0630)	(0.0602)	(0.0648)	(0.0630)	(0.0488)	(0.0491)	(0.0479)
log(areaint)	-0.0702**	-0.0851**	-0.0852**	-0.0729**	-0.0739**	-0.0876**	-0.0890**	-0.0782**	-0.0913**	-0.0823**	-0.0962**	-0.1002**	-0.0964**	-0.0921**	-0.0965**
	(0.0342)	(0.0393)	(0.0391)	(0.0370)	(0.0361)	(0.0421)	(0.0414)	(0.0340)	(0.0409)	(0.0358)	(0.0431)	(0.0423)	(0.0399)	(0.0391)	(0.0384)
log(areaext + 1)	0.0146	0.0149	0.0143	0.0139	0.0140	0.0143	0.0138	0.0162	0.0156	0.0156	0.0149	0.0116	0.0119	0.0129	0.0128
	(0.0125)	(0.0135)	(0.0139)	(0.0128)	(0.0128)	(0.0138)	(0.0143)	(0.0128)	(0.0141)	(0.0131)	(0.0144)	(0.0130)	(0.0143)	(0.0142)	(0.0145)
quarterstostart	-0.0385***	-0.0378***	-0.0422***	-0.0379***	-0.0382***	-0.0372***	-0.0419***	-0.0478***	-0.0502***	-0.0453**	-0.0477***	-0.0473***	-0.0519***	-0.0503***	-0.0380**
	(0.0131)	(0.0132)	(0.0139)	(0.0130)	(0.0129)	(0.0132)	(0.0135)	(0.0169)	(0.0158)	(0.0184)	(0.0173)	(0.0173)	(0.0149)	(0.0145)	(0.0166)
nrooms	0.0114	0.0124	0.0123	0.0089	0.0100	0.0101	0.0118	0.0152	0.0141	0.0149	0.0140	0.0188	0.0264*	0.0262*	0.0242
	(0.0149)	(0.0149)	(0.0149)	(0.0152)	(0.0137)	(0.0154)	(0.0139)	(0.0141)	(0.0143)	(0.0133)	(0.0140)	(0.0143)	(0.0150)	(0.0139)	(0.0149)
nbathrooms	0.0879***	0.0884***	0.0902***	0.0844***	0.0844***	0.0852***	0.0872***	0.0831***	0.0848***	0.0806***	0.0821***	0.0738***	0.0663***	0.0647***	0.0669***
	(0.0226)	(0.0238)	(0.0238)	(0.0202)	(0.0202)	(0.0211)	(0.0212)	(0.0219)	(0.0233)	(0.0199)	(0.0210)	(0.0225)	(0.0204)	(0.0202)	(0.0202)
ntoilets	0.0138	0.0123	0.0132	0.0140	0.0134	0.0124	0.0125	0.0202*	0.0178*	0.0189	0.0163	0.0133	0.0042	0.0032	0.0022
	(0.0117)	(0.0097)	(0.0101)	(0.0116)	(0.0126)	(0.0096)	(0.0110)	(0.0109)	(0.0101)	(0.0119)	(0.0108)	(0.0104)	(0.0132)	(0.0134)	(0.0134)
nbedrooms	0.0105	0.0142	0.0152	0.0128	0.0123	0.0163	0.0162	0.0118	0.0186	0.0130	0.0196	0.0150	0.0171	0.0159	0.0186
	(0.0200)	(0.0210)	(0.0210)	(0.0215)	(0.0206)	(0.0226)	(0.0218)	(0.0206)	(0.0218)	(0.0214)	(0.0227)	(0.0208)	(0.0152)	(0.0142)	(0.0152)
factor(typeextfactor2)balcony	-0.0017	-0.0084	-0.0127	-0.0035	-0.0048	-0.0100	-0.0149	-0.0058	-0.0164	-0.0083	-0.0187	-0.0366	0.0857	0.0932	0.0896
	(0.0836)	(0.0826)	(0.0809)	(0.0834)	(0.0782)	(0.0830)	(0.0766)	(0.0958)	(0.0927)	(0.0884)	(0.0861)	(0.0836)	(0.0864)	(0.0851)	(0.0871)
factor(typeextfactor2)balcorner	-0.0758	-0.0846	-0.0906	-0.0770	-0.0773	-0.0856	-0.0907	-0.0814	-0.0935	-0.0818	-0.0932	-0.1228	-0.0103	0.0013	-0.0066
	(0.0933)	(0.0928)	(0.0884)	(0.0930)	(0.0881)	(0.0931)	(0.0846)	(0.0991)	(0.0942)	(0.0915)	(0.0879)	(0.0881)	(0.0915)	(0.0907)	(0.0909)
factor(typeextfactor2)loggia	-0.0103	-0.0268	-0.0317	-0.0119	-0.0127	-0.0281	-0.0328	-0.0063	-0.0267	-0.0081	-0.0281	-0.0474	0.0836	0.0931	0.0826
	(0.0910)	(0.0925)	(0.0914)	(0.0911)	(0.0862)	(0.0929)	(0.0871)	(0.1036)	(0.1023)	(0.0960)	(0.0953)	(0.0942)	(0.0999)	(0.0980)	(0.1008)
factor(typeextfactor2)sunspace	0.0556	0.0451	0.0449	0.0486	0.0489	0.0388	0.0403	0.0825	0.0764	0.0806	0.0747	0.0561	0.1777*	0.1873*	0.1857*
	(0.0910)	(0.0901)	(0.0880)	(0.0920)	(0.0889)	(0.0917)	(0.0869)	(0.0969)	(0.0945)	(0.0920)	(0.0897)	(0.0900)	(0.1064)	(0.1041)	(0.1060)
factor(typeextfactor2)terrace	-0.0156	-0.0230	-0.0246	-0.0172	-0.0171	-0.0244	-0.0244	-0.0157	-0.0229	-0.0151	-0.0216	-0.0479	0.0851	0.0929	0.0864
	(0.1063)	(0.1051)	(0.1019)	(0.1060)	(0.1025)	(0.1053)	(0.0989)	(0.1113)	(0.1072)	(0.1045)	(0.1010)	(0.0980)	(0.1116)	(0.1089)	(0.1097)
factor(numberextfactor2)1ext	0.0754	0.0741	0.0796	0.0808	0.0818	0.0791	0.0846	0.0756	0.0792	0.0807	0.0839	0.1187*	-0.0112	-0.0168	-0.0129
	(0.0769)	(0.0755)	(0.0745)	(0.0757)	(0.0700)	(0.0749)	(0.0678)	(0.0824)	(0.0795)	(0.0708)	(0.0686)	(0.0715)	(0.0764)	(0.0751)	(0.0768)
factor(numberextfactor2)2ext	0.0834	0.0814	0.0872	0.0906	0.0921	0.0881	0.0946	0.0713	0.0733	0.0791	0.0810	0.1142	-0.0284	-0.0351	-0.0288
	(0.0838)	(0.0835)	(0.0825)	(0.0813)	(0.0741)	(0.0815)	(0.0727)	(0.0925)	(0.0902)	(0.0771)	(0.0750)	(0.0724)	(0.0675)	(0.0668)	(0.0685)
factor(numberviewsfactor2)2		0.0423**	0.0726*			0.0424**	0.0726*		0.0651		0.0656	0.0674	0.0648	0.0652	0.0655
		(0.0207)	(0.0434)			(0.0207)	(0.0432)		(0.0523)		(0.0526)	(0.0496)	(0.0518)	(0.0504)	(0.0488)
factor(numberviewsfactor2)3+		0.0464*	0.0659			0.0466*	0.0685		0.0502		0.0543	0.0616	0.0548	0.0545	0.0565
		(0.0242)	(0.0459)			(0.0242)	(0.0448)		(0.0458)		(0.0476)	(0.0454)	(0.0457)	(0.0448)	(0.0425)
factor(erasmusbrugfactor)Yes		0.0220	0.0434			0.0218	0.0457*		0.0488**		0.0506**	0.0441*	0.0449**	0.0482**	0.0454**
		(0.0169)	(0.0267)			(0.0166)	(0.0268)		(0.0240)		(0.0243)	(0.0236)	(0.0218)	(0.0226)	(0.0229)
floorlv:factor(numberviewsfactor2)2			-0.0016				-0.0015		-0.0012		-0.0012	-0.0013	-0.0012	-0.0012	-0.0012
			(0.0014)				(0.0014)		(0.0017)		(0.0017)	(0.0016)	(0.0017)	(0.0016)	(0.0016)
floorlv:factor(numberviewsfactor2)3+			-0.0011				-0.0012		-0.0005		-0.0006	-0.0009	-0.0007	-0.0007	-0.0008
			(0.0013)				(0.0013)		(0.0014)		(0.0014)	(0.0013)	(0.0013)	(0.0013)	(0.0012)
floorlv:factor(erasmusbrugfactor)Yes			-0.0006				-0.0007		-0.0007		-0.0008	-0.0006	-0.0007	-0.0008	-0.0006
			(0.0008)				(0.0008)		(0.0008)		(0.0008)	(0.0008)	(0.0007)	(0.0007)	(0.0008)
factor(marketedpenthousefactor)Penthouse				0.0169	-0.0163	0.0156	-0.0319			-0.0456	-0.0521	0.0252	-0.1994**	-0.2052**	-0.1897**
				(0.0299)	(0.0875)	(0.0302)	(0.0848)			(0.0770)	(0.0750)	(0.0700)	(0.0855)	(0.0863)	(0.0849)
floorneighbors												0.0081	0.0066	0.0036	0.0059
												(0.0069)	(0.0059)	(0.0056)	(0.0056)
'relative floor height2'														0.1525*	0.0576
														(0.0848)	(0.0889)
floorlv:factor(marketedpenthousefactor)Penthouse					0.0010		0.0014			0.0018	0.0020	-0.0015	0.0087***	0.0083***	0.0082***
					(0.0021)		(0.0019)			(0.0018)	(0.0016)	(0.0019)	(0.0021)	(0.0021)	(0.0020)
floorlv:factor(towername)Tower 10								0.0074***	0.0080***	0.0075***	0.0081***	0.0068**	0.0065***	0.0056**	
								(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0027)	(0.0024)	(0.0023)	
floorlv:factor(towername)Tower 11								0.0142***	0.0123***	0.0146***	0.0127***	0.0052	-0.0023	-0.0042	

