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Cultural evolution in Vietnam's early 20th century: A Bayesian networks analysis of Hanoi Franco-Chinese house designs

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This work is dedicated to the late professor André Farber (1943–2017) of l'Université Libre de Bruxelles.

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ABSTRACT

The study of cultural evolution has taken on an increasingly interdisciplinary and diverse approach in explicating phenomena of cultural transmission and adoptions. Inspired by this computational movement, this study uses Bayesian networks analysis, combining both the frequentist and the Hamiltonian Markov chain Monte Carlo (MCMC) approach, to investigate the highly representative elements in the cultural evolution of a Vietnamese city's architecture in the early 20th century. With a focus on the façade design of 68 old houses in Hanoi's Old Quarter (based on 248 photos and 78 data lines), the study argues that it is plausible to look at the aesthetics, architecture, and designs of the house façade to find traces of cultural evolution in Vietnam, which went through more than six decades of French colonization and centuries of sociocultural influence from China. The in-depth technical analysis, though refuting the presumed model on the probabilistic dependency among the variables, yields several results, the most notable of which is the strong influence of Buddhism over the decorations of the house façade. Particularly, in the top 5 networks with the best Bayesian Information Criterion (BIC) scores and small *p*-values, the variable for decorations (DC) always has a direct probabilistic dependency on the variable B for Buddhism. The paper then discusses these findings and suggests integrating Bayesian statistics in social sciences in general and for studies of cultural evolution and architectural transformation in particular.

1. Introduction

"Les temples et les Bouddhas de pierre pour mes pères

Les femmes courbées dans les rizières pour mes mères

Dans la prière, dans la lumière, revoir mes frères

Toucher mon arbre, mes racines, ma terre …"

– "Bonjour Vietnam" by Marc Lavoine

The application of Bayesian analysis could foster a stronger and more unified framework for social scientific statistical practice (Gill, 2002; Jackman, 2000, 2009). In the Bayesian methods, because all unknown quantities are treated probabilistically, researchers are positioned to be more cautious and prudent in evaluating the evidence of an effect, avoiding the trap of overestimating effects, or more dangerously, committing logical inconsistencies (Gill, 2002; Kruschke, 2015; McElreath, 2016). The temporal dynamics of observable data in social sciences make the field particularly suitable for Bayesian analysis, which does not assume having infinite amounts of forthcoming data. As such, social scientists can update prior distributions by conditioning on newly

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observed data (Gill, 2002), and refine their inferences when being explicit about estimation biases (Malakoff, 1999). While researchers of archeology and sociology are indeed turning to the Bayesian approach to systematically include qualitative, narrative, and intuitive knowledge into statistical models (Crema, Edinborough, Kerig, & Shennan, 2014; Dediu, 2009; Griffiths & Kalish, 2007; Matthews, Tehrani, Jordan, Collard, & Nunn, 2011; Oinonen et al., 2014; Pagel & Meade, 2005, 2006; Perreault, Moya, & Boyd, 2012; Reali & Griffiths Thomas, 2010; Riede & Edinborough, 2012), the method remains in obscurity among social scientists in Vietnam, where research methodologies are either qualitative or quantitative based on the classical statistical approaches. In an attempt to demonstrate the applicability of Bayesian analysis in the social sciences in general and in the field of cultural evolution in particular, this study seeks to break down the architectural evolution of a Vietnamese city in the early 20th century. The case study will shed light on: (i) how a rigorous Bayesian networks analysis is carried out using a rather small volume of data, (ii) how the presumed model of a social science research may be dismissed to give way for unexpected but insightful results, and notably, (iii) how researchers in societies with similarly syncretic or hybrid behaviors, either due to colonialism or imperialism, could apply this perspective and method to analyze these features.

Showcasing the merits of the Bayesian technique aside, this study also seeks to study cultural evolution from a perspective – the architectural evolution and its underlying influencing elements – unlike much of the extant literature. The scholarship on cultural evolution addresses the issues surrounding the adaptive cultural processes that result from the cognitive details of human social learning and inference (Boyd and Richerson, 1996; Henrich, 2004; Henrich & McElreath, 2003). Within this field, researchers are often divided into two camps, one espousing for taking evolutionary biology as a reference point to illustrate the Darwinian evolutionary properties of human culture (Boyd & Richerson, 1985; Cavalli-Sforza & Feldman, 1981; Mesoudi, Whiten, & Laland, 2006; Youngblood & Lahti, 2018), and the other refusing to simplify modes of cultural transmission by use of analogy with modes of genetic transmission because the two domains do not share the same properties (Blackmore, 2006; Claidière & André, 2012; Dennett & McKay, 2006; Fuentes, 2006; Mulder, McElreath, & Schroeder, 2006). While this kind of debate may go on, it has become clear that this interdisciplinary field has rich insights on the ways human beings behave over time.

