The Effects of Orientation and Elongation on the Price of the Homes in Central Pennsylvania

Shahrzad Fadaei[1], Sohrab Rahimi[2], Jiro Yoshida[3], Lisa D. Iulo[4]

1) MS. Student, Departments of Architecture and Architectural Engineering, Pennsylvania State University, University Park, PA. USA. Email: fadaei@psu.edu
2) Ph.D. Student, Department of Architecture, Pennsylvania State University, University Park, PA. USA. Email: sur216@psu.edu
3) Ph.D., Assistant Prof., Department of Risk Management, Pennsylvania State University, University Park, PA. USA. Email: jiro@psu.edu
4) Assoc. Prof., Department of Architecture, Pennsylvania State University, University Park, PA. USA. Email: ldi1@psu.edu

Abstract:

Although housing trends are changing, single-family detached housing is still mainstream in the United State comprising more than 50% of the housing in 2015. Considering that single-family homes have higher surface area and usually consume more energy that attached homes or apartments, rising prices of energy could be a driving force for homebuyers to look for more energy efficient homes. Orientation and elongation are among the most important factors in reducing energy needs with almost no added cost to the building. North-south orientation with the long sides of the home facing north and south are the desired orientation specifications for these houses. Apart from saving energy, north-south orientation allows for southern exposure to penetrate the house while elongation determines the extent to which the interior spaces are exposed to this desirable natural light. Therefore it's likely to assume that these factors exert an influence on the costumer's choice.

To examine this idea single-family detached homes of Centre County, Pennsylvania are analyzed. Firstly, detailed information of these homes was extracted from real-estate sources. These data are then joined with GIS building footprints shapefiles created by PASDA (The Pennsylvania Spatial Data Clearinghouse) followed by incorporating GIS methods to analyze their orientation and elongation. Considering that building area, age, spatial features, neighborhood and etc. are important for prices, a hedonic pricing model is used to isolate the effect of the defined two factors on house prices.

This research indicates the extent to which these passive solar design decision that are related to sustainable development best practices, affects the market equilibrium price. Our results show that orientation has positive effects on price with mixed significance whereas the elongation has a significantly negative affect. The results of this research can be used to plan for better educating of home-buyers and realtors and assist architects to design marketable and energy-saving houses.

Keywords: GIS, Residential Sustainability, Real Estate analysis, Hedonic pricing

1. INTRODUCTION

According to the U.S. Energy Information Administration (EIA), buildings are involved in more than 40 percent of total energy usage in the US. In addition, buildings consume about 65 percent of total electricity and are substantial greenhouse gas emitters causing approximately 30 percent of greenhouse gas emissions (EPA green buildings). In the building sector, homes are of great importance. According to United States Census Bureau, in 2014 more than 1 million permissions for new residential units were issued ((New Privately Owned), 2014) and homes are responsible for 21.53% of energy consumption in the US (EPA green buildings).

In the U.S., a large amount of new construction, with more than 60% of total number of new homes, is single family housing (New Residential Construction, 2015). Moreover, existing single-family homes account for the majority of the U.S. building sector. These homes have large surface area and are mostly larger than apartments and therefore consume more energy. With that being said, there is almost no doubt in the importance of sustainable housing especially single family residential. However, sustainable homes are believed to cost more to construct and generally clients are unwilling to initially invest more to purchase them. These are primary reasons that investors are usually hesitant to invest in sustainable projects. According to a McGraw-Hill Smart Market Report, higher upfront cost is one of the main restraints in increase of green building activity (Residential Green Building SmartMarket Report, 2012).

