USING QUANTITATIVE ANALYSIS TO ASSESS THE APPROPRIATENESS OF INFILL BUILDINGS IN HISTORIC SETTINGS

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Over the past 40 years or so, and more recently in developing countries, increasing attention has been paid to the preservation of historic settings; however, with continued development and urbanization, a solution is needed for the problem of how to adapt historic settings for contemporary life. Consideration of how to conserve historic settings while introducing new development has been the subject of theoretical study for many years, and despite many mistakes, excellent architectural projects have been completed. However, most research has focused on assessing such projects only at a qualitative and cognitive level; a deeper exploration is therefore needed. Thus, the main goal of this paper is to apply a scientific, quantitative approach to investigating the contextual fit of infill buildings in historic settings. This research is approached mathematically within the framework of architectural theory and visual science. To assess the potential of this methodology, a case-study building facade is analyzed using three attributes: size, proportion, and color. The findings of this research can help in evaluating the contextual fit of architectural designs and thereby lead to improved design guidance for historic settings.

INTRODUCTION

Any building can be studied in a variety of ways, depending on the information one wishes to derive from it. One of the central problems of architectural studies has been that the conservation and renovation of historic settings involve different goals than the design of new buildings does, and these differences often produce conflicts. In order to link these two fields, this paper aims to determine how to measure the fit of "new in old" in terms of the most visible element, a building's facade. This will be achieved through a quantitative approach based on the theory of architectural morphology. The paper is organized into five main parts. First, design guidance and contextual-fit analysis will be reviewed to establish why a quantitative approach to measuring the appropriateness of infill designs in historic contexts is needed. The second part will affirm the importance of respecting context when designing new infill buildings in historic settings. The third part will establish the key architectural attributes selected for the quantitative research methodology and discuss the methodology in detail. The fourth part will describe and evaluate a case study to demonstrate the proposed approach. Finally, the fifth part will summarize the analysis results and discuss the potential weaknesses of the quantitative methodology, together with the conclusions and implications of the research.

CONTEXTUAL FIT: THE NEED FOR A QUANTITATIVE APPROACH

A quantitative approach to evaluating architectural design proposals for historic settings is needed to supplement existing qualitative design guidance. Most countries currently have some form of aesthetic control for architecture, especially in historic settings, but few of these have any form of quantitative assessment. Indeed, several studies have indicated that aesthetic control of architecture is the norm, rather than the exception (Lightner, 1993; Punter, 1984, 1985). Moreover, it would appear that most of these aesthetic controls are based on contextualism, and as such, projects are evaluated based on how they relate to existing urban settings. Many authors have discussed the need for and application of contextualism in urban architectural aesthetics (Brolin, 1980; Cullen, 2012; Lightner, 1993; Riza and Doratli, 2015). The intent of such an approach is to provide "enough visual linkages between existing buildings and a proposed project so as to create a cohesive overall effect. The new building should strengthen and enhance the characteristics of its setting, or at least maintain key unifying patterns" (Hedman and Jaszewski, 1985:9).

In addition to outlining the necessity of design control in historic settings, many authors have highlighted which building attributes have been subject to control (Carmona, *et al.*, 2010; Duerksen, 1986; Groat, 1988; Lightner, 1993; Punter and Carmona, 2013). All of these lists include criteria such as the height and mass of buildings; other controlled attributes include character, style, complexity of overall form, roof profile, proportion, projections from the facade, doors and windows, location of the entrance, materials, color, and degree of detail. Other authors have tried to identify which contextual design principles are used, with Brolin (1980), Cullen (2012), and Lightner (1993) suggesting that the only general urban-design principle is that there are no general urban-design principles and that each case must be evaluated in terms of its own unique context. Hedman and Jaszewski (1985) suggested that contextual design depends on both the "fit" of a building using the criteria listed above and the impact the building would have on environmental preferences. Other design principles can be found in formal policy documents on environmental aesthetics. Accordingly, Stamps (1994:225) stated "that contextual principles such as harmony, compatibility, congruity, fits with and variety from nearby buildings are important aspects of contemporary urban design controls."

Another reason why there is a need to study the physical attributes of a building's facade, such as size, proportion, and color, is that design controls tend toward vague or anthropomorphic expressions that can be difficult to interpret and implement (Hinshaw, 1995). For example, design guidance documents often contain vague expressions such as

> *"new buildings should resemble existing ones" and "new buildings should use existing buildings as inspiration but not as a basis for imitation," and "both the criteria and the relative magnitudes of their effects will depend on undefined contextual situations." Anthropomorphic expressions include urban design principles such as "new projects should recall the detail of other buildings" and "new projects should respect existing urban design patterns." Recollection and respect are activities of living things. Use of these verbs to describe visual relationships just leads to confusion. ... Clearly, if research could identify which building attributes or visual relations among buildings affect the aesthetics of environments then urban design controls could be based on definite, firm foundations rather than on nebulous generalizations.*
> (Stamps, 1994:226)

A quantitative analysis of a building's attributes is appropriate because most of the research on the harmony between new and old is conducted using psychological or cognitive surveys rather than architectural analysis. Basically, psychological and cognitive methods focus on mental processes such as memory, perception, and preference. It is believed "that what we perceive is the result of an interaction between the physical environment and the person" (Volker, 2010:15). Growing attention has focused on the visual impact of the built environment in the past few decades, and many studies on the assessment of visual impact and environmental aesthetics have been conducted (Nasar, 1994; Sotoudeh and Wan Abdullah, 2013). It is assumed "that people represent the diverse forms of the experienced built environment as abstract images," and prototype and feature frequency have an important impact on people's judgments (Abu-Obeid, *et al.*, 2009:163). Also, a considerable number of empirical studies and experiments by Stamps have attempted to apply a logical theory of environmental aesthetics using cognitive surveys (Stamps, 1994, 1997, 2000; Stamps and Nasar, 1997). These reveal that the quality of the built environment or the relationship between new and old tends to be evaluated according to physical features. However, the studies mentioned above mainly focus on the issue of which facade elements influence the public's evaluation but neglect to establish *how* these elements influence that evaluation. The physical attributes of a facade's elements do affect the public's aesthetic evaluation of a building and are therefore worth studying in depth.

This paper is concerned with how to evaluate the contextual fit of a new infill building in a historic context in a quantitative way from the perspective of its architectural features. The first issue to be investigated is the necessity of a quantitative evaluation of contextual fit. A review of current literature suggests there are three reasons why there is a need for a quantitative research approach to understanding the role of building attributes in design controls: (1) most countries have implemented design controls for new developments in historic settings, (2) many existing design controls are too vague to be useful, and (3) most studies of contextual fit are conducted using psychological or cognitive surveys while the physical attributes of buildings are neglected. Thus, a quantitative understanding can enhance the assessment of the contextual appropriateness of new infill buildings. This highlights two fundamental questions: first, why should there be a "fit" between new infill buildings and their historic settings, and second, are there any appropriate rules or design methods for new infill buildings?