									(0.0034)	(0.0041)	(0.0033)	(0.0040)	(0.0059)	(0.0050)	(0.0049)
floorlv:factor(towername)Tower 12									0.0024	0.0032*	0.0031*	0.0039**	0.0041	0.0018	-0.0049
									(0.0016)	(0.0018)	(0.0018)	(0.0019)	(0.0030)	(0.0017)	(0.0043)
floorlv:factor(towername)Tower 13									0.0002	0.0002	-0.0002	-0.0002	0.0003	0.0019	0.0042**
									(0.0006)	(0.0007)	(0.0006)	(0.0008)	(0.0019)	(0.0016)	(0.0017)
floorlv:factor(towername)Tower 14									-0.0036**	-0.0038***	-0.0031	-0.0032*	-0.0032	0.0008	-0.0012
									(0.0015)	(0.0015)	(0.0019)	(0.0017)	(0.0022)	(0.0019)	(0.0019)
floorlv:factor(towername)Tower 15									-0.0033**	-0.0034***	-0.0028	-0.0028*	-0.0033	0.0025	0.0008
									(0.0013)	(0.0012)	(0.0019)	(0.0016)	(0.0029)	(0.0024)	(0.0023)
floorlv:factor(towername)Tower 2									0.0081***	0.0080***	0.0080***	0.0079***	0.0087***	0.0100***	0.0076***
									(0.0009)	(0.0010)	(0.0010)	(0.0010)	(0.0018)	(0.0015)	(0.0023)
floorlv:factor(towername)Tower 3									0.0032***	0.0017	0.0032***	0.0016	0.0047***	0.0059***	0.0021
									(0.0005)	(0.0012)	(0.0006)	(0.0012)	(0.0018)	(0.0015)	(0.0027)
floorlv:factor(towername)Tower 4									-0.0004	-0.0008	-0.0005	-0.0008	-0.0013	-0.0022	-0.0009
									(0.0013)	(0.0015)	(0.0013)	(0.0014)	(0.0015)	(0.0015)	(0.0018)
floorlv:factor(towername)Tower 5									0.0016	0.0013	0.0013	0.0010	0.0020	0.0033*	0.0054**
									(0.0013)	(0.0017)	(0.0014)	(0.0017)	(0.0027)	(0.0019)	(0.0021)
floorlv:factor(towername)Tower 6									-0.0005	-0.0009	-0.0006	-0.0009	0.0001	0.0012	0.0025*
									(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0018)	(0.0015)	(0.0015)
floorlv:factor(towername)Tower 7									0.0049***	0.0051***	0.0049***	0.0052***	0.0029	0.0037*	0.0055**
									(0.0009)	(0.0007)	(0.0009)	(0.0008)	(0.0025)	(0.0021)	(0.0022)
floorlv:factor(towername)Tower 8									0.0082***	0.0047*	0.0081***	0.0046*	0.0017	0.0039	0.0040
									(0.0009)	(0.0024)	(0.0010)	(0.0027)	(0.0032)	(0.0033)	(0.0032)
floorlv:factor(towername)Tower 9									-0.0002	-0.0015	-0.0005	-0.0018	-0.0016	-0.0015	-0.0041**
									(0.0014)	(0.0019)	(0.0015)	(0.0019)	(0.0018)	(0.0017)	(0.0019)
floorlv:floorneighbors												-0.0010***	-0.0011***	-0.0010***	-0.0010***
												(0.0004)	(0.0004)	(0.0004)	(0.0004)
factor(towername)Tower 10:factor(marketedpenthousefactor)Penthouse													0.1562**	0.1446**	0.1299**
													(0.0642)	(0.0592)	(0.0592)
factor(towername)Tower 11:factor(marketedpenthousefactor)Penthouse													0.0654	0.0845	0.0725
													(0.0819)	(0.0827)	(0.0797)
factor(towername)Tower 12:factor(marketedpenthousefactor)Penthouse													0.0507	0.0438	0.0505
													(0.1144)	(0.1092)	(0.1137)
factor(towername)Tower 13:factor(marketedpenthousefactor)Penthouse													-0.4256***	-0.4053***	-0.4081***
													(0.0523)	(0.0563)	(0.0565)
factor(towername)Tower 14:factor(marketedpenthousefactor)Penthouse													-0.1237**	-0.1356***	-0.1130**
													(0.0513)	(0.0484)	(0.0535)
factor(towername)Tower 15:factor(marketedpenthousefactor)Penthouse													-0.1668***	-0.1798***	-0.1647***
													(0.0594)	(0.0569)	(0.0624)
factor(towername)Tower 4:factor(marketedpenthousefactor)Penthouse													0.0122	0.0117	-0.0050
													(0.0243)	(0.0242)	(0.0263)
factor(towername)Tower 5:factor(marketedpenthousefactor)Penthouse													-0.3768***	-0.3643***	-0.3563***
													(0.0703)	(0.0694)	(0.0782)
factor(towername)Tower 6:factor(marketedpenthousefactor)Penthouse													-0.2098***	-0.1939***	-0.1948***
													(0.0455)	(0.0497)	(0.0485)
factor(towername)Tower 8:factor(marketedpenthousefactor)Penthouse													-0.0933***	-0.1034***	-0.1042***
													(0.0359)	(0.0336)	(0.0369)
factor(towername)Tower 9:factor(marketedpenthousefactor)Penthouse													-0.0777	-0.0605	-0.0680
													(0.0552)	(0.0585)	(0.0561)
factor(towername)Tower 10:`relative floor height2`															0.1343**
															(0.0553)
factor(towername)Tower 11:`relative floor height2`															-0.0331
															(0.0947)
factor(towername)Tower 12:`relative floor height2`															-0.0127
															(0.0570)
factor(towername)Tower 13:`relative floor height2`															0.1096
															(0.0757)
factor(towername)Tower 14:`relative floor height2`															-0.0276
															(0.0401)
factor(towername)Tower 15:`relative floor height2`															0.0171
															(0.0506)
factor(towername)Tower 2:`relative floor height2`															0.1862***
															(0.0440)
factor(towername)Tower 3:`relative floor height2`															0.0673
															(0.0503)
factor(towername)Tower 4:`relative floor height2`															-0.0192
															(0.0619)
factor(towername)Tower 5:`relative floor height2`															0.1238
															(0.0820)
factor(towername)Tower 6:`relative floor height2`															0.0524
															(0.0439)
factor(towername)Tower 7:`relative floor height2`															0.1858**
															(0.0813)
factor(towername)Tower 8:`relative floor height2`															0.0811
															(0.0772)
factor(towername)Tower 9:`relative floor height2`															-0.0441
															(0.0339)
Constant	8.2369***	8.2789***	8.2517***	8.2534***	8.2560***	8.2941***	8.2697***	8.2794***	8.2916***	8.2943***	8.3091***	8.2726***	8.2674***	8.2962***	8.2679***
	(0.1408)	(0.1520)	(0.1614)	(0.1571)	(0.1548)	(0.1669)	(0.1757)	(0.1387)	(0.1693)	(0.1524)	(0.1823)	(0.1931)	(0.1813)	(0.1837)	(0.1829)
Note:															*p<0.1; **p<0.05; ***p<0.01

Regression model outcomes

TRUE

4.1.1. Floor levels premiums

This thesis researches the effects of an apartments' floor level on developer unit prices. This section considers the strength of this relation in different regression model configurations as specified in table 6.

General floor level premiums (GFLPs) are consistently significant at the $p<0.01$ level for model 1 through 13. Model 1 displays a 0.51% increase in developer unit prices per when locating one floor level higher, *ceteris paribus*. Controlling for views marginally decreases the strength of the relation to 0.50% increase in developer unit prices per floor level, as shown in model 2. However, this thesis hypothesizes that the quality of views is positively influenced by height. Consequently, model 3 tests if the effect size of views on developer unit prices depends on the floor level by including interaction terms between views and floor levels. The model reports negative values for these interaction terms, though insignificant. Simultaneously, the value of the GFLP increases 0.50% to 0.63% per floor level. The role of views in floor level premium compositions is further discussed in section 4.1.2.

Model 4 reports a GFLP of 0.50% when controlling for penthouse effects. The decrease from 0.51% to 0.50% (compared to model 1) is of a small magnitude. Interpretation of this magnitude is provided in section 4.1.3. This thesis considers the penthouse effect as a representation of prestige, which in turn is a partial representation of status. Model 5 investigates if developers further increase unit prices if a penthouse is located higher – which may be considered as extra prestigious (imagine a penthouse on the 50th floor versus a penthouse on the 22nd floor, all else equal). This is done by including an interaction term between the penthouse variable and floor level variable. No further change in the GFLP on developer unit prices is distinguishable when including this interaction term.

Controlling for view effects (model 2) and penthouse effects (model 4) only slightly decreases GFLP magnitude. Model 6 includes control variables for both effects simultaneously and reports a comparable decrease from 0.51% to 0.50%. Model 7 adds floor level interaction terms for both effects and reports an increase of GFLP magnitude to 0.62%. Similar to model 3, interaction terms between views and floor levels assume a negative sign – though still insignificant. Since all other control variables are reported to have only marginal impact on GFLP, this thesis attributes the increase in GFLP magnitude in this regression model to the interaction terms between views and floor levels. The resemblance in magnitude growth between model 3 and 7 further corroborates this statement.

Figure 25 displays the nonlinear regression lines of the means of developer unit prices regressed on floor levels for each tower in the employed dataset[5]. The figure shows that there are severe differences in unit price developments over floor levels, both inter-building and intra-building. The inter-building differences are considered a representation of developer heterogeneity in applying floor premiums during apartment price formation. This means that a *general* floor level premium may not accurately reflect floor level premiums for all towers in the employed dataset. In order to analyze the differences in floor level premiums between different towers, regression model 8 through 15 include an interaction term between building-fixed effects and floor levels. The addition of this interaction term results in a decrease in magnitude of the GFLP effect from 0.51% to 0.42% in model 8. When obtaining regression coefficients at the 5% or better significance level for the interaction terms, the towers' floor level premiums are considered to significantly deviate from the GFLP. This is the case for multiple observed towers and in some cases compensate the decrease in magnitude of the GFLP – but in some cases display a negative sign, resulting in even lower floor level premiums.

[5] Only regressed on floor levels, no other effects are controlled for in figure 25 and 26.

These tower-specific floor level premiums (TSFLPs) are discussed in more detail at the end of this section.