However, there are means of sustainable design that do not necessarily increase the upfront cost. Benefits of direct solar energy through passive solar design are among these strategies. Obtaining the proper north-south orientation, with the long sides of the home facing north and south and short sides facing east and west, helps the the homes to benefit from the southern sun exposure (in Northern hemisphere) throughout the year ("Solar Site Design -

Oikos Green Building Library," n.d.). In winter, homes can receive solar energy (sun-generated heat) from 9am to 3pm while in the summer, with the sun being higher in the sky and with proper use of overhangs, direct sunlight and unnecessary heat gain will be blocked (Friedman, 2013). Throughout the year homes designed for proper passive-solar advantage provide for natural light and reduce or eliminate the need for electrical lighting during the day. Incorporating passive solar strategies can reduce energy consumption (heating fuel and electricity) up to 25 percent, which considering the rising prices of different sources of energy, is considerable (Rashkin, 2010). Apart from energy and the related environmental benefits, presenting day lighting through proper elongation and orientation, improves the wellbeing of occupants and provides them with a sense of orientation, time, weather and in general the world outside of the building (Phillips, D. 2004).

In this situation, marketing of sustainable homes and emphasizing these features becomes essential. To date, most of the marketing focus in this sector is on the technical aspects of green homes such as energy efficient equipment. While these topics are highly important, another important aspect of sustainable homes, which is the effect of architectural design features on both energy saving and occupants feelings is usually neglected. In order to develop suggestions for different sectors to pay more attention to the importance of architectural design in marketing of sustainable homes, there is a need to quantify the extent to which occupants acknowledge proper design features such as solar considerations.

As observed through this study, hedonic pricing is the most common method for evaluating different variables on property values. In this model the value of the item being researched is considered to be a function of a number of variables where a change in the amount of a variable would change the value of the original item. The hedonic model decomposes the item into its constituents helping the value of each variable being revealed (Rosen, S., 1974; Edmonds, R. G., 1984). Hedonic pricing is based on regression analysis, a statistical calculation for estimating the relationships of different variables. Using independent and dependent variables, regression analysis keeps all the variables fixed except for one, allowing researchers to monitor how the value of dependent variable changes based on a change in value of the independent variable (Draper, N. R. et al. 1966). In real estate analysis, hedonic pricing provides a model for understanding the impact of common variables such as size, age and location and less prevalent variables such as mechanical systems, provisions for solar energy, or even architectural style on the price of a property.

The purpose of this research is firstly to find if proper orientation and elongation have any influence on residential building's price and secondly if the influence is positive. In this research, three variables are being assessed: Orientation, elongation, combination of orientation and elongation.

In the following section, an overview of the current literature on the effect of sustainable features, decisions and amenities on property value is provided. The majority of real estate analyses of sustainable features are studies of commercial buildings. To capture ideas from multiple sources, research on the commercial building sector is discussed in this section however the emphasis is on the residential sector.

2. LITERATURE REVIEW

Discussing the relationship of sustainability and price of the buildings, one of the most popular research topics is the effect of eco-labeling on property values. Dermisi studied the effect of the USGBC LEED® rating system on assessed and market value of offices in the United States. She used assessor-generated values from the CoStar Group, USGBC and County/City Assessors and Treasurers websites across the U.S. to evaluate 351 office buildings in 36 states. From this information regression analysis was used to determine the impact of different variables such as area, age, LEED® and ENERGY STAR certification. The research concludes that ENERGY STAR certification has a considerable positive impact on both assessed and market value of buildings while the effects of LEED® varies based on the level of certification and geographic aggregation (Dermisi, 2009). In a 2011 research report Das, Tidwell and Ziobrowski used CoStar and USGBC data from 2007 through 2010 in the San Francisco and Washington DC areas to study rental rate dynamics of certified green office properties in these two cities. They found that there is a rental premium for green office properties; however, green premiums are not static. Instead, in order to offset negative effects of down-markets, the rents are stabilized in many conditions of the real estate market (Das, P. et al., 2011).

While the amount of research conducted in housing sector is considerably less, there are a number of real estate studies that address the residential market. In an article evaluating the effect of ENERGY STAR certification on green houses, Bloom, Nobe and Nobe (2011) studied a sample of 300 homes in Fort Collins, Colorado consisting of 150 ENERGY STAR qualified homes and compared them to 150 non-ENERGY STAR qualified homes using hedonic regression analysis. They concluded that ENERGY STAR homes initially sell for approximately $93.22 per square meter ($8.66 per square foot) more than conventional ones (Bloom, B, et al, 2011). Two years later (2013) Yoshida and Sugiura used transaction prices of 1,452 green projects and 10,481 non-green ones in Tokyo.