In this regard, the current research adds to the literature on architectural evolution, such as on the rural cemetery of the Anglo-American (Schuyler, 1984), the Soviet structures under Stalin (Paperny, 2002), the distribution of Egyptian military bases over time and across borders (Ellen, 2004), the wooden long-houses on the Pacific Northwest coast (Jordan & O'Neill, 2010). More importantly, it underlines the slow pace at which cultural evolution occurs—that practices and artifacts recorded in social anthropology and history were the results of years, decades, and even centuries of influence and transformation. As large-scale architecture has the power to stir up "romantic nostalgia for a lost world in which one has not participated, but which might be imagined or scientifically resurrected" (Houston, 1998, p. vii), in examining the evolving house front designs in the old streets of Hanoi, the study aims to evoke a meaningful discussion on the intertwined relationship between a longing for the past and a yearning for modernization. The nostalgia is best captured in the paintings of old Hanoi streets by the Vietnamese artist Bui Xuan Phai, whose name is synonymous with oil paintings about bygone Hanoi Old Quarter—"*Phố Phái*" (literally, "Street Phai") (Taylor, 1999). Bui Xuan Phai (1920–1988) is one of the "Four Pillars" of Vietnamese paintings, belonging to the realm of folklore and myth (Naziree, 2006; Taylor, 1999; Thai, 1994). "*Phố Phái,*" originated from the early 1960s (TT&VH, 2010), implies not just the Vietnamese respect for a great artist but also a symbol of aesthetics in the Vietnamese souls. Fig. 1 is an example of "*Phố Phái*"—the brown brick roofs, the whitewashed walls, the black undecorated windows, and the nearly empty narrow streets and alleys.

Fig. 1. A painting of Hanoi Street by Bui Xuan Phai (2012).

These paintings have captured the very essence of what is known in Vietnam as the "tube house" ("*nhà ống*")—traditionally attached street houses whose widths are narrow while their lengths are very long (Kien, 2008a; b). This research, inspired by "*Phố Phái*" and the cultural-historical continuity as reflected in Hanoi architecture, will delve into the elements of cultural and religious influences in the house designs, especially the façade. More importantly, the research situates itself amid the rapid urbanization and commercialization in Vietnam as it tries to capture the old fragments of the capital city. Many old houses in Hanoi are being changed and may not stand the test of time. The internal structure of the houses would make for an interesting inquiry, but the research's focus on the house façade alone is driven by the principal concern over "face" in Confucian society. In other words, the front of house reflects the face of the family, and therefore, its culture. As Vuong et al. (2018b) have shown, the "cultural additivity" in Vietnamese architecture is reflected in the front of a house in the co-existence of French-styled columns, Confucian scrolls, the Taoist yin-yang sign, and the Buddhist lotus sculpture. The statistical analysis, therefore, will show how French and Chinese cultures have influenced the designs of the old houses in Hanoi.

1.1. Research questions

This research sets out to answer the following two questions:

RQ1 Is it plausible to look at the aesthetics, architecture, and designs of the house façade in Hanoi to find traces of cultural evolution in the early 20th century in Vietnam, which went through more than six decades of French colonization and centuries of sociocultural influence from China?

RQ2 What are the most notable elements that affect the perception of cultural evolution of Vietnamese people who are familiar with or have been exposed regularly to this type of architecture and cultural behavior?

2. Literature review

2.1. Franco-Chinese aesthetics and architecture in Vietnam

Given the cultural specificity of this study, it is important first to be familiar with the aesthetics and architectural history of Vietnam and Hanoi. French troops captured the citadel of Gia Dinh in 1859, defeating the last Vietnamese dynasty Nguyen and paving the way for its establishment of French Indochina (initially comprising Annam, Tonkin, and Cochinchina) in 1887. Under French imperialism, the Cornudet Law that

was passed by its government in 1919 stipulated the rules for urban planning and development in its colonies, such that contemporary Western construction techniques would take into account the native aesthetics and humid tropical climate (Le, 2013; Nguyen, 2014; Vongvilay, Shin, Kang, Kim, & Choi, 2015). This style, made famous by the French architect Ernest Hebrard, comes to be known as the *Indochine* style—which is an effortless fusion of traditional Vietnamese and grand European elements for both aesthetics and practical purposes (Le, 2013).

According to Nguyen (2014), the development of Indochinese architecture peaked in Vietnam in 1920–1945 and waned in the 1960s. In the post-1945 period, the designs were either filled with nostalgia and longing for traditions or touched with some stroke of creativity from the internationalization trend at the time (Nguyen, 2014). In a slightly different account, Herbelin (2016) argues that this movement took place in 1920–1930, with one wave of affluent Vietnamese people building houses entirely in the footsteps of the French and another pursuing a more modern style incorporating northern Vietnamese decorative elements. However, the architectural fusion, which used both indigenous construction materials such as bamboo, wood, hut, mud and metropolitan materials such as iron, concrete, tiles, and bricks, turned out to be costly and only those very wealthy could afford it (Herbelin, 2016).

In the past decade, there have been many monumental works on the French architecture and urban planning in Vietnam, particularly the Indochine style seen in Hanoi and Saigon (now Ho Chi Minh City). For example, Tran and Nguyen (2012) have provided a meticulous and comprehensive work on the legacy of French architecture in Hanoi, documenting the changing cityscape from as early as the mid-nineteenth century and comparing it with the construction of Indochine houses in Saigon in the early twentieth century. Walker (2011), together with photographer Jay Graham, has published over 300 colored photos of the architecture, furniture, and handicrafts in Vietnam, Laos, and Cambodia, drawing insights into the combined influence of Indian, Chinese and French traditions in this region. More recently, Herbelin (2016) has taken a contrarian view by pointing out that the Indochine style was not entirely successful due to its high cost, which prompted the French to return to its classical design, such as in the case of the then Ministry of Finance (1927) and now Ministry of Foreign Affairs. Taking a departure from the popular praises of Saigon as "the pearl of the Far East" and Hanoi as comparable to Paris, Herbelin (2016) instead shows how the architecture in Vietnam under French colonialism was the result of negotiations and political strategies between various authorities, between colonial and local authorities, between the native population and the French, as well as between the different technical and aesthetic solutions that were offered at that time. The book reveals, thus, there is no such thing as a proper colonial architecture but just a phenomenon of hybridization, of intertwined cultures that contribute to the colonial moment (Thu Hang, 2017). Along this vein, Truong (2012) analyzes the harmonization of Eastern and Western elements in the Indochine style in Vietnam to conclude on there being a strong imprint of traditional Vietnamese architecture. The Indochine style, the author argues, was after all born in Vietnam, and without doubt carries a large part of the native architectural elements, such as the use of wood and bamboo and the addition of balconies, verandahs, and internal corridors to accommodate the hot and humid tropical climate.