NEW INFILL BUILDINGS IN HISTORIC SETTINGS

Increased concern regarding the aesthetic appropriateness of new buildings in historic settings came to the forefront of the public's attention with the emergence of conservation movements in the late 1960s. However, this conflict between the traditional town and modern development was denounced much earlier by Pugin (1836) in his book *Contrasts*, in which he illustrated the differences between the buildings from the Middle Ages in a town in 1440 and the more modern buildings in the same town in 1840. One had church steeples dominating the traditional townscape, while the other had modern, multistory buildings and factory chimneys (Warren, *et al.*, 1998). New development in historic settings is, in most cases, an inevitable fact of life in the evolution of cities. Indeed, Lynch (1972:236) poignantly noted that "the exposure of successive eras of history and the insertion of new material that enhanced the past by allusion and contrast would be encouraged, the aim being to produce a setting more and more densely packed with references to the stream of time rather than a setting that never changed." While the revitalization of the existing historic fabric is preferred, new development in historic settings is also imperative, particularly if historic buildings have become functionally, economically, or structurally obsolete (Tiesdell, *et al.*, 1996). Typically, such developments take the form of infill buildings, which should preferably respect, complement, and enhance both the urban context and the architectural character or identity of the setting to achieve a harmonious relation with the existing context.

The debate between new and old can be linked to a number of different eras and schools of thought throughout architectural history. Traditionally, architectural styles have undergone gradual changes over centuries, with revivals of old forms and motifs being commonly accepted. However, with the emergence of the modern movement in the early 20th century, the position of architects was characterized by a dichotomy between new and old. Indeed, the aims of modern architecture were seen as quite different from anything in the past. After the destruction caused during the First World War, there were efforts to rebuild many destroyed areas in their old forms, such as in Arras, France, and Louvain, Belgium (Warren, *et al.*, 1998). However, the supporters of the modern movement in architecture were categorically and morally opposed to any imitation or use of past styles in contemporary buildings. Le Corbusier (2013:7), for example, declared that

> *[t]he history of Architecture unfolds itself slowly across the centuries as a modification of structure and ornament, but in the last fifty years steel and concrete have brought new conquests, which are the index of a greater capacity for construction, and of an architecture in which the old codes have been overturned. If we challenge the past, we shall learn that "styles" no longer exist for us, that a style belonging to our own period has come about; and there has been a Revolution.*

The idea of an interruption between modern creativity and technology and that of the past became the dominant approach starting in the early 20th century. "If modernism blew apart the relationship between history and the city, destroying the perception of architectural illusions that the nineteenth century put into place, then architecture in the 1970s and 1980s attempted to restore [the central role of] the public realm of the city, to reweave the shredded urban fabric, and to reconstruct a sense of collectivity and cooperation" (Boyer, 1996:4). In postmodern architecture from the late 1970s, architects were more contextually aware and tried to design new buildings that were more compatible with historic surroundings, although arguably this was through the insensitive use of historical architectural motifs. "[I]n propagating the conservation of architectural as well as urban heritage," international organizations such as the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the International Council on Monuments and Sites (ICOMOS) "encourage new architectural intervention to be distinguishable from its settings so as to protect [the integrity of] the historical fabric and yet still aesthetically fit within" its context (Sotoudeh and Wan Abdullah, 2013:87).

> *In contemporary design practice, attitudes toward architectural design often reflect architects' personal preference, even though it is governed by design guidelines laid out by relevant commissions, organisations and/or local councils. An important aspect of an appropriate design is measured based on the quality of viability and vitality in its context or the quality of sensibility to that particular setting. ... For new additions in the urban historic context, there are no simple rules for achieving quality of design, although a clear and coherent relationship of all parts of the new work to the whole, as well as to their surroundings is essential.*
>
> (Sotoudeh and Wan Abdullah, 2013:86-87; see also Bentley, *et al.*, 1985).

FIGURE 1. Examples of out-of-character and compatible new buildings on a historic street.

While creating a harmonious relationship with neighboring buildings can be achieved using any number of techniques, designers generally select one of two major approaches — replication or contrast — at the initial stage of the design process and then apply that approach to various degrees throughout the remainder of the process (Sotoudeh and Wan Abdullah, 2013; see also Al-Izzi, 1989; Askari and Dola, 2009; Brolin, 1980; Cramer and Breitling, 2007; Eleishe, 1994; Loew, 1998; Smith, 1987). Brolin (1980:48) used examples to illustrate what he regarded as "successful fit-ins," and in most cases, he praised harmony rather than contrast. It is obvious from his evaluation of two buildings that "this is architecture as object, the typical modernist approach which ignores what is to the left and right" (*ibid.*). This body of literature can provide a useful framework for examining infill buildings in historic districts, and most theories suggest that new developments in historic settings should derive inspiration from their respect for and sensitivity to a setting's particular aesthetic qualities, both spatial and architectural. Tiesdell, *et al.* (1996:183) argued that there are

> *two distinct levels where design control and/or consideration is required: firstly, in terms of the overall massing and urban form of the development. This might be regarded as the morphological or spatial character of the quarter ... . Secondly, the elevation of the proposed development, which defines and encloses the external urban space and the public realm. This might be regarded as the architectural character of the quarter; a concern for the architectural articulation of the building's elevation or facade.*

The focus of this paper is to discuss the harmonious relation in an architectural context, particularly relating to the principal externally visual properties of architectural form.

SELECTION OF VISUAL PROPERTIES

According to Ching (2007), there are seven visual properties of architectural form: shape, size, color, texture, position, orientation, and visual inertia. The challenge of selecting appropriate visual properties for buildings can be approached in a number of ways. However, taking into account the operability of quantitative analysis, this paper will focus on three visual attributes of architectural form: size, proportion, and color.

Size

Size comprises the physical dimensions of the architectural form: length, width, and depth (Ching, 2007:34). Size is an obvious choice for this research, with building height being mentioned in 90% of architectural design controls (Stamps, 1997). Height is the vertical size of a building's facade, while width is its horizontal size. The height and width of buildings contribute significantly to the visual character of existing buildings and settings. While a new building does not necessarily need to be exactly the same height and width as its neighbors to be compatible, it should be designed to respect existing building heights and widths. For example, a new five-story building in a block of two- and three-story buildings will usually detract from the character of the street. While a new building that is more than one story higher or lower than existing buildings that are all the same height will tend to be out of character with its neighbors, a new building in a setting of existing buildings of varied heights may be more than one story higher or lower than its immediate neighbors and still be compatible (Wagner, *et al.*, 1997) (Figure 1). New infill development should therefore carefully consider the surrounding size or dimensions of the existing buildings to create a sense of visual order.