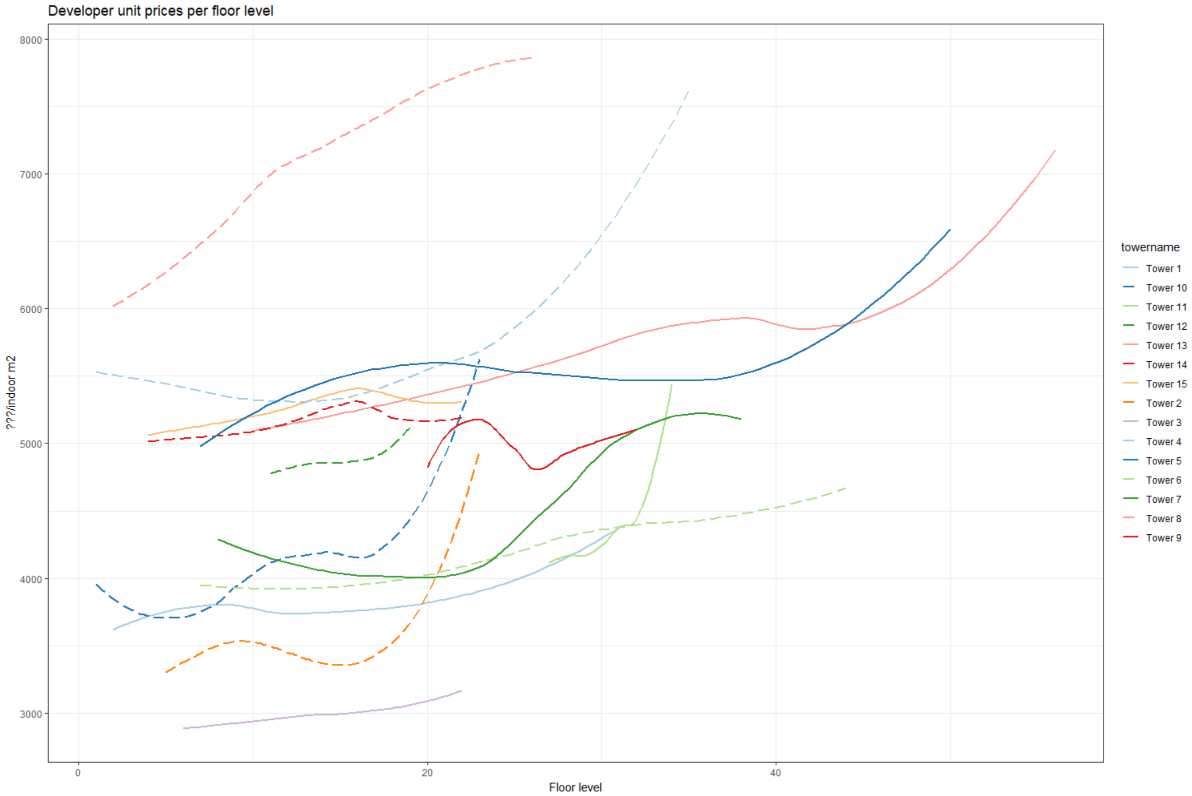


Figure 23. Developer unit prices in relation to floor levels (without controlling for other effects).

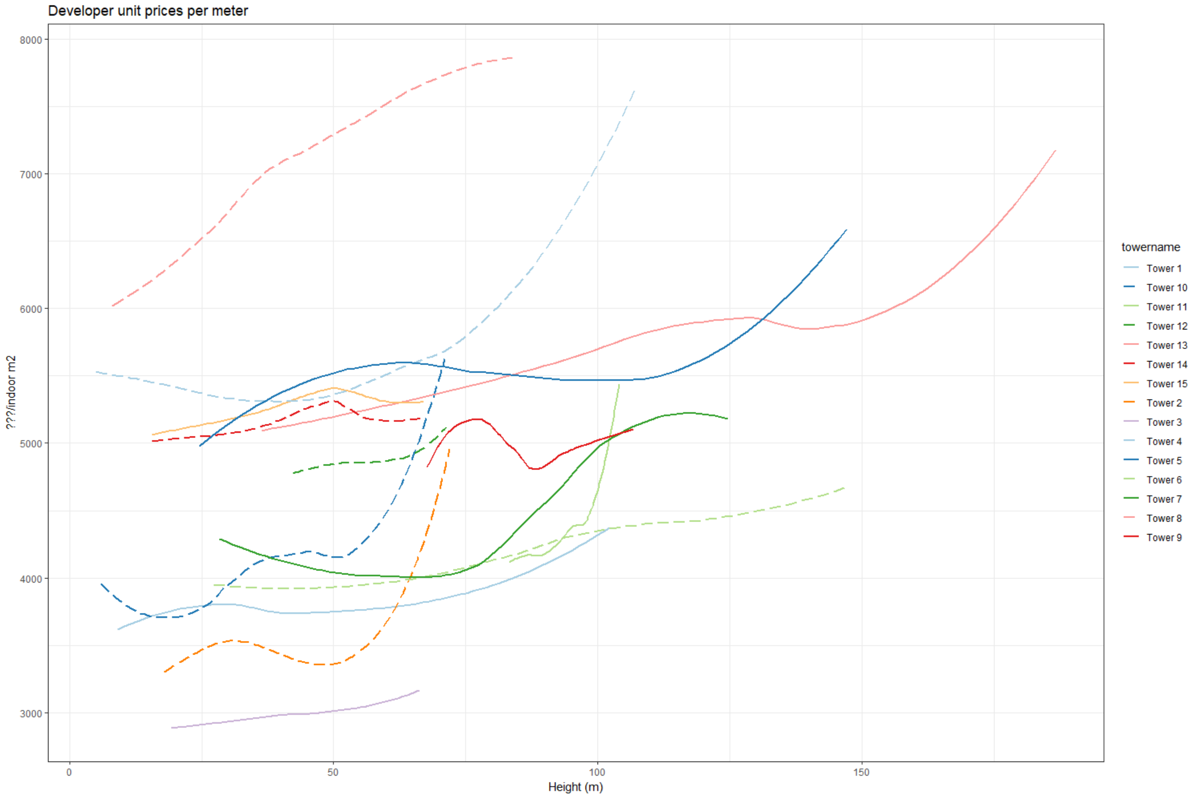


Figure 24. Developer unit prices in relation to absolute height (without controlling for other effects).

Model 9 adds control variables for views and interaction variables between views and floor levels on top of the control variables employed in model 8. Similar to model 3 and 7, the addition of interaction variables between views and floor levels results in a quarters growth of the GFLP magnitude, increasing it from 0.42% to 0.53%. The interaction terms themselves display negative signs, as was the case for model 3 and 7.

Model 10 tests the effects of including the penthouse control variable and floor level interaction term. GFLP magnitude remains unchanged at 0.42% and only marginal impact on TSFLPs is observed. Model 11 employs control variables for both view effects as well as penthouse effects and their interaction terms with the floor level variable. The impact on GFLP is comparable to model 9, as the impact on developer unit prices also increases from 0.42% to 0.53%. Changes in TSFLPs are also comparable to model 9, indicating that the impact of penthouse effects is negligible compared to the effects of views. The repeatedly small impact of employing a control variable and floor level interaction variable for penthouse effects is discussed in section 4.1.3 and investigated in more detail from model 13 onwards.

One of the aspects that is deemed a representation of status is the extent to which a resident has to share the concerning floor with neighbors. Model 12 includes an interaction term for number of floor neighbors times floor level. The addition of this interaction term results in an increase of the GFLP from 0.53% to 0.58% (compared to model 11). The impact on TSFLPs is substantial, displaying both negative and positive effects of different sizes on the regression estimates. The discrepant effect of this variable is interpreted as a sign that it enables more detailed approximation of the floor level premiums.

The significant deviation in effects per tower suggests that developers behave heterogenous when it comes to putting a price on benefits that accompany height. Heterogeneity in pricing behavior especially forms a problem when trying to estimate the value of apartment characteristics that are not homogenous over the different towers. One characteristics that fits this description in and excellent manner is the variable for whether or not an apartment is marketed as a penthouse. The reason for this is a qualitative one. Penthouses are often highly unique residences, varying significantly in their characteristics. This thesis does not pretend to have defined when an apartment is or is not a penthouse, but simply considers whether or not the developer has marketed the concerning apartment as a penthouse. Due to heterogenous developer behavior, some developers may apply a lower threshold to put the title of penthouse on an apartment than others and some may even use the title of penthouse as a marketing strategy. As a result, 'Marketed as penthouse' observations in our dataset may differ significantly in their characteristics. However, considering penthouse effects per tower (and, thus, per developer) instead of over the entire dataset provides regression estimates for groups of observations that are less heterogenous. Model 13 through 15 include interaction terms between building-fixed effects and the penthouse variable. In contrast to non-tower specific penthouse variables, an effect on the GFLP can be observed, decreasing the regression estimate from 0.58% to 0.55%. The penthouse effects are further discussed in section 4.1.3.

The intra-building differences in regression line slopes displayed in figure 25 and 26 imply that the floor level premiums may not be linear. It is not unreasonable to argue that going from floor level 25 to floor level 26 is accompanied by a different floor level premium in a 50-story building that in a 26-story building. This would imply that floor premiums may be dependent on relative floor height, rather than absolute floor height, and reflects the value of the concept of '*being on top of others'*. In figure 25 and 26, nearly all observed towers display a sharper unit price increase on their highest floors, suggesting that developers assign larger floor level premiums to the highest floors. This may partially be attributed to penthouse effects, though the figures display convex movements for multiple floors on the highest levels and a pure penthouse effect would display a sharper movement in the regression lines. This notion is reinforced by the prior findings that indicate that height premiums are non-monotonic and convex (Coulson et al., 2018; Danton & Himbert, 2018). Figure 27 displays the coefficients resulting from model 2 for each floor level apart (compared to floor level 02). The figure clearly displays peculiarities that challenge the linearity of floor level premiums at several specific floor levels. This suggests that there are specific building heights that residential tall buildings in Rotterdam adhere to, which are distinguishable in figure 25: ~23 floors, ~33-34 floors and ~44 floors. Floor level heights differ per tower, but in reality this means that the total buildings heights amount to approximately the same height in meters. This is more clearly illustrated in figure 26, where a graph similar to figure 24 employs absolute height in meters instead of floor levels as a variable for the x-axis. The graph shows that Tower 2, Tower 3, Tower 10, Tower 12, Tower 14 and Tower 15 do not exceed the 70 meter barrier. Tower 1, Tower 4, Tower 9 and Tower 11 do not exceed the 100 meter barrier. Tower 6 and Tower 5 are capped at 150 meters. Tower 7 is also capped at 150 meters, but this is not reflected clearly in figure 25 nor figure 26 because no data on the top level apartments/penthouses was acquired. Only two towers do not adhere to the height barriers of 70, 100 and 150 meters: Tower 8 (88 meter) and Tower 13 (215 meter). These barriers are placed in a broader context in section 4.2. The peculiarities in figure 27 occur at the same heights that are discussed above: floor level 23 (70m), floor level 34 (100m), floor level 44, 46, 50 (150m). The fact that the peculiarities occur at the top levels corroborates the idea that top levels command greater premiums.