From a broader perspective, Hartingh, Craven-Smith-Milnes, and Tettoni (2007) review Vietnamese architecture from ancient to modern time and conclude that, although Vietnam's interior design has a touch of both Chinese and European cultures, the native design is quite diverse thanks to the varying characteristics of different Vietnamese localities. The book showcases the diversity of Vietnamese culture, as evidenced by the myriad temples, shrines, and pagodas across the country. Similarly, when looking at the traditions of Vietnamese architecture, Chu (2003) has documented a rich history of folkloristic architecture, from the way each household unit builds its house to the way a village and its folks contribute to the traditional architecture.

For the purpose of this study, based on extensive research on the topic, the team has summarized some notable ornamental characteristics in Table 1. These characteristics will form the basis of the analysis into the house façade in Hanoi.

2.2. Hanoi Old Quarter and the house façade designs

Upon its settlement in Hanoi in the late 19th century, the French soon began building its own streets and administrative offices. In 1883, the first governor issued a plan to turn some streets in the southeast of the Sword Lake (Ho Hoan Kiem)—equivalent with the streets of Le Phung Hieu, Ly Thai To, Le Thanh Ton, and Ngo Quyen today—fully into the style of French architecture. This area, dubbed by the Vietnamese as the

Table 1
A summary of the non-Vietnamese and Vietnamese use of materials and ornamental designs.

	Non-Vietnamese	Vietnamese
Materials	Rock serves as one of the main materials in Western construction, such as in columns and balcony.	Rock is rarely used in house façade, instead it is used in sculpture of sacred animals.
	Cement is also an important Western invention but is costlier and not as flexible as a construction material.	Ornamental designs are made primarily of ceramics. Meanwhile, houses are built of wood, and monuments are built of bricks.
	The use of ceramics in ornamental design originated from southern China and became popular in Vietnam since the Nguyen dynasty (1802–1945).	The Vietnamese combination of honey, lime, paper pulp, and bagasse created a kind of dry mix mortar (*nề vữa*) suitable for construction.
Ornaments	Flowers of Chinese origins: lotus (Buddhism), chrysanthemum (Taoism), or peony (China's unofficial national follower)	In the façade of many houses in Hanoi, the pattern known as "Lily of the valley" (*Hoa huệ tháng Năm*) is the most popular. Examples: - K Hospital today, earlier the Radium Institute of Indochina (1915–1920). - Houses on 94 Hang Bong, 57 Hang Dieu, 161 Phung Hung, 23 Nguyen Quang Bich, 144 Nguyen Thai Hoc (1920–1945)
	Flowers and leaves associated with the West: lilies, tulip, olive branches, oak leaves, pine fruit, laurel branches, etc.	There is a dearth of Vietnamese research on the use of lily as an ornamental feature in architecture, although much has been written on the popularity of lily in the famous paintings of To Ngoc Van, Le Pho, Tran Van Can.
	Seashell: an image seen from the ancient time, featured prominently in Western aesthetics.	The Vietnamese folk belief has long looked down on shells (*nghêu - sò - ốc - hến*), and thus, these images were never used in the native decorations.
	While ancient Chinese people had used shells (贝) as a form of currency to exchange for precious things, only with some Western influence did China begin to use shells in ornamental designs.	With French influence, the image of seashell has appeared in some French architecture in Hanoi. Examples: - The Workers' Theatre on Trang Tien street (earlier Cinema Palace). - Cambodia Embassy (71a Tran Hung Dao). - Buildings on 107 Tran Hung Dao, and 64–68 Ly Thuong Kiet, 190 Hang Bong.
	Traditional Chinese symbols: wine gourd, coin, four sacred flowers, four sacred mythical creatures (Taoism), words such as 寿 (longevity), 福 (happiness), 乐 (joy), 喜 (delight), 万 (ten thousand/great number).	

"Western quarter," stands in contrast with the old commercial area that is known as Hanoi's 36 streets located in the north of the Sword Lake (Dinh & Groves, 2006). A recent review of French urban planning in Hanoi pointed out that the French had built 157 streets in their style here between 1884 and 1945, of which 74 were strictly French with houses built in accordance with European style (Phan, Nguyen, Dao, Ta, & Nguyen, 2017). Table 2 summarizes the three major periods of French influence over Hanoi architecture, based on the research by Tran Hau Yen The (2011).

Studies on the house façade in Hanoi Old Quarter have taken mostly a qualitative approach, delving into the ornamental designs and their historical and aesthetic values, as shown by Tran Hau Yen The (2011) and Phan Cam Thuong (2008). When looking at the house façade, one of the outstanding features is the combined use of Vietnamese national script (*Chữ Quốc Ngữ*), French, and Chinese (*Hán*) characters on advertisement billboards and entryways. The construction of many houses in Hanoi prior to 1945 shows the undeniable aesthetic appeal of having some Chinese texts on the façade. The display of written texts on the house façade, according to Tran Hau Yen The (2011), was a practice originated from Europe. Thanks to such inscriptions, one could observe the transforming aesthetics in Hanoi, from pure European style to an integrated East-West style.