Proportion

> *Proportion is a correspondence among the measures of the members of an entire work, and of the whole to a certain part selected as standard. From this result the principles of symmetry. Without symmetry and proportion there can be no principles in the design of any temple; that is, if there is no precise relation between its members, as in the case of those of a well shaped man.*
> (Vitruvius, 1914:72)

An important characteristic of unity is the proportion of the parts or elements that make up an architectural composition. Proportioning systems "can visually unify the multiplicity of elements in an architectural design by having all of its parts belong to the same family of proportions" (Ching, 2007:300). Architectural practice "has often used proportional systems to generate or constrain the forms considered suitable for inclusion in a building. In almost every building tradition, there is a system of mathematical relations which governs the relationships between aspects of the design" (Boundless, n.d.). These systems are often quite simple whole-number or incommensurable ratios determined using geometric methods. Indeed, thousands of years ago, building designers and constructors knew how to make beautiful, harmonious structures using rational mathematical theories such as the Golden Section (Ching, 2007). Gothic, Renaissance, Egyptian, Babylonian, Arab, Greek, and Roman traditions all used harmonious proportions; human proportions; cosmological/astronomical proportions and orientations; and various aspects of sacred geometry, the golden ratio, and small whole-number ratios in their architecture (Boundless, n.d.).

Generally, the goal of a proportioning system is to produce a sense of coherence and harmony among the elements of a building and among different buildings.

> *Proportions are dimensional relationships among the building elements. These relationships exist at several levels: the relationship between the dimensions (height, width and depth) of each element of the building, the relationship of the dimensions of the element to each other and to the building as a whole, and the dimensional relationship of the building to other buildings along a block-face. ... The overall sense of a building working well within a particular context is often the result of carefully developed dimensional relationships. Poorly proportioned buildings may seem out of balance, inconsistent or inharmonious with their surroundings.*
> (Punter, 1999:132)

The appropriate proportion is therefore crucial to make a harmonious relation with a historic setting or context. In historic settings, the proportions of existing buildings tend to reflect the architecture principles of that particular historic period. As Figure 2 shows, "A simple change in proportions can often have an enormous impact on how a building fits into its surroundings" (Punter, 1999:132).

Color

We are surrounded by color in the physical environment. As Ching and Binggeli (2012:107) argued, "Color, like shape and texture, is an inherent visual property of all form." From the perspective of visual theory, historic settings can be seen as a combination of form and color, where the color is a reflection of architectural culture, as well as the most powerful and direct element of an architectural image (Figure 3). Moreover, Moughtin, *et al.* (1999:133) noted, "There is a renewed interest in the use of colour, one of the most effective methods of decorating the city." Color has been a

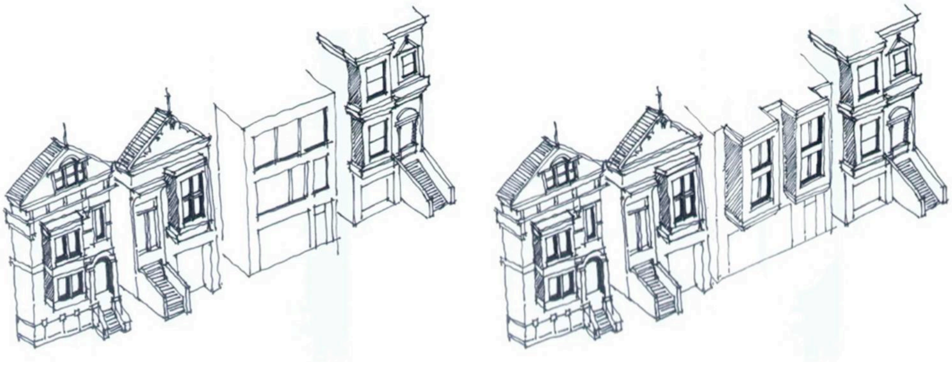

FIGURE 2. A change in window proportions helps a building fit into its surroundings. (Adapted from Punter, 1999:132.)

powerful element affecting the general appearance of buildings and cities dating back to the ancient Egyptian period, and first impressions are often obtained from the geometric forms and facade colors of buildings (Ünver and Dokuzer Öztürk, 2002).

The architectural features of building facades play an important role in creating the special character of a particular townscape. To make an effective and attractive environment, buildings have to be harmonious with each other and their surroundings. “Color is the attribute that most clearly distinguishes a form from its environment” (Ching, 2007:34). Indeed, a building’s facade color is an inseparable part of its architecture and one of the elements for creating meaningful, expressive, and discernible architectural environments. In this context, facade colors should be harmonious with their surroundings.

According to Burchett (2002:28), colors that, when seen together, produce a “pleasing affective response are said to be in harmony.” However, there are a number of different approaches to color harmony in the literature. O’Connor (2006) summarized three approaches: color harmony based on (1) hue similarity, (2) contrasting or complementary hues, and (3) color symbolism and the connotative meanings of color. Nevertheless, few studies have investigated the aesthetic harmony of facade color using a quantitative approach. In historic settings, analysis of color properties is crucial for ensuring the harmony between new developments and their historic surroundings.

METHODOLOGY

This research was conducted using mathematical quantitative methods to measure and assess the fit of new buildings in historic settings using three architectural attributes: size, proportion, and color. In terms of size, the authors collected building data related to the total height and width of the building, the segmented height (roof, middle, and bottom) and width of the building, and the height and width of openings (windows and doors) (Figure 4). Four indicators were used for the proportion data: proportion of the total building facade and the segmented facade (height/width), proportion of the windows, composition of the openings in the main facade, and the horizontal and vertical rhythms of the facades. The proportions of the total building facades were derived from the relationship between the total horizontal dimension (width) of a structure and its total height in terms of a specific unit of measurement. The total area of window openings in relation to the overall wall surface area was also an important characteristic of the facade.

In the analysis of color, three attributes — hue, saturation, and brightness — that define all colors are discussed. To analyze the relationships among colors, the “natural” and “objective” connec-

Forbidden City – Chinese royal buildings with red walls and yellow tiles

Chinese southern residential buildings with white walls and dark roofs

Florence – a city of red-tile roofs

FIGURE 3. Buildings in historic settings.

tions among these items must be identified. While there are several models for expressing color, the most popular ones are RGB (red, green, and blue) and HSB (hue, saturation, and brightness). This research used the HSB color model to pinpoint the colors abstracted from the facades. In the HSB model, hue (H) is represented from 0-360° on a color circle, while saturation (S) and brightness (B) range from 1-100%. An HSB cylindrical coordinate system can then be established to pinpoint all of the experimental colors (Figure 5).