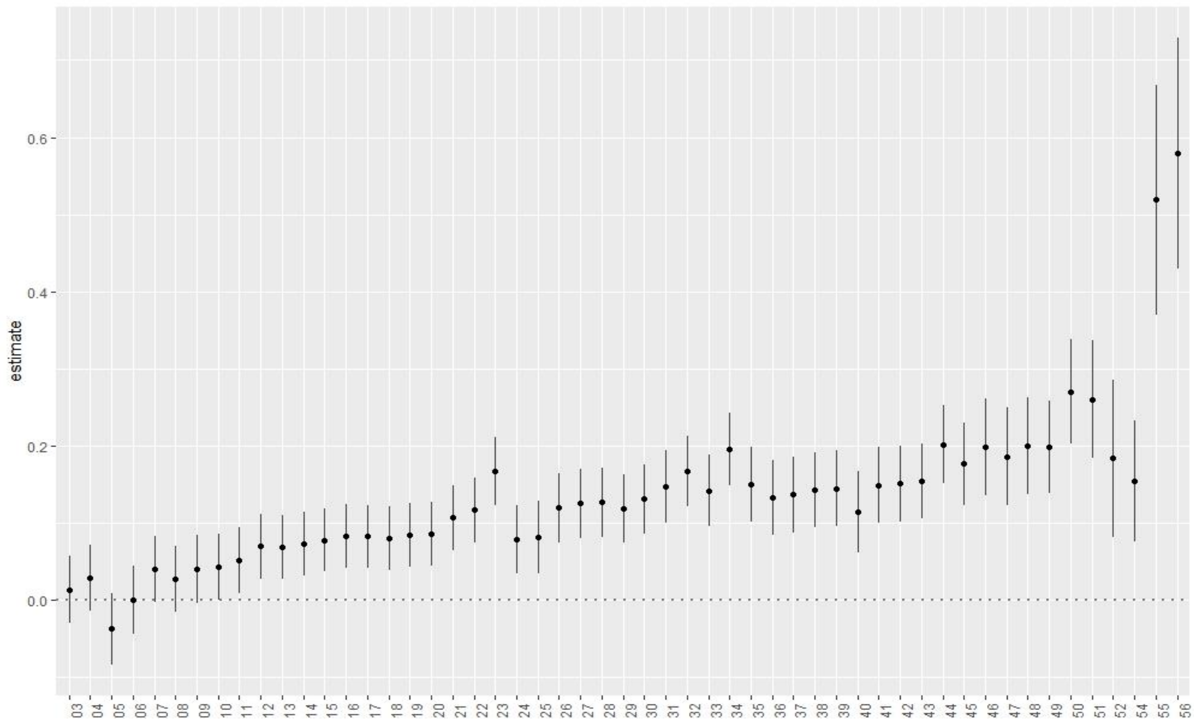


Figure 25. Regression estimates (dots) per floor level and 95% confidence intervals for the estimates (lines). Baseline = floor level 02.

This thesis hypothesizes that developers exploit homebuyers' willingness to pay for status in the form of *being on top of others* by assigning an increasingly larger floor level premium for apartments located on higher floors, resulting in a convex relation between developer unit prices and floor levels, *ceteris paribus*. Regression model 14 models this concept by including a squared relative floor level variable, which is created by transforming the floor level variable. The significance of the GFLP is eliminated after adding the squared relative floor level variable, which is attributed to the fact that both variables represent the same concept (floor level), but assign a different distribution of scores to the apartments. The squared relative floor level variable obtains a regression estimate of 0.1764 at the 5% significance level. In other words, the developer assigns a 17,64% unit price premium to an apartment on the highest floor compared to an apartment on ground floor level, *ceteris paribus*. The interpretation of this effect is presented in section 4.1.3. Furthermore, significant changes in TSFLPs are observable and displayed in table 6 and 7.

Similar to linear floor level premiums, different developers may differently price their higher apartments. Model 15 removes TSFLPs and adds an interaction term between squared relative floor level and building-fixed effects (TSRLFPs). The GFLP estimate remains insignificant. Interpretation of regression estimates for the squared relative floor level premiums is presented in section 4.1.3.

Regression estimates are of a lower magnitude than those of other studies where transaction prices were employed as dependent variable data in their hedonic pricing analysis. One unit increase in floor level was found to impact transaction prices by 2.2% in San Diego (Conroy, Narwold, & Sandy, 2013). A study on developers' supply functions in Singapore found a wide spectrum of floor level related premiums, ranging from -0,9% to 15,5% depending on time and place (Coulson et al., 2018). This strengthens the need to consider floor level premiums on a building level, as in the employed dataset apartments' 'time and place' is linked to the tower they are located in. Danton and Himbert (2018) report a 2% increase in unit rent levels after controlling for different factors and conclude that the floor level premiums are influenced by building height, view features and location. This thesis accounts for these effects by interacting the floor level variable with the tower dummy variables in all models and also by interacting the floor level variable with view variables. These interaction variables return statistical significance at the 5% level for several towers and indicate deviation from the general floor level premium for several others. This is interpreted as additional evidence for heterogeneity in developer behavior regarding the use of floor levels in apartment price formation. The difference in general floor level premiums compared to these studies is attributed to contextual differences.

The result of this heterogeneity is a wide range of floor level premiums, influenced by different determinants. An overview of the floor level premiums applicable for each regression model per observed tower is available in table 8. The table is divided in various sections, denominated by the vertical titles on the left side of the table. The top of the table presents the control variables that are employed in each model. The GFLPs section displays the general floor level premiums per model. The TSFLPs section displays additional premiums, which are displayed if the tower-specific floor level premiums deviate from the GFLP at the 5% or sharper significance level. If present, then these premiums should be added to the GFLP coefficients. The *significant determinants* section displays additional premiums resulting from determinants that significantly impact the floor level premiums, selected at the 5% or sharper significance level. No coefficients are reported for height-induced view effects since these variables were not reported to be statistically significant at the 5% level. Significant additional premiums were found using interactions terms for penthouse and floor levels as well as number of floor level neighbors (in number of apartments) and floor levels. Note that the floor level premium for penthouses (PHFLP) is only applicable if the concerning apartment was marketed as a penthouse. The interaction term between number of neighbors and floor levels should be multiplied by the number of neighboring floor level apartments that is applicable for the concerning apartment's floor level. The GRFLPs section displays coefficients for the general relative floor level premiums. Note that the coefficient is significant at the 5% level for model 14, but not for model 15 – (clustered standard errors are depicted in brackets). An exception is made, and the coefficient is included in the overview for reference sake. The bottom section displays the tower-specific relative floor level premiums, which are also only displayed if significant at the 5% or better significance level.

$$FLP_{apt} = flv_{apt} * (\beta_{GFLP} + \beta_{TSFLP} + \beta_{PHFLP} * (1 \vee 0) + \beta_{NFLP} * N_{flv} + \frac{flv_{apt}}{(flv_{max})^2} * (\beta_{GRFLP} + \beta_{TSRFLP}))$$

FLP_{apt} = floor level premium of the concerning apartment
flv_{apt} = floor level of the concerning apartment
β = coefficient reported by the regression models.
GFLP = general floor level premium
TSFLP = tower-specific floor level premium
PHFLP = penthouse floor level premium
NFLP = number of neighbors floor level premium
N_{flv} = number of neighboring apartments on the concerning floor level
flv_{max} = highest floor level of the concerning tower
GRFPL = general relative floor level premium
TSRFLP = tower-specific relative floor level premium

The coefficients reported in table 8 can be used to estimate floor level premiums (FLPs) for each apartment. By entering the coefficients found in a model in the equation above, the floor level premium (FLP) for a specific apartment can be estimated. Table 6 reports that model 14 is most effective in estimating developer unit prices, yielding an adjusted R^2 of 0.930. However, this does not mean that it is also most effective in estimating each apartments specific floor level premium – and, thus, does not enable the selection of a single best model for estimating floor level premiums. The table shows that different towers vary significantly from the GFLPs and GRFLPs, indicating that FLPs for apartments in one tower may be more accurately estimated using model X and FLPs for apartments in another tower are more accurately estimated using a different model. This corroborates the theory that developers are heterogenous in determining their floor level premiums.

I argue that different models are more suitable to estimate premiums based on different determinants. Supplementary example: an apartment located on the top floors of a tower is likely to be more accurately estimated using the architecture of regression model 14. Model 15's architecture enables an even more accurate approximation of top-level apartments in towers that significantly deviate from the GRFLP. One of the main takeaways for this thesis is that the floor level premium is composed of different determinants and one should very carefully consider the quality of height-related characteristics of an apartment when applying floor premiums during price formation. Note that in the equation, the inclusion of interaction terms increases the amount of noise in the formula and diminishes the pureness of the FLP since the interaction terms partially include the value of other characteristics of an apartment (e.g. penthouse effect).

Table 8. Floor level coefficients per model and tower.

	Regression model numbers	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Control overview	Standard control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	View control variables	-	Yes	Yes	-	-	Yes	Yes	-	Yes	-	Yes	Yes	Yes	Yes	Yes
	View * floor level IV	-	-	Yes	-	-	-	Yes	-	Yes	-	Yes	Yes	Yes	Yes	Yes
	Penthouse control var.	-	-	-	Yes	Yes	Yes	Yes	-	-	Yes	Yes	Yes	Yes	Yes	Yes
	Penthouse * floor level IV	-	-	-	-	Yes	-	Yes	-	-	Yes	Yes	Yes	Yes	Yes	Yes
	Building FE * floor level IV	-	-	-	-	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
	Neighbors * floor level IV	-	-	-	-	-	-	-	-	-	-	-	Yes	Yes	Yes	Yes
	Building FE * Penthouse IV	-	-	-	-	-	-	-	-	-	-	-	-	Yes	Yes	Yes
	Relative floor level^2	-	-	-	-	-	-	-	-	-	-	-	-	-	Yes	Yes
	Building FE * relative floor level^2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Yes
GFLPs	Floor level *(GFLP)*	*0.51%*	*0.50%*	*0.63%*	*0.50%*	*0.50%*	*0.50%*	*0.62%*	*0.42%*	*0.53%*	*0.42%*	*0.53%*	*0.58%*	*0.55%*	-	-
TSFLPs (add to GFLPs)	Tower 2	-	-	-	-	-	-	-	0.81%	0.80%	0.80%	0.79%	1.04%	1.14%	0.79%	-
	Tower 3	-	-	-	-	-	-	-	0.32%	-	0.32%	-	0.59%	0.69%	-	-
	Tower 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 5	-	-	-	-	-	-	-	-	-	-	-	-	0.48%	0.65%	-
	Tower 6	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33%	-
	Tower 7	-	-	-	-	-	-	-	0.49%	0.51%	0.49%	0.52%	0.52%	0.57%	0.67%	-
	Tower 8	-	-	-	-	-	-	-	0.82%	-	0.81%	-	-	0.67%	0.54%	-
	Tower 9	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.40%	-
	Tower 10	-	-	-	-	-	-	-	0.74%	0.80%	0.75%	0.81%	0.93%	0.86%	0.65%	-
	Tower 11	-	-	-	-	-	-	-	1.42%	1.23%	1.46%	1.27%	-	-	-	-
	Tower 12	-	-	-	-	-	-	-	-	-	-	-	0.62%	0.35%	-	-
	Tower 13	-	-	-	-	-	-	-	-	-	-	-	-	0.34%	0.53%	-
	Tower 14	-	-	-	-	-	-	-	-0.36%	0.38%	-	-	-	-	-	-
	Tower 15	-	-	-	-	-	-	-	-0.33%	0.34%	-	-	-	0.45%	-	-
Sign. Dets.	Views * floor level IVs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Penthouse * floor level IV *(PHFLP)*	-	-	-	-	-	-	-	-	-	-	-	-	*0.95%*	*0.86%*	*0.87%*
	Neighbors * floor level IV *(NFLP)*	-	-	-	-	-	-	-	-	-	-	-	*-0.07%*	*-0.08%*	*-0.08%*	*-0.07%*
GRFLPs	Relative floor level^2 *(GRFLP)*	-	-	-	-	-	-	-	-	-	-	-	-	-	*17.64% (8.65%)*	*6.99% (9.9%)*
TSRFLPs	Tower 2: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*19.85%*
	Tower 3: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 4: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 5: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*16.18%*
	Tower 6: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 7: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*24.65%*
	Tower 8: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*13.20%*
	Tower 9: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 10: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*16.25%*
	Tower 11: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 12: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 13: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*16.28%*
	Tower 14: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tower 15: \`relative floor height2\`	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

4.1.2. View effects

Two categorical variables in the context of view and height are included. The first concerns the number of view features provided by an apartment. Model 2 includes these variables and reports that developers command a unit premium of 4.23% for having two view features instead of one. An increase of 4.64% for having three or more view features instead of one is reported as well, but this regression estimate does not meet the 5% significance level. Controlling for penthouse effects in model 6 and 7 seems to have only a marginal effect on the magnitude of the number of view feature variables and interaction terms. Model 9 controls for tower-specific floor level effects, which results in a decrease in premium magnitude from 7.26% to 6.51% for two view features and a decrease from 6.59% to 5.02% for three view features. Note that the estimates in model 9 are no longer significant at the 5% level. Further models add additional variables which only seem to have a marginal impact on both magnitude as well as significance on the number of view features control variable.