The extensive literature review here lays an important foundation for this study. The aesthetic features to be examined are not only highly representative of their originating cultures, whether that be French or Chinese, but are also reflective of the relationship between the architectural theories and practical application. On this basis, the research team could categorize the most notable variables and structure the coding of such data in its Bayesian model. The following section will go into details the materials and methods of this research.

3. Materials and methods

3.1. Materials

This study started in 2007 when our artist, Bui Quang Khiem, started to take pictures of old houses in the Old Quarter of Hanoi. Each street in the 36 streets was originally home to a different trade, as reflected in the name of the street, such as Hang Bun for Rice Noodle Street or Hang Non for Conical Hat Street (Dinh & Groves, 2006). As the craftsmen and traders brought their village culture and customs to Hanoi, the city saw an emergence of buildings characteristic of traditional Vietnamese village life, such as the communal house (*đình*), village pagoda (*chùa*), or village gate (*cổng làng*). Most of the houses in these streets were built during the French colonial period and they exhibit the typical characteristics of the two-storied tube houses built around the 20th century (Kien, 2008b). These houses are influenced by the architecture of the French houses and also reflect the wealth of their owners (Dinh & Groves, 2006). From 2007 to 2018, Bui Quang Khiem took more than 500 pictures of the façades of the old houses around Hanoi. Fig. 2 shows two examples. The process of photo-taking is meticulous and time-consuming, given the lively economic life of the city and the country (Vuong, 2014). Many of the houses are covered in advertisement boards, as these houses are still used for daily activities, including small businesses. Hence, the photographer had to wait for the moment when the advertisements boards were put away. Many of the houses have been destroyed during the time and the pictures are the limited documents left of them. All of the pictures have been deposited openly online in the Open Science Framework (OSF)'s database and can be accessed at https://osf.io/tfy6k/.

In September 2018, the research team started to select pictures that are suitable for the purpose of this study. This study has left out the

Table 2
An overview of the major historical events and characteristics of Hanoi architecture from 1860 to 1945, based on the research by Tran Hau Yen The (2011).

Time period	Historical notes	Hanoi architecture	Notable examples
1860–1900	Only French army engineers could design and build houses, thanks to their experience in building army bases in Algeria. French troops officially took over Hanoi in 1882.	Most constructions were for military residence, jail/prison, and church. "Early colonial architecture": all architectural designs were imported straight from France and Europe (Vietnam Associations of Architects, 2003).	- Vietnam Military History Museum (earlier Hôtel du quartier général de l'armée) (1877) - Notre-Dame Cathedral Basilica of Saigon (1877–1880) - St. Joseph's Cathedral in Hanoi (1883–1887)
1900–1920	The French began building administrative offices and houses in the city. Rapid urbanization gave rise to many urban centers and resort towns from the north to the south. The École Française D'Extrême-Orient (EFEO), French School of Asian Studies, was founded in 1900, headquartered in Hanoi.	The dominant architecture is classical and neoclassical style with a touch of different French regions.[a] Major administrative buildings were built in the grand style, all designs were strictly symmetrical.	- Hanoi Presidential Palace (earlier, Residence of the Governor-General of French Indochina) (1901–1907) - Vietnam People's Supreme Courthouse (earlier Courthouse) (1906). - Hanoi Opera House (earlier Municipal Theatre) (1901–1911).
1920–1945	This period saw an integration of East-West values in the local architecture, evidenced in the designs of the roof, console system, and various decorations. EFEO established a full Archeological Service, appointing both European and local staff as faculty and assistants in the preservation and restoration of historical monuments in Indochina (Clementin-Ojha & Manguin, 2007).	The Indochine style (Ernest Herbrad, Charles Batteur): more attention paid to the roof, ventilation, patios, doors and windows; designs taking into account symbols originated from Buddhism, Confucianism, and Taoism. The Franco-Chinese style: more elaborate Chinese decorations in Western buildings, more emphasis on the chimney and the surface design of the roof. The windows and doors of this style do not have as many shutters as those in the Indochine style. The Art Décor style: became popular in 1930–1945; known for its usage of geometric shapes, zigzag lines, bold color and patterns, and metallic/iron materials.	- Vietnam Museum of History - Vietnam Ministry of Foreign Affairs - House No. 18 on Le Hong Phong Street - State Bank of Vietnam Headquarters (earlier Banque de l'Indochine) - Villa No. 9 on Le Hong Phong Street. - Trang Tien Palaza (earlier Godard House)

[a] According to Tran Hau Yen The (2011) , these differences are as follows: Northern France: cold, snowy, steep roof, undecorated with a larger ratio for the roof; wall made of only one material—often rock or artificial rock. Northeast France: wooden structure attached to the wall, influenced by Germany and the Netherlands. Central France: roofless steep (about 35–45 degrees) and using more wooden console, roof decorated with ceramic brick; shuttered windows; main materials being brick, ceramic, porcelain, and wood. Southern France: similar to the North, but height of houses shorter, with bigger yard; main materials being rock with roof using pipe tiles.

Fig. 2. Two examples of the photos of Hanoi's old houses used in this study.

pictures that were not taken from a direct angle or did not show the decorative details or of not good quality. In the end, 248 photos of 68 old houses were chosen and encoded into 78 data lines in the excel sheet. The OSF's folder that stores these photos is "Sorted images of Hanoi Houses", which can be accessed at https://osf.io/tfy6k/. The following section describes how the photos are encoded and the next section describes the statistical method employed in this study, the Bayesian Network analysis.