In this approach, a series of pictures is taken of the facade by the same photographer, at the same time of day, and with the same equipment before undertaking a color comparison. Obviously, there can be many colors on even one facade, so to simplify the process, the colors can be separated into two categories: the main color, which is the most obvious color on the facade, and the subcolor,

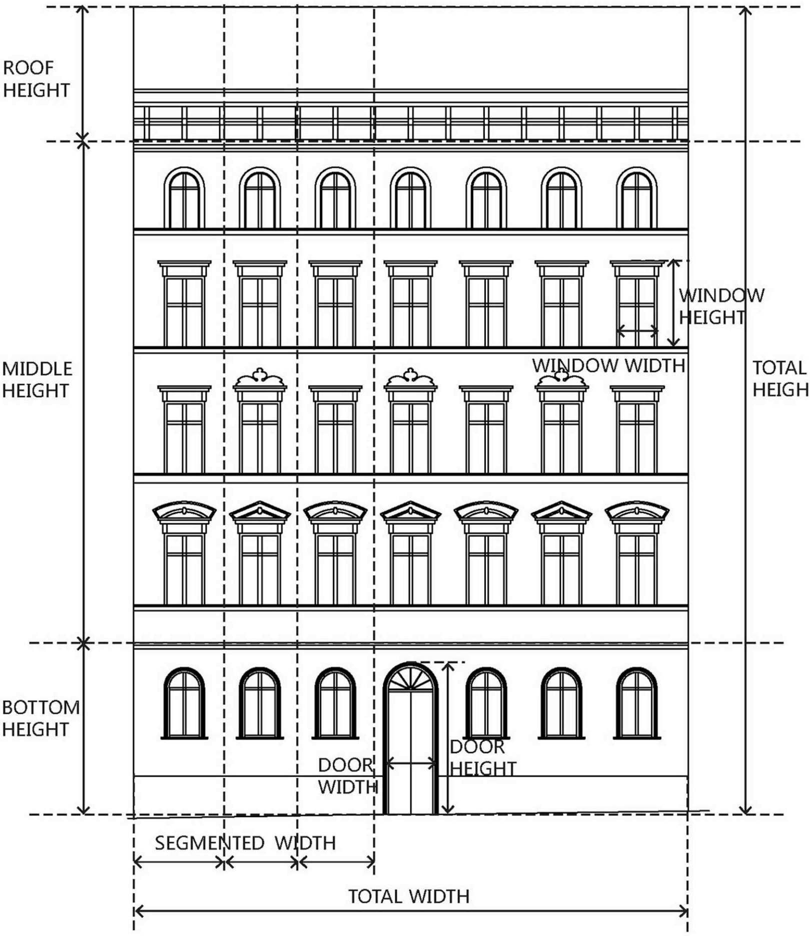

FIGURE 4. Diagram of aspects of data on building size.

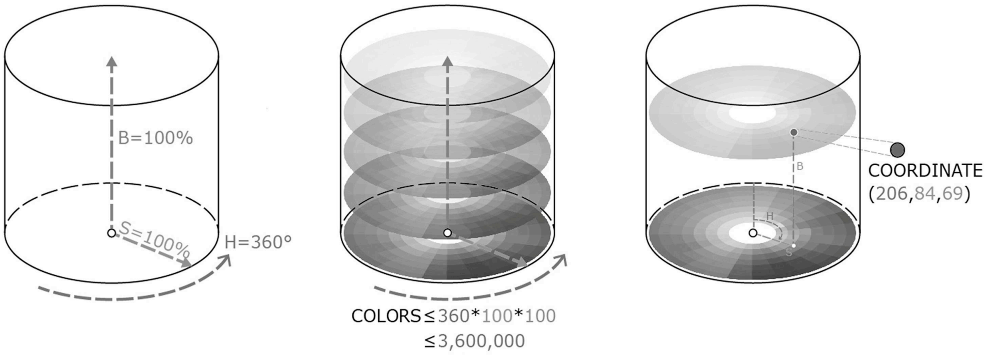

FIGURE 5. The HSB cylindrical coordinate system.

which is the next most obvious color. Using the HSB model, the attributes of each color can be expressed by three numbers, providing multiple values for analyzing their relationships (see Figure 5).

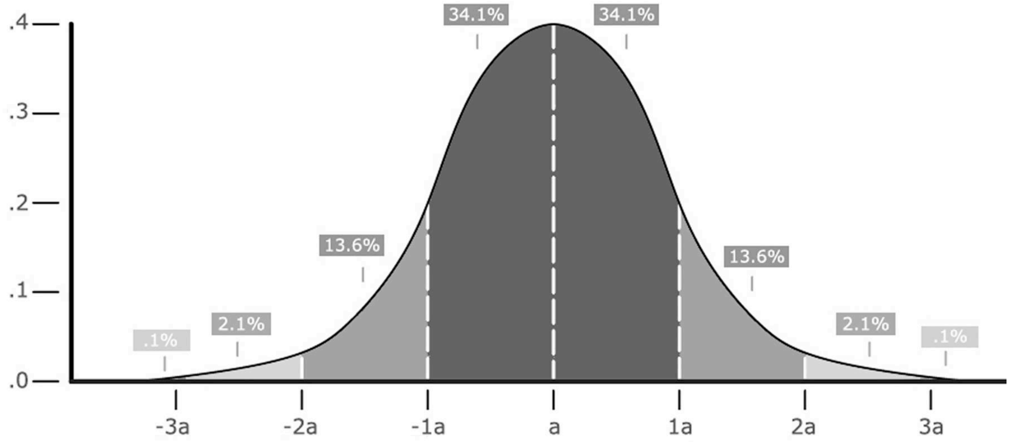

FIGURE 6. Normal distribution diagram.

Moreover, color composition — the ratio of different colors used in the architectural facade — is another important factor in the color study of facades. In this study, architectural color was classified into three types according to the ratio of color areas: main color, secondary color, and embellishment color. The main color was the dominant color of the building, such as the color of the main wall, while the secondary color was any color that was used to a lesser degree on the elevation. Embellishment color referred to the color of doors, windows, and ornamental elements.

After the facade color data were collected, the authors analyzed the data, with standard deviation (SD) showing how much variation or dispersion existed from the mean. A low SD indicated that the data points tended to be very close to the mean, while a high SD illustrated that the data points were spread out over a large range of values. Thus, SD was used to analyze the fluctuation introduced by a new infill building in a historic setting.

In this analysis, when a new sample (*i.e.*, a new building) was introduced into the case setting (*i.e.*, the historic setting), if the SD became larger, it indicated that the new sample increased the fluctuation of the data set. Conversely, if the SD became smaller, it indicated that the new sample reduced the volatility of the data set. In SD analysis, if uncoordinated factors are introduced, the original data set will fluctuate dramatically; on the contrary, if harmonious factors are incorporated, the data set will be more stable. Therefore, SD analysis is an important measure for assessing the influence of new infill design in a historic setting. Normal distribution is used to predict valid intervals and evaluate the degree of compatibility between new and old. In practice, about 68% of values drawn from a normal distribution are within one SD away from the mean, about 95% of the values lie within two SDs, and almost 100% are within three SDs. This is known as the 68-95-99.7 rule or the three-sigma rule (Figure 6). It is therefore relatively easy to calculate the valid intervals of a data set to serve as the evaluation criterion.

In order to cope with the hierarchical relationships of these facade characteristics and the ambiguity of criteria, a fuzzy synthetic evaluation model was used to make a comprehensive evaluation based on the data analysis of the chosen factors (size, proportion, and color). The fuzzy synthetic evaluation method is a broader application of fuzzy mathematics, which transfers a qualitative evaluation into a quantitative evaluation in order to make an overall assessment according to the influential degree of each factor. In this research, the authors constructed a fuzzy synthetic evaluation model with four steps: target level, item level, factor level, and index level (Figure 7). First, the authors established a collection of evaluation factors. Then, the evaluation criteria were set. Next, the authors defined the weight of each factor, and finally, the synthetic evaluation was undertaken.