The second categorical variable in the context of view and height is whether or not one of the view features of an apartment is a view on the Erasmus bridge, a local icon. Model 2 is the first to include this variable and returns an insignificant regression estimate of 2.20% (clustered SE 1.69%). Adding interaction terms between views and floor levels increases the estimate to 4.34%, but the estimate remains insignificant. Controlling for penthouse effects slightly increases the significance to meet the 10% significance level and further increases the magnitude to 4.57%. When adding interaction terms for tower-specific floor level effects, the regression estimate increases to 4.88% and raises its significance to the 5% level. The estimated developer unit price increase remains stable at ~5% at retains its significance when adding additional control variables in model 11 through 15.

As reported in section 4.1.1., the magnitude of the GFLP increases with ~25% when adding interaction terms between views and floor levels. Combined with the outcomes reported above, this is interpreted as corroborative evidence for the hypothesis that height-induced views offered by an apartment impact the magnitude of floor level premiums set by developers. However, the interaction terms do not return any significant findings on the size of the impact on floor level premiums. This is mainly attributed to the quality of data used in the regression analysis. As Benson et al. (1998); Rodriguez and Sirmans (1994) already indicated, more details are required to determine the properties of each apartments' view. Only then can estimations be made on the role of the view properties in floor level premium composition and apartment price formation. Prior studies address views as a key determinant in height premiums (Nase et al. (2018) for Amsterdam offices) and was also used to substantiate height premiums in other studies (e.g. Liu et al. (2018), Koster et al. (2013)). This thesis contributes to this subtopic within urban economics by considering developers' point of view within the residential sector. Further research into developers' perception of height premiums is advised, where more detailed specification of variables and data for view aspects should play a central role in order to attempt to quantify the effects of these variables.

4.1.3. Perception of social power

This thesis models the effects of perception of social power by the stepwise addition of different variables over multiple regression models. Three concepts are defined to represent perception of social power: firstly, the level of prestige, secondly the extent to which a resident shares the floor with neighbors and thirdly the extent to which a resident's apartment is located on top of others – also interpretable as the extent to which no others are located above the resident's. For each concept, a variable is constructed to enable the quantification of these concepts that represent perception of social power. For the three concepts these variables are, respectively, whether or not the developer has marketed the apartment as a penthouse, the number of floor level neighbors (measured in number of apartments) and lastly, squared relative floor level – which is constructed by dividing the concerning floor level by the total number of floors and squaring the outcome. This section dissects the regression outcomes of these variables and presents this thesis' interpretation of the results.

Model 4 adds a control variable for whether or not an apartment is marketed as a penthouse. As reported in section 4.1.1., the impact on the magnitude of the floor level effect is marginal. The magnitude of the penthouse effect is reported at 1.69% and as highly insignificant with its clustered standard error reaching 2.99%. This thesis theorizes that the level of prestige gained from a penthouse is impacted by its vertical location. The corresponding hypothesis would be that the size of the penthouse effect on developer unit prices depends on the value of the floor level variable. Therefore, model 5 adds an interaction term between the penthouse variable and the floor level variable. The model reports a value of 0.1% for this interaction term, accompanied by a clustered standard error of 0.21% - rendering the interaction term insignificant. The general floor level premium is reported as unaffected by the addition of the interaction term and the penthouse effect changes from 1.69% to -1.63%, but the clustered standard error substantially increases to 8.75%, thus also making this term insignificant. This is interpreted as evidence for the notion that developers' behavior varies significantly when it comes to penthouse pricing strategies.

These results are not surprising, because penthouses are often highly unique residences and vary significantly in their characteristics. This thesis does not pretend to have defined when an apartment is or is not a penthouse, but simply considers whether or not the developer has marketed the concerning apartment as a penthouse. Due to heterogenous developer behavior, some developers may apply a lower threshold to put the title of penthouse on an apartment than others and some may even use the title of penthouse as a marketing strategy. As a result, 'Marketed as penthouse' observations in our dataset may differ significantly in their characteristics. However, considering penthouse effects per tower (and, thus, per developer) instead of over the entire dataset provides regression estimates for groups of observations that are less heterogenous. Model 13 through 15 include interaction terms between building-fixed effects and the penthouse variable. In contrast to non-tower specific penthouse variables, an effect on the GFLP can be observed, decreasing the regression estimate from 0.58% to 0.55%. Furthermore, the penthouse variable as well as the floor level interaction variable become highly significant after the addition of this interaction term. The models report an initial penthouse penalty on developer unit prices of ~20%, which are compensated by an additional 0.95%, 0.86% and 0.87% developer unit price increase per floor level. The outcome is then further adjusted according to the tower-specific penthouse premiums, some of which display significant deviation from the general penthouse effect. Those that do not acquire significant coefficients for tower-specific penthouse premiums are adequately estimated using the general penthouse premium and the floor level penthouse premium. This corroborates the theory that not only penthouses are highly heterogenous, but developers' behavior when it comes to pricing these objects as well. The regression outcomes suggest that these objects should be considered on a building level when trying to estimate its impact on developer unit prices.

Figure 18 in section 3.3.1. displays that, on average, the number of neighboring apartments per floor level decreases on greater vertical locations in residential tall buildings. This thesis hypothesizes that the effect size of the number of neighbors depends on the apartments' vertical location and introduces an interaction term between floor level and number of neighboring apartments on the concerning floor. The variable for floor level interacted with the number of floor neighbors is highly significant ($p<0.01$) and largely consistent throughout all models, ranging from -0.07% to -0.08% times the number of neighbors for each floor level. This may seem small, but with a mean number of neighbors of 4.6, this coefficient reduces the floor level premiums by 0.32% up to 0.37%. Obviously, this effect is further strengthened, *ceteris paribus*, for apartments that are located higher in towers. The penalty origination from this variable is partially compensated by an increased GFLP and in some cases by increased TSFLPs. However, as figure 18 shows, the number of neighbors decreases on higher floor levels. This variable is, therefore, a worthy addition to the hedonic pricing model as it battles the linearity of the estimated coefficient of floor level and accurately reflects floor level premiums related to the number of neighbors. This thesis considers the number of neighbors as a representation of the extent to which a resident '*has the entire floor for him-/herself'* – which in turn is regarded as an important part of perception of social power. Thus, this thesis partially models the effect of the perception of social power through this variable. The effect on the GFLP is noticeable and significant, which is deemed as evidence for the hypothesis that the number of floor neighbors in relation to height plays a role in the composition of floor level premiums. However, the effect of *the extent to which a resident has the entire floor to him-/herself* on willingness to pay - and indirectly impacting developer unit prices as developers exploit homebuyers' willingness to pay - is a quite subjective topic and more research should be conducted in order to broaden the body of knowledge on this subject.

The next part of perception of social power that this thesis attempts to simulate is whether the resident is *'on top of others'*. The squared relative floor level variable is employed to model this effect in model 14 and 15. The variable absorbs most of the general floor level variable's predictive power, rendering it highly insignificant while achieving high significance for itself ($p<0.05$). Therefore, it can be inferred that the squared relative floor level variable is a strong variable in explaining the floor level premium. However, this comes as no surprise because the data for this variable is constructed by transforming the floor level data. The finding is in contrast with the study of Wong et al. (2011), who found that relative floor levels in Hong Kong residential buildings were not significant. I attribute this to contextual differences and a difference in heterogeneity of data, as the other study compared towers part of a single large urban development program, while this thesis compares towers that together form a more heterogenous dataset.

The estimated coefficient is reported as 0.1764 in model 14. This means that when an apartment is located on the top floor, it is assigned a 17.64% developer unit price premium compared to an apartment on the ground floor. The variable assigns scores to apartments based on their floor level, but in a nonlinear fashion that results in higher apartments obtaining relatively high scores. This is graphically depicted in figure 19 in section 3.3.1.

Similar to linear floor level effects on developer unit prices, squared relative floor level premiums may differ significantly per developer and tower. This theory is tested by the introduction of tower-specific relative floor level effects (TSRFLPs) in model 15, while removing tower-specific linear floor level effects in order to decomplicate the interpretation of the regression model output. The addition of this interaction variable has a considerable impact on the general relative floor level effect. Its magnitude is reduced to 6.99% and its clustered standard error is increased to 9.9%, thus substantially diminishing the accuracy of the reported coefficient.

Several towers display significant deviation from the GRFLP when adding TSRFLPs in model 15. The main takeaway from these outcomes is that those TSRFLPs that deviate sizably correspond to towers that are icons and break records for residential tall building heights in Rotterdam or the concerning Rotterdam neighborhood when they are completed, consistent with the implications of Koster et al. (2013)[6]. The concerning height record-breaking buildings are all constructed in boom times, which is consistent with the findings of Barr (2012). This thesis theorizes that from a certain floor level, the apartments in these towers provide the unique characteristic of living in an apartment located on a greater vertical location than apartments in other towers in the city or neighborhood. It can be inferred that the sizable deviation from the GRFLP displayed by these towers is a result of developers placing larger floor level premiums on apartments that possess this unique characteristic of being located higher than apartments in any other tower in the area. Floor level premiums in relation to height of surroundings and inter-building social power competition are out of the scope of this thesis and should be investigated in future research as they potentially play an important role in floor level premiums composition.