3.2. Construction of variables

The full dataset is stored in the file "FCCE1.181113.csv", which is deposited openly in OSF's sub-folder "Processing + Suppl" in the folder "Statistical Investigations" [Doi: https://osf.io/tfy6k/].

Dependent variables:

- **TR: Short for "The traditional feeling."** This categorical variable takes on one of these values strong, medium or none (coded as *"TR_S," "TR_M"* and *"TR_N*" respectively)
- **MD: Short for "The modern feeling."** This categorical variable takes on one of these values strong, medium or none (coded as *"MD_S," "MD_M*" and *"MD_N"* respectively). Strong means the façade brings a feeling of French-ness, Medium means the façade is a good mixture of Franco and Chinese style, none means the French-ness is unclear or none at all.
- **CE: Short for "Cultural evolution."** This categorical variable is about the cultural evolution and acculturation being represented on a façade. It takes on one of these values: beginning, strong representation of cultural evolution (evolving), or complete (coded as *"C_B," "C_E"* and *"C_C"* respectively). When a façade looks traditional, it is judged the cultural evolution and acculturation process just started *("C_B")*. When a façade looks like there is a tradition from the traditional and the modern, it is judged the cultural evolution and acculturation process is evolving *("C_E")*. When a façade looks like it is completely modern and similar to the houses in modern Hanoi, it is judged the cultural evolution and acculturation process has been completed *("C_C")*. All of the team members participate in making this judgment, each makes his or her decisions in choosing the value for the houses independently.

Independent variables:

- **B: Short for "Buddhism-inspired decorations."** This categorical variable takes on one of these values: strong, none or weak (coded as *"B_S," "B_N"* and *"B_W"* respectively). Based on the appearances of Buddhism-inspired patterns/symbols such as flower, peach, lotus, wheel, etc., we rate how strong the characteristic of Buddhism on the façade is. When patterns/symbols are in the center, big or repeatedly used, it is rated as strong.
- **T: Short for "Taoism-inspired decorations."** This categorical variable takes on one of these values: strong, none or weak (coded as *"T_S," "T_N"* and *"T_W"* respectively). Based on the appearances of Taoism -inspired patterns/symbols such as cloud, the octagonal *feng-shui bagua* mirror to ward off bad energy, yin-yang, etc., we rate how strong the characteristics of Taoism on the façade is. When patterns/symbols are in the center, big or repeatedly used, it is rated as strong.
- **C: Short for "Confucianism-inspired decorations."** This categorical variable takes on one of these values: strong, none or weak (coded as *"C_S," "C_N"* and *"C_W"* respectively). Based on the appearances of Confucianism -inspired patterns/symbols such as dragon, Chinese characters, paper rolls, etc., we rate how strong the characteristics of Confucianism on the façade is. When patterns/symbols are in the center, big or repeatedly used, it is rated as strong.
- **DC: Short for "Decoration."** This categorical variable takes on one of these values: French, Chinese or Hybrid (coded as *"DC_FR," "DC_CN*" and *"DC_HY"* respectively).
- **DO: Short for "Door."** This categorical variable takes on one of these values: French, Chinese or Hybrid (coded as *"DO_FR," "DO_CN*" and *"DO_HY"* respectively).
- **PL: Short for "Pillar."** This categorical variable takes on one of these values: French, Chinese or Hybrid (coded as *"PL_FR," "PL_CN*" and *"PL_HY"* respectively).
- **RF: Short for "Roof."** This categorical variable takes on one of these values: French, Chinese or Hybrid (coded as *"RF_FR," "RF_CN*" and *"RF_HY"* respectively).

3.3. The initial conceptual model

Fig. 3 presents the initial Bayesian network model for the probabilistic dependency among the variables. DC is probabilistically dependent on C, T and B. MD is probabilistically dependent on DC, RF, PL, and DO. Meanwhile, TR is probabilistically dependent on DC. CE is probabilistically dependent on TR and MD. These relationships are encoded into a directed acyclic graph (DAG) and its visualization can be seen in Fig. 3.

This study deployed the **bnlearn** package (short for "Bayesian network learning") to create the DAG, for further technical explanation, see *Bayesian Networks - With Examples in R* of Scutari and Denis (2014).

To create the DAG, the following codes are run in the program R (v.3.3.1).

```
library(bnlearn)

dag <- empty.graph(nodes = c("B", "T", "C","DC","RF","DO","PL","MD","TR","CE"))
nodes(dag)
```

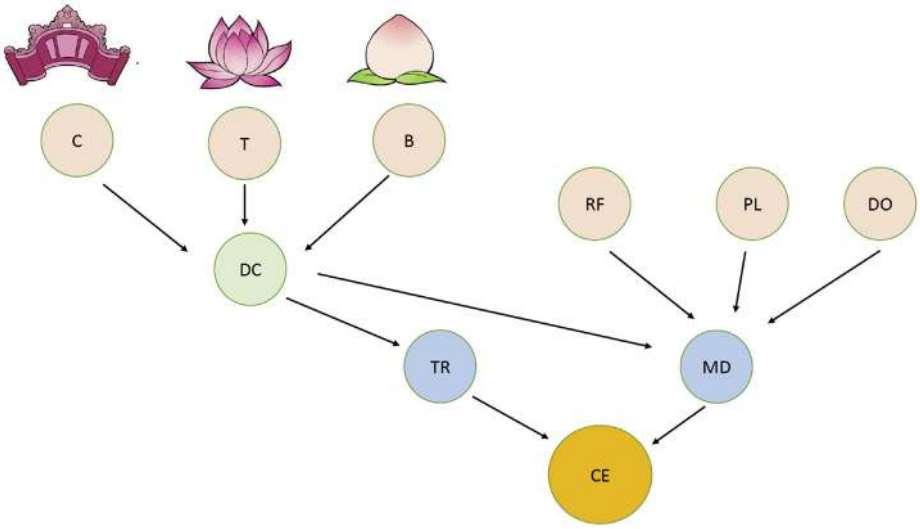


Fig. 3. The initial Bayesian network model. A directed acyclic graph which represents the probabilistic dependency among the variables.