They reported that the initial transaction premium of green buildings might be negative due to higher expected maintenance costs of these buildings. However, the premium becomes positive after two years due to slower depreciation of green buildings (Yoshida, J., & Sugiura, A., 2013).

In a 2011 study from the demand side, Goodwin analyzed responses from 9,138 survey respondents from the 2009 NAR (National Association of Realtors) Home Buyer and Seller Survey about the importance of green home amenities. He found that sustainable amenities are more important for first-time homebuyers and those who buy a home through its first transaction. In addition, these amenities were of less importance for homebuyers under 40 compared to those older than 40 (Goodwin, K., 2011).

A few studies have also analyzed the effect of architectural design features on the price of buildings. Architecture and design related features are not easy to quantify with a measurable variable and therefore are generally not being considered during appraisals and in hedonic pricing models of homes (Plaut, S., & Uzulena, E., 2005). Most of the times, only remarkable features such as view or specific style of architecture, which are mentioned in the listings, are assessed.

Smith and Moorhouse (1993) also studied the effect of architecture on residential sector prices in Boston. Their regression analysis considered variables of lot and house size, neighborhood characteristics, construction materials, architectural style, and individual architectural features and found that in total, these features account for 14% of the price. Their findings, again, support the notion that architecture and planning can have a positive impact on property values (Smith, M. S., & Moorhouse, J. C., 1993).

Internationally, there are bodies of literature discussing architecture's effect on the value of buildings. In a 2006 housing study, Latvia, Plaut and Uzulena also used hedonic pricing to evaluate which style of architecture is more popular to the extent that people are willing to pay a price premium. Using data from 3500 transactions that took place between 1997 and 2003, they ran regression analysis to determine the impact of different architecture styles on the value of the homes. They concluded that new or renovated units have higher-value coefficients and there are premiums associated with some features such as brick material, high ceilings or having balconies (Plaut, S., & Uzulena, E., 2005).

Research discussed above shows that most of the time, there is relationship between green features and price, although this relationship is not always predictable. There is also evidence that architectural design can be effective on the price. However, there is no research studying the relationship of specific sustainable architecture features such as orientation or elongation on the price.[1]

3. METHOD

For this research two sets of data were incorporated. The first set of the data was retrieved from real estate websites (Interfaceexpress, 2015) for all single family housing units constructed after 1800 and before 2015 in Centre County, Pennsylvania which numbered to 18,646 units. This data included information on the units' addresses, buildings' features (e.g. number of bedrooms and bathrooms, heating system, roof type, exterior façade material, building area, lot area, parking type, year built, current and sold prices, and a brief description on general features of the house). The second set of data was retrieved from The Pennsylvania Spatial Data Clearinghouse (PASDA) and included 2,379,678 polygons and 4,147,110 points. This data was a result of a program launched in 2007 that collected building footprints and geocoded addresses from different counties in Pennsylvania however, of all 67 counties within Pennsylvania only, 18 counties had the data for both the building footprints and addresses.

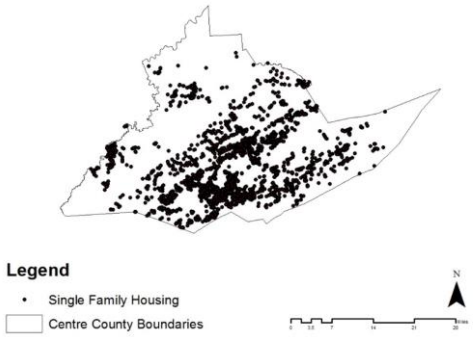

Figure 2. Single family houses in Centre County

[1] The authors have already published an extended literature review on this subject. Please refer to the citation below for more details. Fadaei, S., Iulo, L. D., & Yoshida, J. (2015). Architecture: A missing piece in real-estate studies of sustainable houses. *Procedia Engineering*, *118*, 813-818.