4.1.4. Other control variables

Table 2 in section 3.1.3. provides an overview of all control variables included in the analysis. Every model includes the same basic set of control variables and their outcomes are displayed in table 7. The first observation is that building fixed effects are significant and of substantial magnitude. This comes as no surprise since a high degree of apartment characteristics are stored in these variables e.g. architectural value, location value, building amenities, time related values, et cetera. These differences are easily distinguishable in figure 25 and 26. Coefficients for building-fixed effects are mostly consistent throughout the models, though the addition of tower-specific floor level effects seems to decrease most building-fixed effects estimates to some extent.

The variable for number of yearly quarters until construction start is significant and ranges from -3.59% to -5.23%, growing in magnitude when adding variables. As reported before, this variable is created using the dates that are reported on apartment lists and brochures. Validity of some of the

[6] An exception is Tower 2, which is partially rental and partially owner-occupied. The owner-occupied apartments are located on floor 5 through 8 and floor 17 through 23. Floors 9 through 16 only host rental apartments. The gap in data for these floors levels creates a peculiarity in the regression estimates, as the models pick up a sharp increase on the higher levels and, I theorize, attribute this to the tower-specific relative floor level premium.

reported dates is unproven and this creates a problem for interpreting the outcomes on this variable. However, the variable is still included in the models because it picks up effects from price recalibration for different apartments in Tower 5, where apartments were placed on the market in two phases. More research is advised in order the determine the effect of this variable.

Log-transformed variables for indoor and outdoor surface area are included in all models. Estimated elasticities between indoor surface area and developer unit prices are consistently significant at the 5% level and range from -0.0702 in model 1 to -0.0970 in model 15, generally displaying a decrease as more variables are added to the regression models. No significant results are obtained by any model for outdoor surface area. Further research is required to discover if the effect size of outdoor surface area is dependent on its qualities e.g. orientation (exposure to sun) or type of outdoor space.

Orientation dummy variables indicate that developers raise unit prices of apartments with living rooms oriented to the west by 5.55% 6.95% compared to apartments with living rooms oriented to the north. This magnitude shrinks as more variables are added to the regression models. There is also weak evidence that the south orientation is also more highly valued by developers than the northern orientation.

The group of variables for numbers of different types of rooms provide significant results for bathrooms only, which are highly significant at the 1% level and range from 6.88% to 8.79%. A slight decrease in effect magnitude is a consequence of adding more variables to the model. There is also some weak evidence that developers raise unit prices of apartments when increasing the number of toilets in the concerning apartments. The lack of significance is attributed to the clustered standard errors. Overall, regression outcomes for these variables indicate that adding rooms causes developers to increase apartment prices, with the extent to which prices are raised depending on the development.

Business cycle dummy variables are excluded from the regression analyses by the employed software. This is attributed to their multicollinearity with tower dummy variables.

One would expect that developers would increase apartment prices when adding more outdoor spaces to an apartment. However, not a single model provides any significant evidence for this being the case. When looking past significance, the lack of which is attributed to the clustering of standard errors, there is some weak evidence that having one external space instead of none has a positive effect on developer unit prices. This is in line with the findings in the thesis of den Dekker (2009), who found that a personal outside space was considered a must-have for many homebuyers in Rotterdam, preferably a loggia and otherwise a balcony. Having multiple outside spaces, however, only adds a marginal premium on top of the premium commanded for a single outside space. The nonlinear premium is explained using the law of diminishing marginal utilities: having a single outside space instead of none provides new residential possibilities, while the added value of having multiple outside spaces instead of one is marginal when applying the same perspective.

4.2. Floor level premiums in the context of costs

Understanding the value of apartment characteristics is crucial in pricing strategies as it enables developers to set prices that enable profit maximization whilst being able to sell apartments at a satisfactory speed. Apartments are designed for certain target groups and this means that pricing is also an interpretation of what these groups are willing to pay for certain products that accompany an apartment. In this thesis’ regression analysis, 54 different independent variables are considered and corresponding coefficients for how developers price these products in their developments are provided. The models consistently acquire adjusted-R^2s of over 0.9, a result in which building-fixed effects play an important role[7]. However, no claim is made that all aspects that influence prices are captured in the models. Nevertheless, novel insights on developers' vertical price premium behavior result from this research. These products are the general floor level effects, role of views, and different aspects that contribute to the perception of social power: floor level times number of neighbors *('the extent to which the resident has to share the floor level with others'),* squared relative floor level *('the extent to which the resident is on top of others')* and penthouse effects *('the prestige of living in a penthouse', which represents a certain uniqueness).* Additionally, outcomes for tower-specific real floor level premiums suggest that inter-building status competition leads to additional premiums, as the highest floors of height record-breaking buildings offer the unique characteristics of living taller than any other resident in the concerning area.

On average, the analysis finds general floor level premiums of 0.5%, but shows that some developers significantly deviate from this premium magnitude. This is attributed to their interpretation of buyer willingness to pay for aspects related to height. In any case, it is evident that developers raise unit prices of apartments with greater vertical location. van Oss (2007) concludes that marginal building costs per floor increase when adding floor levels, which amounts to 0.8% for certain typology office buildings pre-2008. While this thesis cannot use these numbers for the mainly post-2008 residential towers in our dataset, it is necessary acknowledge that construction costs per floor increase when adding floor levels since the cost driving mechanisms are also applicable for the tall buildings in our dataset. One could argue that the floor level premiums developers set for apartments should negate any floor level related costs premiums, because otherwise the development's business case would not favor adding floor levels. The overall 0.5% premium that is found in this thesis does not weigh up against the 0.8% indication from van Oss (2007). While it is unclear if the 0.8% cost premium per floor is applicable for the buildings included in our dataset, it may the case that 0.5% premiums in developer unit prices per floor is not enough to obtain profit for adding extra floors. The research of Ahlfeldt and McMillen (2018) add to the urgency to place the developers' apartment floor level premiums is the larger context of costs, as they found that the cost of height is greater for residential tall buildings than for commercial tall buildings. One issue at hand is that if marginal costs per floor are larger than marginal revenues per floor, then marginal profits per floor are negative and tall building developments cannot be justified from a financial perspective. The following part of this thesis provides an explanation that rationalizes the development of residential tall buildings in an economic sense.

This thesis argues that marginal costs per floor and floor level premiums play different roles in the development process and apartment pricing process. Total building costs, overhead costs, financing costs, risk and profit, etcetera, together make up for the costs section of the development's business case. Developers monitor the costs side of the development by considering the costs/m^2 and total costs. As the development progresses, more product certainty is achieved, and this enables the specification of more accurate, project-specific costs/m^2. Actual construction costs are at some point agreed upon with the construction company, based on detailed building plans. It remains so that the developer keeps monitoring and acting on all this information. With clear knowledge on total development costs/m^2 - if applicable including land costs paid to the municipality - the developer is tasked with realizing a financially healthy business case. On the revenue side of the business case, it is important to realize that the developer does not sell single m^2 units, but apartments. As is evident from the performed regression analyses, apartments are priced according to their characteristics. This thesis proves that floor level is an apartment characteristic that plays a role in apartment price formation, as developers exploit homebuyers' willingness to pay for benefits of height. These

[7] Removing building-fixed effects from the regression models decreases the adjusted R^2 to 0.7

dynamics are depicted in figure 28. As the figure shows, construction costs do not directly impact apartment prices. While the developer is tasked to set apartment prices to create a healthy business case - based on construction costs and other development costs - premiums for certain apartment characteristics are driven by homebuyers' willingness-to-pay. This supply and demand interaction for an apartment and its characteristics is leading in floor level premium formation. Ultimately, homebuyers never come in contact with the construction or development costs and are only willing to pay for what they do come in contact with: the apartment and its characteristics. The developer acts as a spider in the web of these dynamics. This thesis concludes that vertical price premiums for apartments are, therefore, not impacted by increasing marginal floor costs. On the other hand, the overall apartments costs are indirectly influenced by marginal floor costs. This thesis provides an elaboration on those dynamics below.

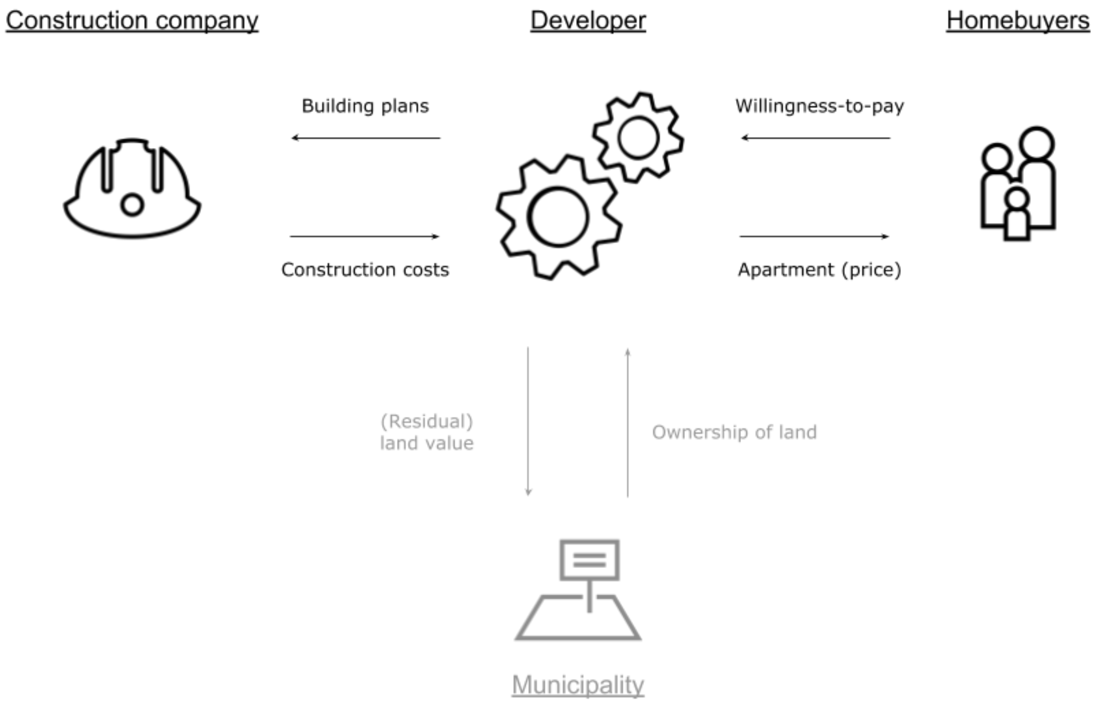


Figure 26. Apartment price formation dynamic in the development process.

As mentioned before, the only perspectives developers assume for costs are total costs and costs/m^2. As visible in figure 26, developers tend to develop residential tall buildings to certain heights: 70 meters, 100 meters and 150 meters. One explanation is the extremely nonlinear increase in costs/m^2 related to height, mainly originating from fire safety measures and structural safety measures:

- 70 meters and taller - mainly caused by the necessity to have at least two fire brigade elevators, but also a equipped command center, staging area for a fire truck and an internal communication system (van Oss, 2007).
- 100 meters and taller - additional costs caused by the necessity to have a sprinkler system throughout the entire building with a double connection to the water local infrastructure and pumps driven by emergency power (van Oss, 2007).
- 150 to 200 meters - additional demands for structural foundations (Gemeente Rotterdam, 2011).