It is important to note that in the beginning the DAG is an empty graph, meaning there is no probabilistic dependencies encoded in it. The next step is to add the relationships among the variables.

```
dag <- set.arc(dag, from = "B", to = "DC")
dag <- set.arc(dag, from = "T", to = "DC")
dag <- set.arc(dag, from = "C", to = "DC")

dag <- set.arc(dag, from = "RF", to = "MD")
dag <- set.arc(dag, from = "PL", to = "MD")
dag <- set.arc(dag, from = "DO", to = "MD")

dag <- set.arc(dag, from = "DC", to = "TR")
dag <- set.arc(dag, from = "DC", to = "MD")

dag <- set.arc(dag, from = "TR", to = "CE")
dag <- set.arc(dag, from = "MOD", to = "CE")
```

To test whether the DAG is correct, the plot function can be used. The result can be seen in Fig. 4.

```
modelstring(dag)
[1]
"[B][T][C][RF][DO][PL][DC|B:T:C][MD|DC:RF:DO:PL][TR|DC][CE|MOD:TR]"

plot(dag)
```

The formal definition of how the dependencies are encoded in the map into the probability space via conditional independence relationships is provided in Equation (1):

$$\begin{aligned}&\Pr(C,T,B,DC,\ RF,PL,DO,\ MD,TR,CE)\\&=\Pr(C)\Pr(T)\Pr(B)\Pr(RF)\Pr(PL)\Pr(DO)\Pr(DC|C,T,B)\Pr(MD|DC,\\&RF,PL,DO)\Pr(\mathrm{TR}|\mathrm{DC})\Pr(CE|MD,TR)\end{aligned}\tag{1}$$

The conditional probabilities in the local distributions can be estimated with the empirical frequencies in the datasets, for example, Equation (2) shows the conditional probabilities of a façade exhibits a strong presence of cultural evolution given it also gives off a strong feeling of modern:

$$\begin{aligned}\widehat{PR}(CE=CE\_E|MD=MD\_S)&=\frac{\widehat{Pr}(CE=''CE\_E'',MD=MD\_S)}{\widehat{Pr}(MD=MD\_S)}\\&=\frac{number\ of\ observations\ for\ which\ CE=CE\_E\ and\ MD=MD\_S}{number\ of\ observations\ for\ which\ MD=MD\_S}\end{aligned}\tag{2}$$

This is the classic frequentist and maximum likelihood estimates, for further discussions, see (Scutari & Denis, 2014). In this study, in order to evaluate the structure of the Bayesian networks, the Bayesian Information Criterion (BIC) score (Equation (3)) is employed:

$$\begin{aligned}BIC=&\ \log\widehat{\Pr}(C,T,B,DC,\ RF,PL,DO,\ MD,TR,CE)-\frac{d}{2}\log n\\=&\left[\log\widehat{Pr}(C)-\frac{d_C}{2}\log n\right]+\left[\log\widehat{Pr}(B)-\frac{d_B}{2}\log n\right]+\left[\log\widehat{Pr}(T)\right.\\&\left.-\frac{d_T}{2}\log n\right]+\left[\log\widehat{Pr}(RF)-\frac{d_{RF}}{2}\log n\right]+\left[\log\widehat{Pr}(PL)-\frac{d_{PL}}{2}\log n\right]\\&+\left[\log\widehat{Pr}(DO)-\frac{d_{DO}}{2}\log n\right]+\left[\log\widehat{Pr}(DC|C,B,T)-\frac{d_{DC}}{2}\log n\right]\\&+\left[\log\widehat{Pr}(MD|DC,RF,PL,DO)-\frac{d_{MD}}{2}\log n\right]+\left[\log\widehat{Pr}(TR|DC)\right.\\&\left.-\frac{d_{TD}}{2}\log n\right]+\left[\log\widehat{Pr}(CE|MD,TR)-\frac{d_{MD}}{2}\log n\right]\end{aligned}\tag{3}$$

4. Results

4.1. Preliminary evaluation: a search for possible and meaningful causal models

First, the strength of probabilistic dependence corresponding to each arc in the initial model is tested using the ***arc.strength*** function in **bnlearn** package. The test returns non-significant results ($p > 0.05$) across the network. The following box details the codes and the results.

```
strength = arc.strength(dag, data = data1, criterion = "x2")

   from to    strength
1     B DC 9.763066e-01
2     T DC 1.000000e+00
3     C DC 9.999153e-01
4    RF MD 1.000000e+00
5    PL MD 1.000000e+00
6    DO MD 1.000000e+00
7    DC TR 3.093218e-08
8    DC MD 1.000000e+00
9    TR CE 7.989842e-01
10   MD CE 9.174464e-01
```

With the initial Bayesian network model whose Bayesian Information criterion (BIC) score equals −979.0649 and Bayesian Dirichlet equivalent uniform (BDen) score equals −552.611, not showing any significance, 200 random DAGs are generated using machine algorithms for a further investigation of the relationship among the variables. Table 3 provides 21 DAGs that satisfy the technical requirements. The initial criteria for generating the DAGs are: (i) there are connections to CE; (ii) there is no connection from CE; and (iii) the minimum number of connections is at least five.