The PASDA data for Centre County included 83,182 building footprints. These polygons did not completely correspond with the geocoded points since the number of points were higher than the polygons. To apply the addresses in the geocoded points to the building footprints a spatial join was conducted and 51,360 pints were found to be completely within the polygons. Another table join was needed to associate the building footprints with real estate data. One challenge here was to join the two tables (i.e. the table including the Real Estate data and the shapefile including the polygons with addresses) by basing the join on the address, the only potential join, since the addresses in the two tables were not the same format.

Having all the real estate data joined to the shapefile of single family houses made the studying of the impact of elongation and orientation of single family housing on their prices possible. To do so, three new variables were added to the data set: Orientation of buildings, Elongation, and a variable calculated from the combination of two indicating the exposure of the building to the true south (i.e. 13 degrees different from the geographical south). The problem, however, was that the buildings' footprints did not have rectangular geometries in all cases. In order to calculate these three variables, a minimum bounding rectangle was created using the "minimum bounding geometry" tool in ArcGIS (ArcGIS, 2014). The three variables were then calculated for these minimum bounding rectangles (figured 3).

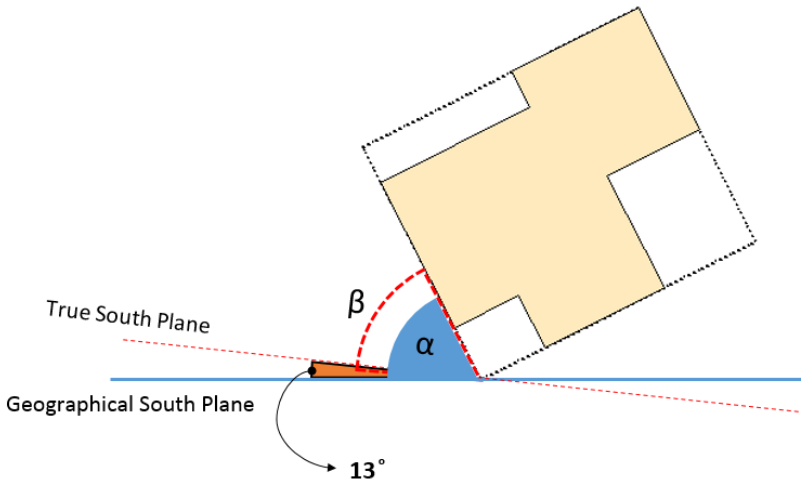

Figure 3. Minimum bounding rectangle for this building footprint is signified by dashed lines. Using the minimum bounding simplifies the calculation process. α denoted the angle between the width of the building and geographical south. β signifies the angle between the width and the true south which is 13 degrees different from α. The closer β to 90 degrees the more sunlight is received from the south.

The elongation variable illustrates the extent to which the building is stretched and is simply calculated by dividing the minimum bounding rectangle's length to its shape. This value is larger than or equal to one. To account for the orientation of the buildings the angle between the length of the building and the true south line was calculated. The ArcGIS software automatically stores the angle between the width of the minimum bounding rectangle and the geographical south plane (α in Figure 3) in a separate field. However, this study is interested in the angle between the width and true south. The true south is the direction that the most favorable direct sun exposure is received from and most easily controlled.

Accordingly, the angle that this study is interested in is $\beta = \alpha - 13$ where $0 < \alpha < 180$. The closer β to 90 degrees the more directly the building receives sunlight from the south. Therefore, the orientation factor was calculated as $\text{Sin}(|\beta|) = \text{Sin}(|\alpha - 13|)$.

Since the amount of sunlight that a building receives from south is a function of both elongation and orientation a dummy variable was defined to account for both at the same time. In other words, a building in which the proportion of length to width is high and faces towards south receives the maximum amount of sunlight from the south. Therefore, the elongation-orientation variable is simply calculated by multiplying the orientation factor (i.e. $\text{Sin}(|\alpha - 13|)$) by elongation factor (i.e. L/W). We also create 4 categorical variables for orientation (0-0.25, 0.25-0.5, 0.5-0.75, 0.75-1) and 2 categorical variables for elongation (1-1.43 (median) and 1.43 and larger).

Finally, we conduct a linear regression analysis with the following specifications (see Appendix A for details):

1. The natural logarithm of home sale price was used as the dependent variable in the regression.
2. Logarithm of square fit variables (i.e. lot size, finished size, and total size) were used in the regression.