Exceeding these heights means that these additional measures need to be accounted for in the costs section of the business case. As a consequence, even though the hypothetical building height would only increase from 99 to 100 meters, sprinklers need to be installed throughout the entire building. This has a huge effect on costs/m^2 as depicted in figure 29. Since developers focus on costs/m^2, they try to spread out the sudden large investment over as much surface area as possible, aiming to minimize the overall costs/m^2. One of their options is to add as many additional floor levels as possible, thus adding a substantial amount of surface area, over which these extra investments costs can be spread out. From an economic point of view, the costs are minimized when adding as much extra floors possible without breaking another height barrier that induces additional large investments. Figure 29 conceptually displays these dynamics. In the figure, a 150m building is economically optimal. This behavior is in line with profit maximization theories as discussed in chapter 2 and leads to the building heights of 70m, 100m and 150m (Barr, 2012; Clark & Kingston, 1930; Garza & Lizieri, 2016). Following the dynamics of figure 29, 70m and 100m building would be economically optimal if the absolute costs/m^2 would start at a higher level or if the absolute revenues/m^2 would start at a lower level. This leads to the conclusion that both marginal cost increase and floor level premiums, as well as absolute costs and revenues, play a role in determining optimal building height. Marginal costs and floor level premiums influence the slope of the lines as depicted in figure 29 and the absolute costs and absolute revenues determine the starting points on the y-axis of the lines. Both aspects together determine the break-even height.

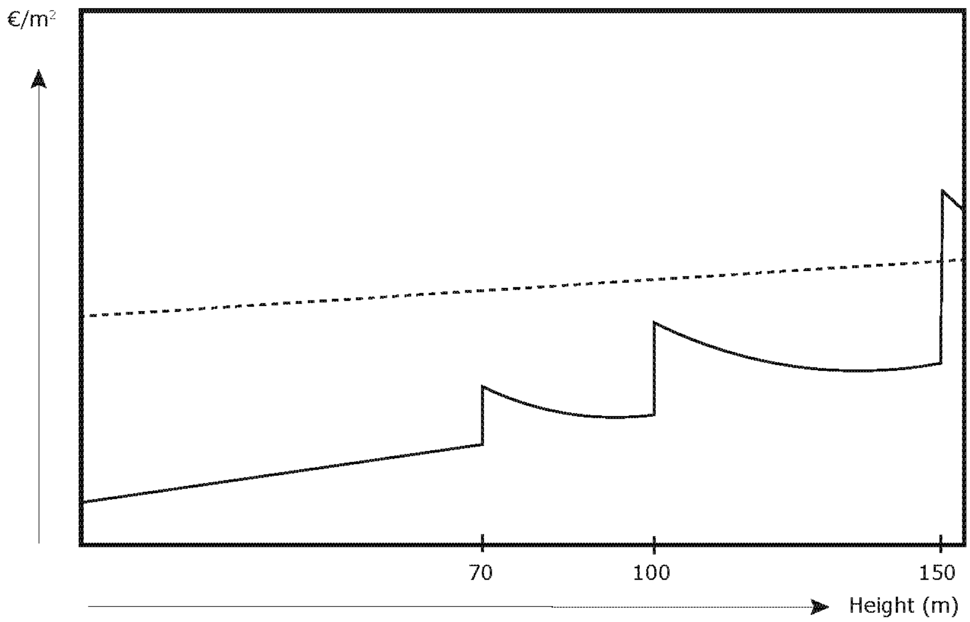


Figure 27. Marginal costs & revenues dynamics. The dashed line represents a linear (e.g. 0.5%/floor) increase in revenues/m^2 and the continuous line represents costs/m^2 (average 0.8% increase/floor).

Building heights were also found to be impacted by building height regulations. Before concluding if the observed tower heights are all determined by profit maximization, the towers must be placed in the context of Rotterdam's building height regulations. The municipalities policy for high-rise sets building height limitations in certain areas are depicted in figure 9 and 10. Of the observed towers of 70m, only Tower 3 and Tower 12 are not located in the zone where >70m is possible and their building height is, therefore, explained by building height limitations. The height of other buildings that do not break the 70m barrier is, however, not explained by building height regulations because their location provides the possibility for building taller than 70m. For Rotterdam, no building height limit for the 100m barrier exists and this thesis infers that the height of observed towers that are capped at 100m originates from profit maximization. The municipalities high-rise policy explicitly states that there is no principal limit for supertalls (Gemeente Rotterdam, 2011). Therefore, it can be concluded that the heights of observed towers that stop at 150m were also a product of profit optimization. To summarize: while building height regulations play a role in building height determination for some towers, the building height of the majority of the observed residential tall buildings is consistent with profit maximization theories. However, this finding should not be used for assumptions on other towers in Rotterdam as the discussion above proves that each tower should be considered apart.

5. Conclusions

The key objective of this research is to provide an in-depth contribution to the body of knowledge on developer vertical price premium behavior. The research analyzes 1406 apartments divided over 15 residential tall buildings in Rotterdam and results show that developers apply floor level premiums in their asking prices. The research adds to the body of knowledge by analyzing developer asking prices rather than transaction prices, which enables developer behavior analysis. This thesis proves that developers exploit homebuyers' willingness to pay for benefits of height in the form of views and status, as these aspects contribute to residential satisfaction and, in turn, the residents quality of life. General estimations land at 0.5% increase in unit price per floor level, but findings provide evidence for substantial heterogeneity in developer vertical price premium behavior and show that floor level premiums range from 0.06% to 1,88% per floor. Premiums displayed both intra-building as well as inter-building variations. The effect of views in the form of number of view features and whether or not an apartment provides a view on the Erasmus bridge, was found to be dependent on floor levels and the findings indicate that height-induced view effects play a substantial role in determining floor level premiums. This implies that developers exploit homebuyers' willingness to pay for better views that accompany apartments on higher floors. Developer behavior regarding building height of residential tall buildings in Rotterdam is largely consistent with profit maximization theories, though building height regulations were also found to be a limiting factor for building heights.

The thesis advances the topic of pricing of status and shows that developers behave heterogeneously when it comes to pricing the aspects of prestige through the label of a *penthouse.* However, the results do show that the developers seem to place a higher value on a penthouse when it has a greater vertical location. More detailed investigations in height-induced effects related to status indicate that a highly significant relation between floor level and number of neighbors is present. The results imply that this variable is an important addition to hedonic pricing models as it reflects the extent to which a resident has to share the floor, which in turn is a partial representation of status. Another representation of status is the extent to which the resident is on top of others. Results show substantial effects for a squared relative floor level variable. Developers of residential tall buildings that break existing height records were found to assign greater floor level premiums to apartments with the unique properties of being located higher than residents in other buildings in Rotterdam.

This thesis pioneers by researching floor level premiums in the city of Rotterdam. Selecting the city of Rotterdam leads to an interesting secondary finding, namely a 5% premium for a view on the Erasmus bridge, a prominent local icon. Other secondary findings concern several standard control variables, including indoor floor area (price elasticity of nearly -0.1%), number of bathrooms (8% per extra unit) and orientation of living room, consistent with prior findings in existing studies.

The thesis' findings provide novel insights in developer behavior in the context of residential tall buildings and contribute to the larger body of knowledge. Limitations of the research include a lack of depth in the view data quality, which needs to be defined in further detail in order to enable results to determine to more accurately quantify the extent to which view quality induced by height is priced by developers. Benson et al. (1998); Rodriguez and Sirmans (1994) may provide a basis for this next step. Another improvement relating to views in this research would be the analysis of the height of surroundings, as this can simulate whether or not a view is blocked. This is also a key step in investigating inter-building social power competition - indicating whether an apartment is *king of the hill*, which would be an interesting expansion on studies relating to status, height and vertical price premiums. Further qualitative findings indicate that height premiums sharply increase starting from the floor where views are no longer blocked by a neighboring building.

The results of the research are highly relevant for real estate actors involved in pricing strategies. They provide evidence that floor level premiums are applied by various developers and additional research in the concerning apartments' time on market would provide valuable insights in the success potential of the applied premiums. The foundation of the findings of this thesis can be used for other cities and smaller buildings by using the notion that floor level premiums are impacted by views and status related aspects. Even though the outcomes may be different, this thesis proves that these mechanics are important determinants in the behavior of developers when it comes to vertical price premiums. An example: the uniqueness of living in a high vertical location is likely to be lower in other cities in the Netherlands due to a lower number of residential tall buildings and developers may apply greater vertical price premiums for apartments in other cities to exploit this situation. However, the high level of developer heterogeneity regarding vertical price premiums found in the analysis of this thesis proves that resulting price premium strategies differ from tower to tower. This corroborates the notion that further research is desired on other building types and cities.

Nevertheless, the findings of this thesis can be used as a reference point for pricing strategies in new developments. This is not only useful for developers, but also for real estate appraisers and advisors. Additionally, homebuyers can use the findings to gain more detailed insights in the price for locating higher – ceteris paribus – when hunting for a new home. Lastly, policy makers should interpret the findings as evidence for the existence of floor level premiums. These floor level premiums contribute to the developers' business case and, therefore, also positively impact residual land values. Consequently, the findings may provide incentive to municipalities to stimulate tall building developments in their urban planning policies.

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7. Reflection

The purpose of this chapter is to reflect on the research process of my graduation. I have split the reflection in four parts: graduation process, research subject, methodology and results.

7.1. Graduation process

The week before the graduation labs presentations I was still quite certain I wanted to find a topic within the Urban Area Development laboratory. Nevertheless, I went to see the presentations for the Real Estate Management and other laboratories as well and suddenly wasn't quite so certain anymore. Ilir's presentation on the tall building economics sublaboratory was inspiring for me, for reasons further discussed in the preface of this thesis. I felt that with this thesis subject, I would *not* lose motivation halfway - which is something many of my fellow students did experience.

The period until P2 was symbolized by a substantial amount of reading and an iterative process of trying to take in as much as possible to keep further defining my research proposal. At P2 I felt that I had positioned myself strongly in the literature on height premiums. Looking back, this is still partly true - but I had also included a lot of 'noise' that was not relevant - or at least is not anymore.

The period after P2 has been quite turbulent for me on a personal level. Several weeks of illness, the break-up with the girl I had a relationship with for 3,5 years and the week before P4, a minor concussion. Fortunately, there are also many good things to reflect on. Data gathering was one of the most crucial parts of my road to P3 and P4. Luckily, this went quite smooth and I managed to obtain more observations in more towers than we had initially expected. Processing the data went evenly smooth, which enabled me to spend time on something else. I set a goal for myself to learn the programming language of R and perform the analysis in it. This required a time-heavy investment in the beginning, but proved to be very useful and time-saving for the regression analysis. I do feel that I took too much time between the dataset creation and the actual analysis. One reason for this is that performing regression analyses was new to me and what I had coded seemed too simple to actually be 'it'. One way I could have prevented this was sitting down with my mentors for the analysis earlier in the process. Nevertheless, preliminary results were present at the P3 session and this provided a steady basis to move forward with towards P4.