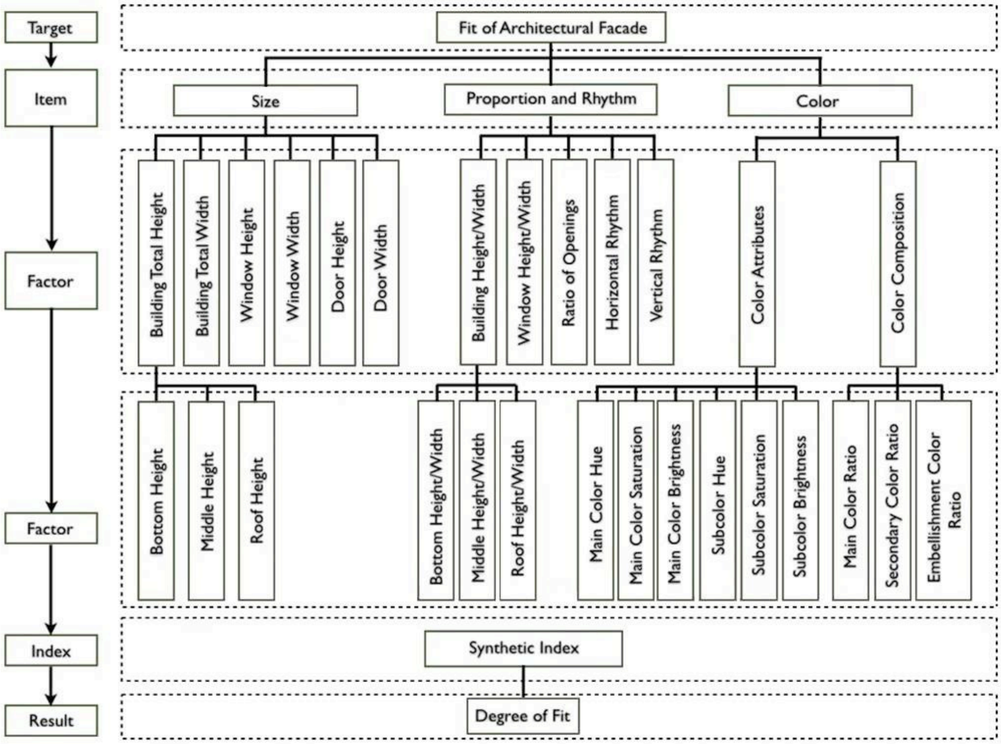

FIGURE 7. The fuzzy synthetic evaluation model of fit of an architectural facade.

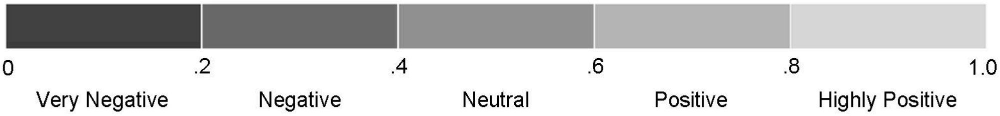

FIGURE 8. The synthetic index range for degree of fit.

In this study, assuming the synthetic index ranged from zero (the most negative condition) to one (the most positive condition), the degree of fit was defined by five levels: very negative ($0 \leq$ index $\leq .2$), negative ($.2 <$ index $\leq .4$), neutral ($.4 <$ index $\leq .6$), positive ($.6 <$ index $\leq .8$), and highly positive ($.8 <$ index ≤ 1) (Figure 8). The weight of each factor represented the importance of each factor on its own. In this case study, analytic hierarchy process (AHP) was used to calculate the weights of all factors.

CASE STUDY: THE “DANCING HOUSE,” PRAGUE

The “Dancing House” is the nickname given to the Nationale-Nederlanden building in Prague, Czech Republic (Figure 9). Completed in 1996, it was designed by Croatian-Czech architect Vladimir Milunic in cooperation with American architect Frank O. Gehry on a vacant city-center riverfront plot left empty after World War II bombings (Figure 10). The building has drawn wide-ranging reviews due to its novel design in a prominent location and marked visual contrast to its historic setting. Indeed, Pesch (1997:14; translated from original) argued that it is “perceived by many people to be an alien element, a Californian eyesore in one of the few central European cities not reduced to rubble and ashes at the end of World War II.”

FIGURE 9. The Dancing House in Prague.

FIGURE 10. The site of the Dancing House. (Adapted from Google map data, 2017 CNES/Airbus, Digital Globe, GEODIS Brno, GeoContent. Used with permission.)

Dechau (1996:6; translated from original) suggested that the building reminded him of a "crushed can of Coke" and thought that "this gap torn by American bombs at the end of the war should have been closed with utmost formal restraint in order to preserve the homogeneous impression of this street." In contrast, another critic referred to the building as the "Dancing Palace" and "a new jewel of the city's architecture … that is adding a new aspect to its history" (Carbonaro, 1996:95; translated from original). Singldinger (1996) pointed out that "Fred and Ginger," as the building is often called, marks a clear contrast with the rather boring recent architecture found elsewhere in Prague. Over time, the fierce debate about the appropriateness of the building's design has calmed down, and it now tends to be seen as a work of art that adds value to the cityscape.

DATA COLLECTION AND ANALYSIS

This quantitative study of the Dancing House focused on the western elevation to the River Vltava. This riverside facade is a continuation of the traditional historic street facade of the existing buildings on the city block. The researchers decided to focus on this elevation because it provided an opportunity to view the facade in its entirety due to the width of the river.

TABLE 1. Analysis of mean and SD.

Factor	Mean (n = 6)	Mean (n = 8)	SD (n = 6)	SD (n = 8)	Variation % of SD
Size					
Building total height	28.1667	29.1813	1.3750	2.2341	62.48%
Bottom height	6.3667	5.9713	.7685	1.1746	52.84%
Middle height	16.8667	18.3963	.7659	2.9444	284.44%
Roof height	4.9333	4.8138	.9647	1.1592	20.16%
Building total width	20.0750	19.4213	3.1154	3.2915	5.65%
Window height	2.5017	2.4563	.2498	.2273	-9.01%
Window width	1.9583	1.8638	.6591	.5839	-11.41%
Door height	4.7250	4.1188	.5040	1.2006	138.21%
Door width	1.6833	1.7250	.2017	.1871	-7.24%
Proportion					
Building total proportion	1.4320	1.5502	.2417	.3543	46.59%
Bottom proportion	.3256	.3177	.0766	.0919	19.97%
Middle proportion	.8569	.9835	.1368	.3010	120.03%
Roof proportion	.2494	.2490	.0592	.0552	-6.76%
Window proportion	1.3639	1.3900	.5219	.4437	-14.98%
Ratio of openings	.2050	.2725	.0345	.1290	273.91%
Color					
Main color hue	52.5000	49.8750	14.0250	12.8111	-8.66%
Main color saturation	7.5000	6.6250	5.6833	5.0692	-10.81%
Main color brightness	79.3333	82.7500	6.5013	8.3794	28.89%
Subcolor hue	101.8330	123.6250	146.7756	130.1855	-11.30%
Subcolor saturation	53.6667	49.2500	33.3806	29.3732	-12.01%
Subcolor brightness	40.8333	43.5000	12.1724	11.4143	-6.23%
Main color ratio	.6146	.5680	.0378	.0952	151.85%
Secondary color ratio	.1811	.2265	.0130	.0921	608.46%
Embellishment color ratio	.2055	.2058	.0352	.0324	-7.95%

Note. Sample size 6 refers to buildings number 2 through 7 on the block; sample size 8 refers to those six buildings, plus the two parts of the Dancing House.