3. The number of bedrooms and bathrooms were used as categorical variables.
4. Dummy variables were created to account for buildings' features (i.e. Two stories, shingle roof, vinyl exterior, wood fireplace).
5. Dummy variables were created for buildings age groups (0, 1-5,…, 25-30, 30-40, 40-50, 50 and older).
6. Categorical variables were defined to account for the municipality in which the building is located (e.g. Bellefonte, State College, etc.)
7. Dummy variables for transaction years are created to account for general price trend.
8. White heteroscedasticity robust standard errors were used.

3. RESULTS

The detailed results from the regression analysis is presented in Appendix A. The R-squared is 0.77 meaning that the model explains 77 percent of the variation in the dataset (Table A2). Overall, the building and lot area, number of bath rooms, location, building's age, and the year of listing, and building style are major variables responsible for the most of the variance. Table 1 shows the estimated log price differences between large and small elongation groups. Overall, the group of houses with large elongation values is associated with 2.2% smaller transaction prices relative to the group of small elongation values. The difference is statistically significant at the 1% level. The magnitude of price difference is particularly large (-3.2%) when the orientation value is large (0.75-1.00).

Table 1. Log price difference between large and small elongation groups

	Log price difference	Std. Err.	T	P>t
Overall	-0.0215	0.0059	-3.66	0.00
Orientation (0.00-0.25)	0.0029	0.0195	0.15	0.88
Orientation (0.25-0.50)	-0.0249	0.0145	-1.71	0.09
Orientation (0.50-0.75)	-0.0127	0.0101	-1.26	0.21
Orientation (0.75-1.00)	-0.0324	0.0090	-3.61	0.00

Table 2 shows the log price difference between groups of large orientation values and the group of the smallest orientation value. A large value of orientation has a positive effect on house price especially when the elongation value is relatively small. For example, house prices are 3.6% higher for the group with the largest orientation value (0.75-1.00) than the group with the smallest orientation value (0.00-0.25). The effect of orientation is also positive but not statistically significant when the elongation value is small. The effect of orientation becomes somewhat larger when we remove observations with an elongation value greater than 2.5.

Table 2. Log price difference relative to the smallest orientation groups

	Log price difference	Std. Err.	T	P>t
Small elongation group				
Orientation (0.25-0.50)	0.0396	0.0187	2.12	0.03
Orientation (0.50-0.75)	0.0193	0.0174	1.11	0.27
Orientation (0.75-1.00)	0.0362	0.0169	2.15	0.03
Large elongation group				
Orientation (0.25-0.50)	0.0118	0.0156	0.76	0.45
Orientation (0.50-0.75)	0.0037	0.0134	0.27	0.79
Orientation (0.75-1.00)	0.0010	0.0131	0.07	0.94

This analysis indicates that home sale prices are positively associated with buildings orientation, particularly when elongation is close to one. The elongation has a significantly negative affect on prices, meaning that the more stretched the house the lower the price.

4. DISCUSSION

It is important to consider the number and distribution of buildings based on their elongation and orientation. As can be seen, in the majority of the buildings studies the elongation factor falls below 1.5 (i.e. the proportion of length to width is below 1.5 for most single family houses).

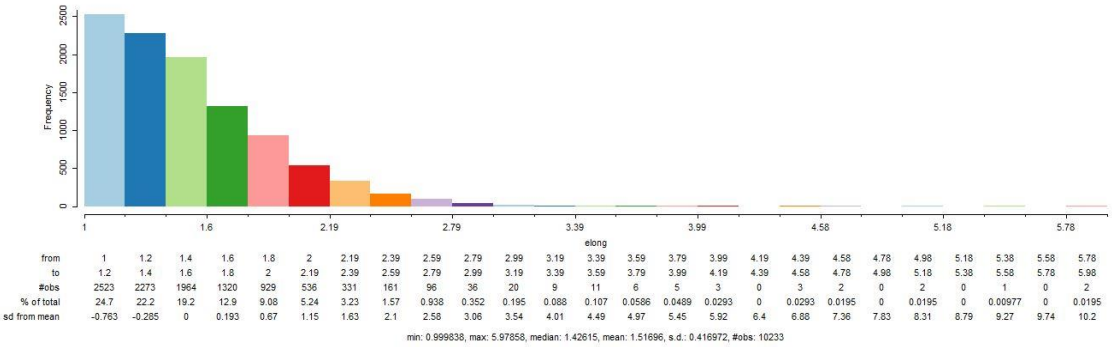

Figure 4. The graph indicates the frequency of different elongations. For most buildings the value is less than 1.5