The following box shows the codes to compute the scores for the generated networks and to select the ones with the best BIC scores.

```
# computing scores from the generated networks
scoreNetwork <- function(nets,data,type = "bic") {
        scNet = c()
        stNet = c()
        for(n in 1:length(nets))
        {
                sc = score(nets[[n]], data = data, type = type)
                scNet <- c(scNet,sc)
                stNet <- c(stNet,modelstring(nets[[n]]))
        }
                return(list('score'=scNet,'model'=stNet))
}
# selecting top 5 models with highest scores among 100
topNetwork <- function(scores,top) {
        sc <- tail(order(scores$score),top)
        scNet = scores$score[sc]
        stNet = scores$model[sc]
                return(list('score'=scNet,'model'=stNet))
}
scores <- scoreNetwork(genNets,data1)
topNet <- topNetwork(scores,5)
```

The top five models were chosen on the basis that they have higher BIC network scores and they are M13, M7, M4, M8, and M5.

4.2. Inference from the top four models

It is notable that all models start with the dependency of decoration (DC) on Buddhism-inspired decorative patterns (B). In other words, the value DC takes (Chinese, French or Hybrid) is probabilistically dependent on the value of B (none, weak or strong). Second, in all the models, there are some forms of interactions between the decoration (DC) variable and Cultural Evolution (CE) variable. For example, in Table 4, for M13 and M7, CE is directly dependent on DC; in M4 and M8, CE is indirectly dependent on DC through the roof design (RF). All four models are statistically significant under the frequentist approach, however, as they can be categorized in the two patterns above, the next section will focus on the best model for each pattern: M4 and M13.

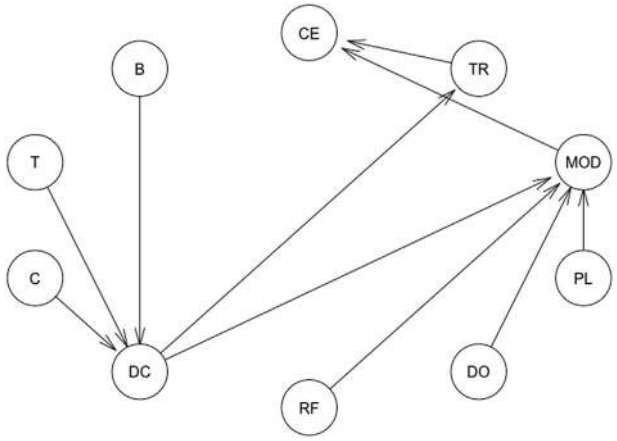


Fig. 4. The DAG created using the bnlearn package. This directed acyclic graph is identical to the one presented in Fig. 3.

In model M13, as shown in Fig. 5, when Buddhism-inspired decorative patterns are strong (B_S), the probability of the Decoration variable (DC) takes on the value of hybrid (HY) and (CN) increases compared with when B equals none (B_N). When there is a weak presence of Buddhism-inspired decorative patterns/symbols, DC most likely takes on the value hybrid (HY) (90%). For the variable Cultural evolution (CE), when the decoration of a façade is hybrid, the probability of the cultural evolution process is happening (CE=CE_E) is highest (90%). When the decoration is judged to be Chinese, the probability of CE just started equals roughly 60%. When the decoration is judged to be French, the probability of CE process has finished equals around 55%.

In Fig. 6, concerning the M4 model, the judgment on the cultural evolution process (CE) is dependent on whether the roof (RF) is Chinese, French or Hybrid. When the roof is Chinese style, the probability of the CE process just started is the highest, 60%. When the roof is hybrid, the probability of the CE process is happening is more than 80%.

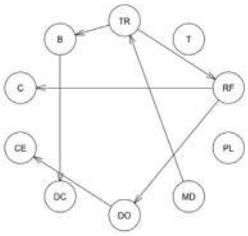
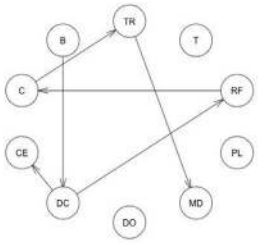
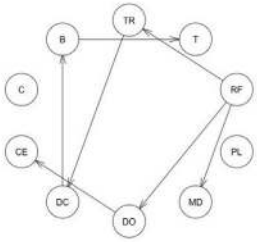
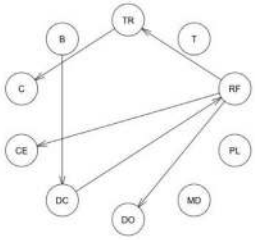
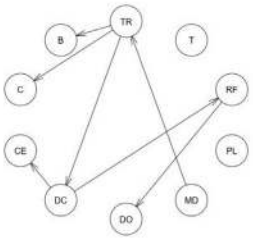
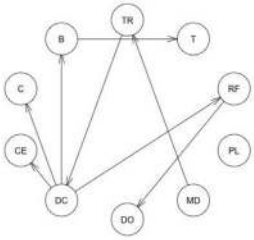
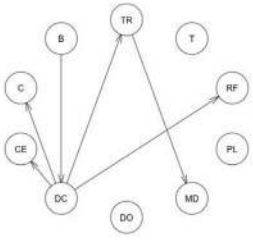
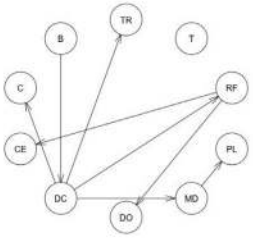
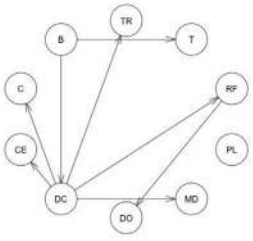
4.3. Robustness verification with Hamiltonian MCMC pondering for Bayesian networks: JAGS and Stan