To analyze the building, the block elevation was divided into its constituent parts, with the Dancing House coded as number one, and the existing buildings coded as numbers two to six. Because there are two main parts to the Dancing House's facade, it was analyzed as two parts: no. 1-1 and no. 1-2.

According to the predicted intervals of each factor, if the project value was very close to the mean (μ), the value of the factor was denoted as one. If the project value was in the range of μ ± ʃ (SD), the value of the factor ranged from .6-.8 based on how close it was to the mean. If the project value was in the range of μ ± 1.96 ʃ, the value of the factor was from .4-.6; if the project value was in the range of μ ± 2.58 ʃ, the value of the factor was from .2-.4; and if the project value was out of the range of μ ± 2.58 ʃ, the value of the factor was from 0-.2.

Size

As Table 1 shows, the SD for total height dramatically increased after the introduction of the new infill building. In simple terms, this means that the new building is quite different from its neighbors in overall size. In fact, in the detailed analysis of total height, the middle height (see Figure 4) accounted for the rise of the overall height more than the bottom height or the roof height (+284.44% versus +52.84% and +20.16% respectively).

Additional analysis of predicted intervals (Table 2) showed that both the total height and the middle height of building no. 1-1 and the middle height of building no. 1-2 exceeded the normal range, which means both parts (nos. 1-1 and 1-2) of the case-study building are out of character with the surroundings in terms of building height. In addition, the bottom height of building no. 1-2 was smaller than the lowest predicted value. However, the data for the bottom height and roof

TABLE 2. Analysis of predicted intervals (n = 6).

Factor	μ ± ʃ	μ ± 1.96 ʃ	μ ± 2.58 ʃ	Building no. 1-1	Building no. 1-2
Size					
Building total height	26.79-29.54	25.47-30.86	24.62-31.71	32.85	31.60***
Bottom height	5.60-7.14	4.86-7.87	4.38-8.35	6.00*	3.57
Middle height	16.10-17.63	15.37-18.37	14.89-18.84	23.88	22.09
Roof height	3.97-5.90	3.04-6.82	2.44-7.42	2.97***	5.94**
Building total width	16.96-23.19	13.97-26.18	12.04-28.11	14.54**	20.38*
Window height	2.25-2.75	2.01-2.99	1.86-3.15	2.30*	2.30*
Window width	1.30-2.62	.67-3.25	.26-3.66	1.60*	1.60*
Door height	4.22-5.23	3.74-5.71	3.42-6.03	2.30	2.30
Door width	1.48-1.89	1.29-2.08	1.16-2.20	1.85*	1.85*
Proportion					
Building total proportion	1.19-1.67	.96-1.91	.81-2.06	2.26	1.55*
Bottom proportion	.25-.40	.18-.48	.13-.52	.41**	.18**
Middle proportion	.72-.99	.59-1.13	.50-1.21	1.64	1.08**
Roof proportion	.19-.31	.13-.37	.10-.40	.20*	.29*
Window proportion	.84-1.89	.34-2.39	.02-2.71	1.47*	1.47*
Ratio of openings	.17-.24	.14-.27	.12-.29	.50	.45
Color					
Main color hue	38.48-66.53	25.01-79.99	16.32-88.68	42.00*	42.00*
Main color saturation	1.82-13.18	-3.64-18.64	-7.16-22.16	4.00*	4.00*
Main color brightness	72.83-85.83	66.59-92.08	62.56-96.11	93.00***	93.00***
Subcolor hue	-44.94-248.61	-185.85-389.51	-276.85-480.51	189.00*	189.00*
Subcolor saturation	20.29-87.05	-11.76-119.09	-32.46-139.79	36.00*	36.00*
Subcolor brightness	28.66-53.01	16.98-64.69	9.43-72.24	51.50*	51.50*
Main color ratio	.58-.65	.54-.69	.52-.71	.38	.47
Secondary color ratio	.17-.19	.16-.21	.15-.21	.43	.29
Embellishment color ratio	.17-.24	.14-.27	.11-.30	.18*	.23*

Notes. * Value falls within the μ ± ʃ interval; ** value falls within the μ ± 1.96 ʃ interval; *** value falls within the μ ± 2.58 ʃ interval.

height of building no. 1-1 and the roof height of building no. 1-2 were quite similar to those of the neighboring buildings. With regard to the size of the openings, it is clear that both parts of the case-study building fit well with the surrounding context in terms of window height and width and door width but not height.

Proportion

As Table 1 shows, the case-study building introduced great changes to the setting in terms of architectural proportion. The SD of the building total proportion (building height/weight) increased by 46.59%. A considerable increase also occurred in the SD of the middle proportion (120.03%), while there was a slight decrease in the roof proportion (-6.76%). According to these figures, the infill building is quite different from the neighboring buildings in terms of its proportion, especially the middle proportion. In terms of window proportion, the SD decreased by 14.98%, which means the introduction of the infill building did not negatively influence its neighboring buildings. With regard to the ratio of openings, there was a dramatic increase in the SD (273.91%), indicating there is a great difference between the infill building and its neighbors in the ratio of openings.

Additional analysis of predicted intervals (Table 2) showed that, in terms of building no. 1-1, the values for building total proportion and middle proportion were both outside the two-sigma range, while the bottom proportion, roof proportion, and window proportion were all within the normal range and quite close to their means. For building no. 1-2, all of the proportion factor figures were in the range of predicted intervals, except ratio of openings. This indicated that there are many similarities between building no. 1-2 and its neighboring buildings.

MAIN COLOR	42, 4, 93	40, 7, 87	31, 15, 84	60, 2, 70	56, 14, 78	68, 4, 74	60, 3, 83
SUB-COLOR	189, 36, 51	221, 46, 35	346, 27, 38	2, 93, 29	0, 81, 55	24, 6, 31	18, 69, 57

FIGURE 11. Block elevation with HSB information for facade colors.

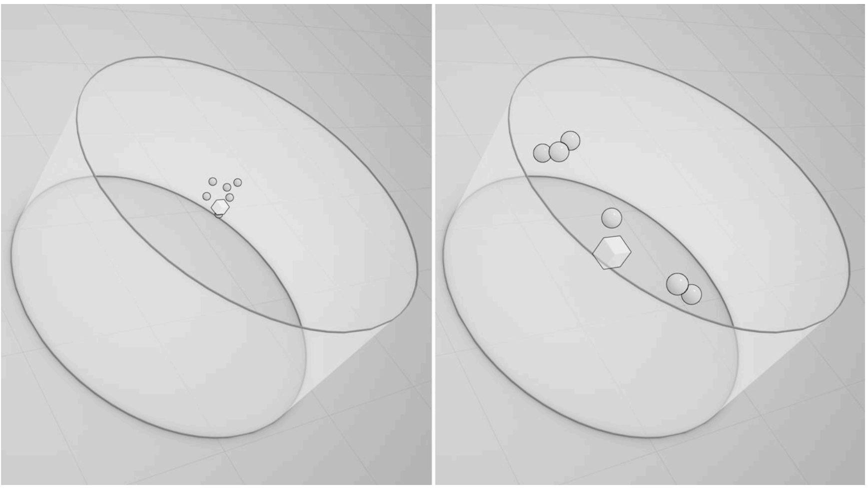

FIGURE 12. Cylinder range of (left) main colors and (right) subcolors.