Figure below indicates the frequency of buildings with different orientations divided in 4 broad groups: below 22.5 degrees with the true south, between 22.5 and 45, between 45 and 67.5 and above 67.5 and less than 90. The majority of buildings are between 22.5 and 67.5 allowing most of these buildings to receive between 70 to 92 percent of the sunlight from the true south.

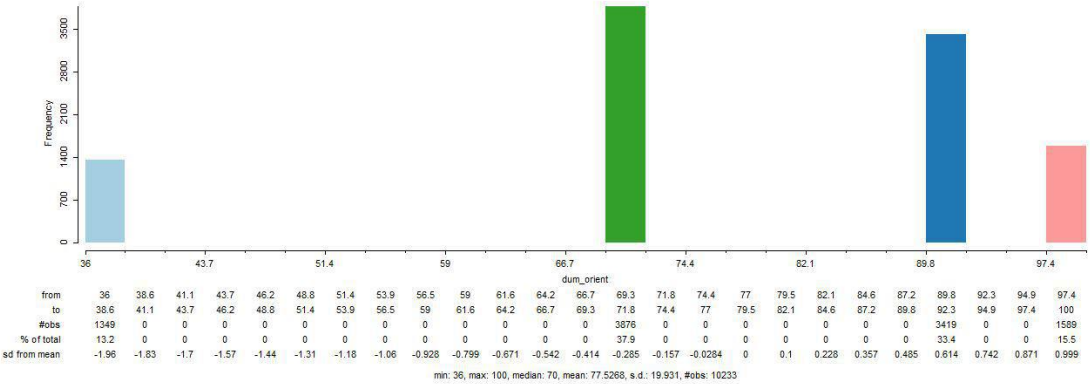

Figure 5. The orientation of buildings categorized in 4 groups. As can be seen the majority of buildings are between 22.5 and 67.5 degrees off true south

Figure 6 is a thematic maps indicating the condition of orientation and elongation in different municipalities. Although the map illustrates slight differences between different municipalities, no significant pattern was identified. A closer look at the neighborhood level might be more telling. To see if there is any identifiable spatial structure in the data set, or in better words to see if the orientation and elongation of housing prices correlate with distance we incorporated the Moran's I method. Moran's I is a measure of spatial autocorrelation that measures correlation in a signal among nearby locations in space. Figure 7 indicates the univariate local Moran's I analysis on single-family houses in State College area. The significant clusters of building with same orientation can be seen in numbers (Moran's I = 0.21). The major reason for this is that most houses are built along the streets and the orientation of buildings is heavily related on the orientation of the streets that they have been placed on.

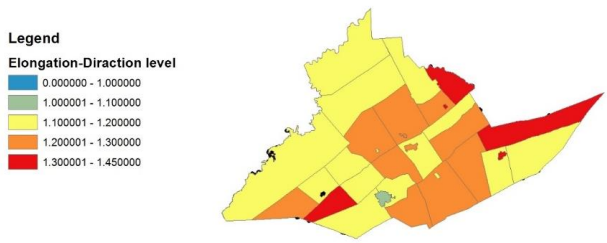

Figure 6. A ranking for different municipalities in Centre County based on both orientation and elongation

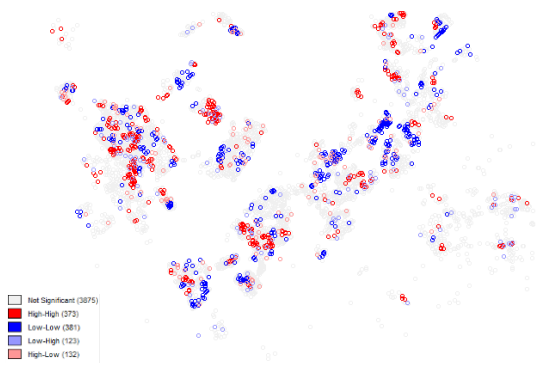

Figure 7. Univariate local Moran's I analysis for orientation of buildings in State College produced by GeoDa (Geoda, 2006).