Until P3 - as expected - motivation to proceed has always been present. However, after P3 my ex-girlfriend and I ended our relationship and my motivation had suddenly gone as well. The time between graduation laboratory presentations → P1 → P2 → P3 was significantly longer than the time between P3 and P4 for me and I had some issues in finding the flow I had before P3. The sessions with my mentors after P3 helped me to relaunch the motivation I had before, resulting is a P4 good enough to obtain the green light for P5. The infrastructure for the regression analyses I had set up in R especially helped me in picking up the pace and efficiently performing the leftover analysis steps - making me extra glad and proud that I invested the effort and time in learning the programming language. Before P1 and at P2, graduation is still a long road towards 'destination unknown'. However, the results in this report are satisfactory for the journey I had and I feel that results are quite substantial in the small field of floor level premium, especially floor level premium determinants.

7.2. Research subject

This thesis is part of the tall building economics laboratory. It fits well within the domain of "*The vertical dimension in urban economics*", as Ilir titled it in his graduation sublaboratory presentation. The thesis provides novel insights on height premiums, assuming the developer point of view rather than the demand side point of view. The domain fits well within the master track of MBE. However, it touches also touches upon some basic spatial econometrics, which I like to call real estate econometrics.

At P2, I had set a goal to also compare floor level premium assigned to apartments to the marginal costs for each floor. At this stage I argue that this is interesting in theory, but does not contribute to the broader understanding of developer behavior regarding premiums in residential tall buildings. The reason for this is that it is not a relevant determinant of floor level premiums, but relevant for other aspects in the development process. This insight enabled me to place it in a broader context and led to the findings presented in section 4.2. Nevertheless, I feel that the goals I had set at P2 were naïve and could have been sharper by more extensive experimentation. On the other hand, the knowledge I have on my thesis subject enables me to say this now, but the lack of knowledge back then must have absolutely been a factor in this matter.

The research subject has given me quite some insight in pricing strategies, tall building development and real estate econometrics. At my graduation firm, I notice that the topic is relevant and contributes to active projects. This reinforces my satisfaction for the choices I have made.

7.3. Methodology

Since the beginning of the graduation process, it had been clear that the core of this research would be of a quantitative nature. However, the process started with a qualitative journey: building a research proposition and studying the existing body of knowledge on relevant themes. The literature research provided a steady basis for the variables that I would research. Of course, a lot of what I had found back then would become less relevant or even irrelevant at some point. Nevertheless, all I have written and read has contributed to the knowledge I gain in the entire graduation process. The process towards and after P4 focused on interpreting the quantitative aspects of the thesis and placing them in a qualitative context. I experience joy in doing so and am satisfied with the idea that I have developed myself well in the thesis subject.

Another thing I have trained myself in is switching between different research styles: qualitative analysis, dataset creation, quantitative analysis and back to reporting. I notice how focusing on one of these enables me to become more efficient in that particular activity, but shifting to another of these activities becomes more difficult. That too is part of the less explicit things student learn during graduation, I suppose. This makes the chosen methodology extra valuable for me.

On a more technical level, it would be interesting to perform 3D-polynomial regression trials, mainly to discover if the relation between unit prices, floor level and indoor floor area is significant.

7.4. Results

Results are discussed in detail in chapter 4. The main roadblocks in working towards the results was variable selection. Quite some variables overlapped, and it took a long time before I managed to bring up the courage to delete these variables. I suppose removing products of work originating from prior phases of the graduation process is difficult for most students. Once I passed this point, things started to move along. However, at one point I had created a wide spectrum of models: different dependent variables, different datasets, different independent variables, with and without clustered standard errors, etcetera. It took a session with Ilir to choose what to proceed with - though the choices seem clearer now. I do feel that making these choices was easier after P4, resulting in some new regression models and additional findings. I am quite glad about the results and feel that it truly adds to the academic, but also professional body of knowledge. Not only the quantitative part, but also with heterogeneity of developer vertical price premium behavior and with the line of reasoning on developer behavior regarding cost premiums versus price premiums in the context of floor levels -

leading up to the conclusion on Rotterdam's residential tall building heights being largely consistent with profit maximization theories.

Appendix A: sources per variable per tower

Variable	Tower 1	Tower 2	Tower 3	Tower 4	Tower 5	Tower 7	Tower 6	Tower 8	Tower 9	Tower 10	Tower 11	Tower 12	Tower 13, 2 &3
epm2int	WvS	WvS	WvS	Ooms	Ooms	NF	EvL	NF	1	WvS	CM	2	EvL
von	WvS	WvS	WvS	Ooms	Ooms	NF	EvL	NF	1	WvS	CM	2	EvL
floorlv	WvS	WvS	WvS	Ooms	Ooms	NF	EvL	NF	1	WvS	CM	2	EvL
quarterstostart	WvS	WvS	WvS	Ooms	Ooms	NF	EvL	NF	1	WvS	CM	2	EvL
quarterstodelivery	WvS	WvS	WvS	Ooms	Ooms	NF	EvL	NF	1	WvS	CM	2	EvL
areaext	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
areaint	3	4	NA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
nelevators	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
floorneighbors	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
nrooms	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
nbathrooms	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
ntoilets	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
nbedrooms	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
relative floor height2	WvS	WvS	WvS	Ooms	Ooms	NF	EvL	NF	1	WvS	CM	2	EvL
Tower name dummy variables	-	-	-	-	-	-	-	-	-	-	-	-	-
Marketed as penthouse	WvS	WvS	WvS	Ooms	Ooms	NF	EvL	NF	1	WvS	CM	2	EvL
Living room orientation	3	4	SA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
Categorized views	3, GM	4, GM	SA, GM	Ooms, GM	Ooms, GM	M, GM	AR2R035, GM	SA, GM	5, GM	6, GM	7, GM	8, GM	9, GM
Business cycle dummy variables	NVM	NVM	NVM	NVM	NVM	NVM	NVM	NVM	NVM	NVM	NVM	NVM	NVM
Number of external areas dummies	3	4	NA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9
Type of external areas dummies	3	4	NA	Ooms	Ooms	M	AR2R035	SA	5	6	7	8	9

AR2R035 = university course in which documents for Tower 6 were made available for analysis

CM = Conny Meuldijk, Marketing, communication & PR – HD Group

EvL = Edwin van Leeuwen, development manager – Amvest

GM = Google Maps

M = Mecanoo archives

NF = Nick Forger, Ooms

NVM = Dutch association for brokers & valuers

Ooms = Rotterdam based broker

SA = Stadsarchief gemeente Rotterdam (building permit plans)

SSC = https://www.skyscrapercity.com/showthread.php?t=234149&page=15

WvS = Wouter van Someren, manager Marketing & Sales – Wilma Wonen

1 through 9 = confidential, available on request.

Appendix B: correlation table & association table

Confidential, available on request.

Appendix C: R code for regression models

```
library(easypackages)
libraries("readxl", "tidyverse", "summarytools", "stargazer", "plm", "lmtest", "multiwayvcov", "sandwich", "GGally")
dataset <- read_excel("Dataset 20190614.xlsx")
dataset$floorlv2 <- dataset$floorlv^2
dataset$areaint2 <- dataset$areaint^2
dataset$lrorientationfactor2 <- factor(dataset$lrorientationfactor, c("N", "NO", "O", "ZO", "Z", "ZW", "W", "NW", "360 degrees"))
dataset$numberextfactor2 <- factor(dataset$numberextfactor, c("0ext", "1ext", "2ext", ">2ext"))
dataset$typeextfactor2 <- factor(dataset$typeextfactor, c("none", "balcony", "balcorner", "loggia", "sunspace", "terrace" ))

reg1 <- lm(data=dataset,
        log(`epm2int`) ~ `floorlv`+
        factor(`towername`) +
        factor(`lrorientationfactor2`) +
        log(`areaint`)+
        log(`areaext`+1)+
        `quarterstostart` + `quarterstodelivery`+
        `nrooms`+`nbathrooms`+`ntoilets`+`nbedrooms`+
        factor(`cyclefactor2`)+
        factor(`typeextfactor2`)+
        factor(`numberextfactor2`))

reg2 <- update(reg1, . ~ . + factor(`numberviewsfactor2`) + factor(`erasmusbrugfactor`))
reg3 <- update(reg2, . ~ . + `floorlv`:factor(`numberviewsfactor2`) + `floorlv`:factor(`erasmusbrugfactor`))
reg4 <- update(reg1, . ~ . + factor(`marketedpenthousefactor`))
reg5 <- update(reg4, . ~ . + `floorlv`:factor(`marketedpenthousefactor`))
reg6 <- update(reg2, . ~ . + factor(`marketedpenthousefactor`))
reg7 <- update(reg3, . ~ . + factor(`marketedpenthousefactor`) + `floorlv`:factor(`marketedpenthousefactor`))

#regs met interaction terms voor floorlv
reg8 <- update(reg1, . ~ . + factor(`towername`):`floorlv`)
reg9 <- update(reg3, . ~ . + factor(`towername`):`floorlv`)
reg10 <- update(reg5, . ~ . + factor(`towername`):`floorlv`)
reg11 <- update(reg7, . ~ . + factor(`towername`):`floorlv`)
reg12 <- update(reg11, . ~ . + `floorlv`*`floorneighbors`)
reg13 <- update(reg12, . ~ . + factor(`towername`):factor(`marketedpenthousefactor`))
reg14 <- update(reg13, . ~ . + `relative floor height2`)
reg15 <- update(reg14, . ~ . - factor(`towername`):`floorlv` + factor(`towername`):`relative floor height2`)

#clustered SE
regcse1 <- coeftest(reg1, vcovCL, cluster=dataset$towername)
regcse2 <- coeftest(reg2, vcovCL, cluster=dataset$towername)
regcse3 <- coeftest(reg3, vcovCL, cluster=dataset$towername)
regcse4 <- coeftest(reg4, vcovCL, cluster=dataset$towername)
regcse5 <- coeftest(reg5, vcovCL, cluster=dataset$towername)
regcse6 <- coeftest(reg6, vcovCL, cluster=dataset$towername)
regcse7 <- coeftest(reg7, vcovCL, cluster=dataset$towername)
regcse8 <- coeftest(reg8, vcovCL, cluster=dataset$towername)
regcse9 <- coeftest(reg9, vcovCL, cluster=dataset$towername)
regcse10 <- coeftest(reg10, vcovCL, cluster=dataset$towername)
regcse11 <- coeftest(reg11, vcovCL, cluster=dataset$towername)
regcse12 <- coeftest(reg12, vcovCL, cluster=dataset$towername)
regcse13 <- coeftest(reg13, vcovCL, cluster=dataset$towername)
regcse14 <- coeftest(reg14, vcovCL, cluster=dataset$towername)
regcse15 <- coeftest(reg15, vcovCL, cluster=dataset$towername)
```