Color

As Figure 11 shows, a main color and a subcolor were identified for each of the seven parts of the block using the HSB cylindrical coordinate system. To judge whether a color from the Dancing House's facade fit with the colors of the neighboring buildings, the researchers constructed two cylinders (one for the main colors and one for the subcolors) using the six color points of the neighboring buildings as the minimum boundary. In the cylinders, the six colors were represented as points, and any color that was compatible with the six colors was represented as a cube (Figure 12). If the cube representing the color from the Dancing House was contained in the cylinder, it meant the Dancing House had a harmonious relationship with its neighbors in terms of color. The results indicated that both the main color and the subcolor of the Dancing House fell within the color range generated by the neighboring buildings (Figure 12). However, the subcolor cylinder was quite large, indicating that the six subcolors abstracted from the neighboring buildings were quite different from one another in HSB. Thus, while the subcolor of the Dancing House was contained in the cylinder, this really only showed that the new subcolor did not extend the color range.

TABLE 3. Synthetic evaluation of building no. 1-1.

Item	Factor I	Weight	Value	Factor II	Weight	Value
Size (index = .4799)	Building total height	.4347	.2101	Bottom height	.1220	.8750
				Middle height	.6483	.0000
				Roof height	.2297	.4500
	Building total width	.1345	.5000	n/a	n/a	n/a
	Window height	.2164	.8000	n/a	n/a	n/a
	Window width	.1408	.8750	n/a	n/a	n/a
	Door height	.0403	.0000	n/a	n/a	n/a
	Door width	.0333	.7500	n/a	n/a	n/a
Proportion (index = .2813)	Building total proportion	.5430	.2447	Bottom proportion	.1007	.7500
				Middle proportion	.6738	.0000
				Roof proportion	.2255	.7500
	Window proportion	.1160	.9500	n/a	n/a	n/a
	Ratio of openings	.0575	.0000	n/a	n/a	n/a
	Horizontal rhythm	.1529	.2500	n/a	n/a	n/a
	Vertical rhythm	.1307	.0000	n/a	n/a	n/a
Color (index = .5818)	Attributes	.8333	.6853	Main color hue	.4231	.5000
				Main color saturation	.1157	.8500
				Main color brightness	.1860	.8250
				Subcolor hue	.1368	.7500
				Subcolor saturation	.0683	.8750
				Subcolor brightness	.0701	.8500
	Composition	.1667	.0645	Main color	.7504	.0000
				Secondary color	.1713	.0000
				Embellishment color	.0782	.8250
Fit (index = .4270)	Size	.6267	.4799			
	Proportion	.2797	.2813			
	Color	.0936	.5078			

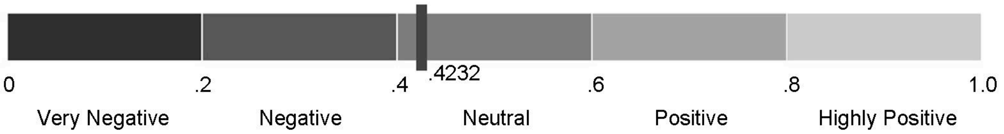

FIGURE 13. Synthetic index results for the entire case-study building.

In the analysis of color composition, the SDs of the main color ratio and secondary color ratio both went up dramatically (151.85% and 608.46% respectively), while the SD of the embellishment color ratio decreased slightly (-7.95%) (Table 1). This meant that the new infill building had a positive relationship with its neighbors in terms of the composition of the embellishment color, but the compositions of both the main color and the secondary color were quite different from those of the neighboring buildings. The ratio of the embellishment color was in the normal, one-sigma range, meaning it was similar to the neighboring buildings (Table 2).

Synthetic Evaluation

Based on the analysis of predicted intervals, the value of each factor was confirmed. Tables 3-5 summarize the synthetic evaluations of building no. 1-1, building no. 1-2, and the entire building.

SUMMARY OF THE ANALYSIS RESULTS

Based on the quantitative analysis and fuzzy synthetic evaluation (Tables 3-5), the overall index for the case-study building was .4232 (Figure 13), indicating that the synthetic degree of fit between

TABLE 4. Synthetic evaluation of building no. 1-2.

Item	Factor I	Weight	Value	Factor II	Weight	Value
Size (index = .5307)	Building total height	.4347	.1723	Bottom height	.1220	.0000
				Middle height	.6483	.0000
				Roof height	.2297	.7500
	Building total width	.1345	1.0000	n/a	n/a	n/a
	Window height	.2164	.8000	n/a	n/a	n/a
	Window width	.1408	.8750	n/a	n/a	n/a
	Door height	.0403	.0000	n/a	n/a	n/a
	Door width	.0333	.7500	n/a	n/a	n/a
Proportion (index = .6350)	Building total proportion	.5430	.6350	Bottom proportion	.1007	.5000
				Middle proportion	.6738	.6000
				Roof proportion	.2255	.8000
	Window proportion	.1160	.9500	n/a	n/a	n/a
	Ratio of openings	.0575	.0000	n/a	n/a	n/a
	Horizontal rhythm	.1529	.7500	n/a	n/a	n/a
	Vertical rhythm	.1307	.5000	n/a	n/a	n/a
Color (index = .5972)	Attributes	.8333	.6853	Main color hue	.4231	.5000
				Main color saturation	.1157	.8500
				Main color brightness	.1860	.8250
				Subcolor hue	.1368	.7500
				Subcolor saturation	.0683	.8750
				Subcolor brightness	.0701	.8500
	Composition	.1667	.1567	Main color	.7504	.1000
				Secondary color	.1713	.1000
				Embellishment color	.0782	.8250
Fit (index = .5661)	Size	.6267	.5307			
	Proportion	.2797	.6350			
	Color	.0936	.5972			

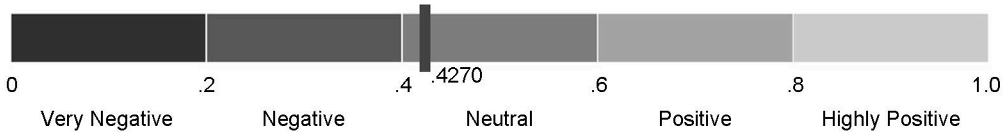

FIGURE 14. Synthetic index results for building no. 1-1.

the building and its neighbors was neutral in terms of facade size, proportion, and color. Closer examination of the synthetic evaluation results of building no. 1-1 and building no. 1-2, whose indices were .4270 and .5661 respectively (Figures 14-15), revealed that building no. 1-2 had established a more harmonious relationship with its neighbors than building no. 1-1, especially in terms of size and proportion.