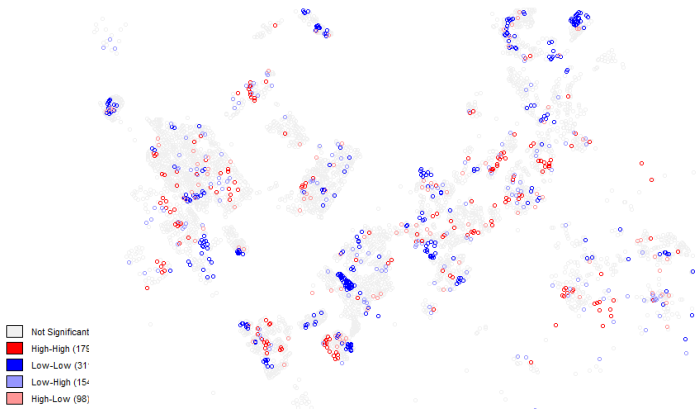

Figure 8. Univariate local Moran's I analysis for elongation of buildings in State College produced by GeoDa (Geoda, 2006).

Clustering patterns were also identified in the elongation of the buildings in state college (figure 8). However the significance of these clustering patterns (Moran's I = 0.08) is not as much as it was for orientation.

As already mentioned in the results, the effect of orientation on house prices, although generally positive, is not uniformly significant. As shown in Figure 7, a reason for this can be the significance of street layout on the orientation. Another possible cause of these insignificant effects might be the type and location of garages. Even when the orientation value is large, a garage may be attached to the south side of a house. This lack of data can create errors in variables and attenuates our estimates. Future research can evaluate type and placement of garage into the analysis and come up with accurate outcomes.

Apart from that, buildings that are properly oriented, may lack proper interior layout and window placement or be under the shade of trees or adjacent buildings. Therefore, the quality of interior spaces might not be elevated as expected and the potential homebuyers may not value the proper orientation. Analysis of window placement is beyond the scope of current GIS tools, however a future study by the authors tends to take into account the proximity and shadow casting of adjacent buildings and evaluate them into Hedonic Pricing analysis.

The results of this paper shows that home-buyers are not necessarily aware of opportunities such as proper orientation and elongation that are cost-free choices in the design and can be highly effective in saving energy and promoting the quality of interior spaces. Here, the necessity of educating homebuyers and marketing agents about these opportunities and developing tools that acknowledge these choices seem valuable topics to be discussed in future studies.

5. CONCLUSIONS

This study was conducted on 8,164 single-family houses in Centre County to gauge the effect of orientation and elongation on housing prices. Both orientation and elongation are two important factors that directly affect the amount of sunlight that the building receives from the south. Elongation and orientation of buildings are two low-cost strategies for designers to take into consideration since the impact of these factors on the quality of lighting as well as building's energy consumption are positive. Our analysis indicates that the extent to which the building receives sunlight from the south has an effect on house prices as predicted, but the effect is not uniformly significant. Our analysis indicates that the orientation of buildings is heavily based on the orientation of the streets that they have been placed on. This means that the orientation problem is rather a large-scale issue that can be addressed in planning policies. In addition, variables such as window placement, interior layout and proximity of adjacent buildings are other facts that may affect the effectiveness of orientation and elongation into pricing of homes.