As previously stated, infill buildings in historic contexts should respect the specific features of their settings; otherwise, they are unlikely to be compatible with their surroundings. The statistical analysis of the main parameters in this case study showed that, although the new building is higher and wider than the surrounding buildings, it establishes a compatible relationship with its surroundings when considered in its two constituent parts. In addition, the analysis of architectural proportion indicated that the dimensions of the windows (height x width) were very harmonious in this case. Closer inspection revealed that the windows were roughly similar in shape and size; in particular, the horizontal rhythm of building no. 1-2 was much more consistent with that of its neighboring buildings, compared with its vertical rhythm. Due to the varying placement of windows in building no. 1-1, neither the horizontal nor the vertical rhythm was compatible with the other buildings on the block. Moreover, the study found that the application of the main color and subcolor was quite successful in terms of color attributes. Although the evaluations of the compo-

TABLE 5. Synthetic evaluation of the entire case-study building.

Item	Factor I	Weight	Value	Factor II	Weight	Value
Size (index = .4312)	Building total height	.4347	.2528	Bottom height	.1220	.4250
				Middle height	.6483	.0000
				Roof height	.2297	.8750
	Building total width	.1345	.0000	n/a	n/a	n/a
	Window height	.2164	.8000	n/a	n/a	n/a
	Window width	.1408	.8750	n/a	n/a	n/a
	Door height	.0403	.0000	n/a	n/a	n/a
	Door width	.0333	.7500	n/a	n/a	n/a
Proportion (index = .3514)	Building total proportion	.5430	.3136	Bottom proportion	.1007	.8750
				Middle proportion	.6738	.0000
				Roof proportion	.2255	1.0000
	Window proportion	.1160	.9500	n/a	n/a	n/a
	Ratio of openings	.0575	.0000	n/a	n/a	n/a
	Horizontal rhythm	.1529	.2500	n/a	n/a	n/a
	Vertical rhythm	.1307	.2500	n/a	n/a	n/a
Color (index = .5841)	Attributes	.8333	.6853	Main color hue	.4231	.5000
				Main color saturation	.1157	.8500
				Main color brightness	.1860	.8250
				Subcolor hue	.1368	.7500
				Subcolor saturation	.0683	.8750
				Subcolor brightness	.0701	.8500
	Composition	.1667	.0782	Main color	.7504	.0000
				Secondary color	.1713	.0000
				Embellishment color	.0782	1.0000
Fit (index = .4232)	Size	.6267	.4312			
	Proportion	.2797	.3514			
	Color	.0936	.5841			

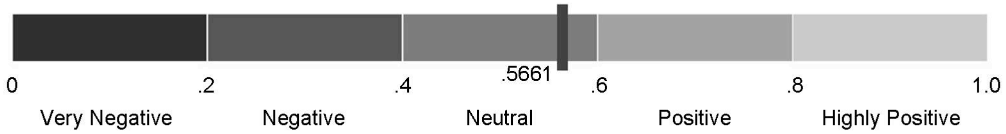

FIGURE 15. Synthetic index results for building no. 1-2.

sitions of both the main color and the secondary color were not positive, the ratio of embellishment color made a great contribution to the harmony of the color composition. In conclusion, the results indicated that, despite its apparent contrasting design style, the Dancing House actually establishes a compatible relationship in some aspects with the neighboring buildings.

Potential Weaknesses of the Quantitative Model

This quantitative research method does have a number of weaknesses that should be addressed before concluding the discussion. For simplification, this study focused on the two-dimensional elevation of the case-study building, and the architectural attributes selected involved a limited number of the variables that would influence the visual impact of the facade. Further, although the selection of the attributes was based on previous research, each historic setting is unique, and the key features in each historic setting are absolutely different. Thus, a comprehensive, hierarchical facade-feature system should be established for each specific location.

The application of the synthetic evaluation in this research was an attempt to provide a comprehensive analysis model involving quantitative analysis with the aim of reducing the ambiguity of traditional analytical approaches. The weight of each factor in this research was determined by

AHP, a method of combining qualitative and quantitative methods organically. However, in the process of analysis, the structure of the judgment matrix was largely based on the experience of the experts leading the qualitative part of the analysis.

This paper proposes a quantitative way to analyze and assess building facades and to provide a reference for new infill design; however, this approach cannot be the only foundation for designing a successful infill building in a historic context. Indeed, architectural design is a complicated process involving rational analysis and logical thinking, as well as creativity, which is why the vision of architects is essential. The proposed quantitative model is only a tool to assist designers and those assessing the appropriateness of new proposals. Generally speaking, judgments of aesthetics and contextual fit are both subjective and objective. The subjective part comprises feelings or cognitive evaluations that individuals have about a historic setting, while the objective part consists of the physical attributes of the setting itself. This research proposes an objective scientific tool to assist with the creation of more harmonious infill buildings in terms of physical building attributes. In this context, more studies need to be undertaken to address the combination of subjective evaluation and objective analysis.

CONCLUSION

Generally, the main quality sought in the design of infill developments in historic settings is harmony with the surrounding context in order to ensure “a visually integrated — but not necessarily homogeneous — townscape” (Brolin, 1980:16). In measuring the fit between new and old, this paper demonstrates that quantitative analysis can play an important role by providing a rational reference during the design and/or evaluation process, particularly in evaluating the contextual fit of designs in terms of architectural size, proportion, and color.

The concept of harmonic proportion has been a commonly accepted principle in architectural design for a long time, with its origins in classical antiquity. In simple terms, it requires that the proportions of all parts of a building are rationally integrated with and sympathetic to neighboring buildings. In an urban context, this often means that a new building’s facade needs to relate to a whole street frontage or area of townscape (Richards, 1994). In this context, new infill designs in historic settings draw inspiration in terms of proportion from their neighbors.

To avoid an inharmonious color combination or color appearance in historic settings, building facade colors should also be designed with consideration for the characteristics of both the building and its environment. Accordingly, the proposed facade color of a new infill development should be assessed at the scales of both the setting and the building. If a color study relies only on the building itself, an undesirable appearance can result, especially in historic contexts. Thus, a detailed quantitative study is essential for the color design of new buildings in historic settings.

Alexander, *et al.* (1987:22) argued that “every increment of construction must be in such a way as to heal the city [and] every new act of construction has just one basic obligation: it must create a continuous structure of wholes around itself.” This is an organic, incremental approach that stresses continuity rather than rupture, typical of the way in which most traditional cities have evolved. Accordingly, when designing new buildings in historic settings, the main aim is to achieve a successful design that not only respects the historic features of the setting but also enhances the value of the setting. The quantitative model of assessment advocated in this paper, while not attempting to stifle design creativity, would provide scientific design cues for infill design within a historic context, as well as an alternative way of thinking and working, in order to increase the likelihood of success. Further, a quantitative approach could be used to reduce the vagueness and uncertainty of design guidance by conducting scientific analysis of historic settings and thereby enhancing planning policy.

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