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APPENDIX A

We estimate the following log-linear regression equation (1) by the ordinary least square method (OLS).

$$(1)\ \ \ln P_{ijt} = \alpha + \beta_1 Orientation_i + \beta_2 Elongation_i + \beta_3 Orientation_i \times Elongation_i + X_i\gamma + y_t + c_j + \varepsilon_{it},$$

where $\ln P_{it}$ is the natural logarithm of transaction price of house i in city j in year t, y_t is year fixed effects, c_j is city fixed effects, ε_{it} is the error term, and X_i is a vector of control variables: the lot size, total floor area, finished floor area, and dummy variables for numbers of bedrooms and bathrooms, two-story house, shingle roof, vinyl exterior, wood fireplace, and 5-year building age groups. In order to allow non-linear effects of orientation and elongation, we also estimate regression equation (2):

$$(2)\ \ \ln P_{ijt} = \alpha + \sum_{q=2}^{4} \beta_{1q} Orientation\ Group_q + \beta_2 Large\ Elongation_i + \sum_{q=2}^{4} \beta_{3q} Orientation\ Group_q \times Large\ Elongation_i + X_i\gamma + y_t + c_j + \varepsilon_{it},$$

where $Orientation\ Group_q$ are dummy variables that correspond to the ranges of 0.00-0.25, 0.25-0.50, 0.50-0.75, and 0.75-1.00, $Large\ Elongation$ is a dummy variable that takes a value of one if elongation is greater than the median value of 1.43. Table A1 shows the descriptive statistics of the data that area used in the regression analysis. We use 8,164 transactions to estimate the equation.

Table A1: Descriptive Statistics

VARIABLES	(1) N	(2) mean	(3) sd
Sales price	8,164	213,549	128,931
Orient	8,164	0.656	0.251
Elongation	8,164	1.523	0.422
# of bedrooms	8,164	3.456	0.804
# of bathrooms	8,164	1.957	0.834
Lot size (sqft)	8,164	61,466	474,600
Floor area (total)	8,164	2,203	930.1
Floor area (finished)	8,164	1,899	770.6
Building Age	8,164	38.52	35.12
D(State College) = 1	8,164	0.610	0.488
D(2 Story) = 1	8,164	0.380	0.485
D(shingle roof) = 1	8,164	0.934	0.248
D(vinyl exterior) = 1	8,164	0.503	0.500

Table A2 summarizes the estimation result. Column (1) shows the estimated coefficients for equation (1). The coefficients on orientation and elongation are positive and negative, respectively, but they are not statistically significant. Column (2) shows the result for equation (2). The coefficients on the Orientation variables indicate the price differential for houses with smaller values of elongation (i.e., relatively square shaped footprint). Relative to the group with the smallest value of orientation (0.00-0.25), the group with a greater value of orientation is associated with a higher house price. In particular, when the orientation value is between 0.25 and 0.50, house prices are 4.0% larger than for the reference group. Similarly, when the orientation value is between 0.75 and 1.00, house prices are 3.6% larger than for the reference group. Column (3) shows a similar result based on a subsample with the elongation value smaller than 1.5. In column (2), the interaction term between Orientation and Elongation indicates the additional price differentials for houses with larger values of elongation. For houses with large elongation values, the largest value of orientation is associated a negative effect (-0.035).

Table A2: Regression Result

Dependent Variable: log house price	(1)	(2)	(3) Subsample Elongation < 1.5
Orientation	0.051		
	(0.043)		
Elongation	-0.009		
	(0.019)		
Orientation × Elongation	-0.032		
	(0.026)		
Orientation (0.00-0.25)		Reference	Reference
Orientation (0.25-0.50)		0.040**	0.039**
		(0.019)	(0.017)
Orientation (0.50-0.75)		0.019	0.020
		(0.017)	(0.016)
Orientation (0.75-1.00)		0.036**	0.034**
		(0.017)	(0.015)
D(Elongation > median)		0.003	
		(0.019)	
Orientation (0.25-0.50)		-0.028	
× D(Elongation > median)		(0.024)	
Orientation (0.50-0.75)		-0.016	
× D(Elongation > median)		(0.022)	
Orientation (0.75-1.00)		-0.035*	
× D(Elongation > median)		(0.021)	
Other control variables	YES	YES	YES
Observations	8,164	8,164	4,660
Adjusted R-squared	0.772	0.772	0.782

White's heteroscedasticity-robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1