In this section, the four best models are verified using the Hamiltonian MCMC method. One of the strengths of the Bayesian statistics approach is that it can generate technical figures for verification (Kruschke, 2015; McElreath, 2016). Using both the JAGs and Stan, this study diagnoses the robustness of the M4 and M13 Bayesian networks. The estimation has in total 20,000 iterations divided into 4 Markov chains. The file that contains all of the results (including the results for model M8, M7, and M5) is deposited in OSF's "Statistical Investigations" folder, "Files" sub-folder [URL: https://osf.io/tfy6k/].

The posterior distributions of all coefficients for model M4, as shown in Fig. 6, all satisfy the standard distribution. In Fig. 7, we presented an example of testing the validity of the coefficients $\beta_{\{CE \cdot RF\}}$ in M4, where CE is dependent on RF probabilistically. Here, one can see the chains fluctuate around 0.4 and has a good-mix (Fig. 7, top left). For the autocorrelation function, the four chains converge very quickly after lag 3 and the effective sample size (ESS) is nearly 66,700, indicating computational efficiency. Shrinking factor of computed mean values converged to 1.0 quite fast, while the Monte Carlo standard error (MCSE) is less than 0.05% (see Fig. 8).

Similar to M4, the model M13 is also verified using the MCMC method. Fig. 9 shows all posterior distributions of the coefficients of this

Table 3
Twenty-one DAGs with the best BIC scores are presented. Note that all of the scores are better than the initial model.

(M1) -527.5334019 [MD][PL][T][TR|MD][B|TR][RF|TR][C|RF][DC|B][DO|RF][CE|DO] 	(M2) -525.1395526 [B][DO][PL][T][DC|B][CE|DC][RF|DC][C|RF][TR|C][MD|TR] 	(M3) -528.9434423 [C][PL][RF][DO|RF][MD|RF][TR|RF][CE|DO][DC|TR][B|DC][T|B] 
(M4) -519.0916518 [B][MD][PL][T][DC|B][RF|DC][CE|RF][DO|RF][TR|RF][C|TR] 	(M5) -521.5010174 [MD][PL][T][TR|MD][B|TR][C|TR][DC|TR][CE|DC][RF|DC][DO|RF] 	(M6) -521.5731987 [MD][PL][TR|MD][DC|TR][B|DC][C|DC][CE|DC][RF|DC][DO|RF][T|B] 
(M7) -517.3542449 [B][DO][PL][T][DC|B][C|DC][CE|DC][RF|DC][TR|DC][MD|TR] 	(M8) -519.8741391 [B][T][DC|B][C|DC][MD|DC][RF|DC][TR|DC][CE|RF][DO|RF][PL|MD] 	(M9) -523.3763526 [B][PL][DC|B][T|B][C|DC][CE|DC][MD|DC][RF|DC][TR|DC][DO|RF] 

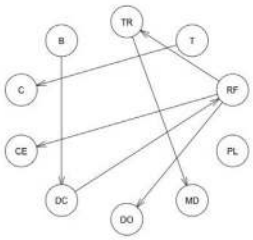
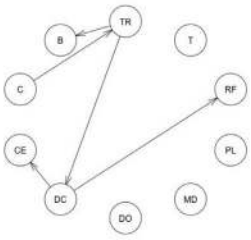
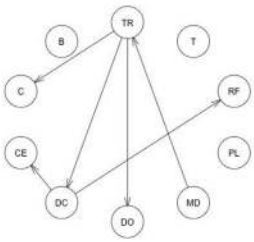
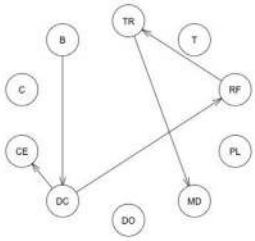
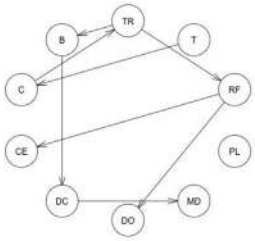
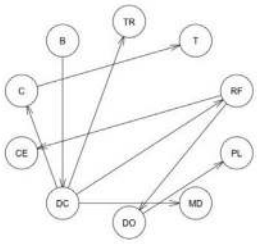
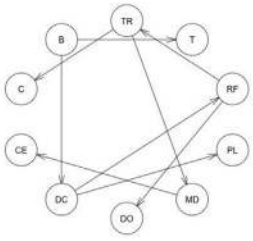
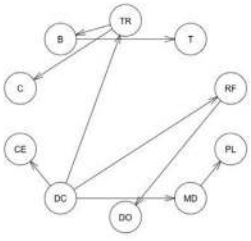
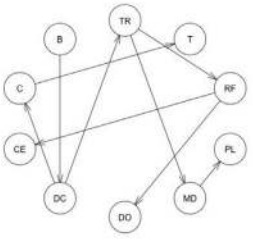
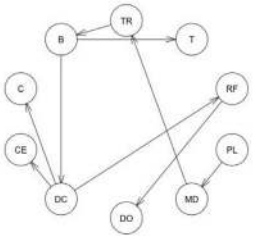
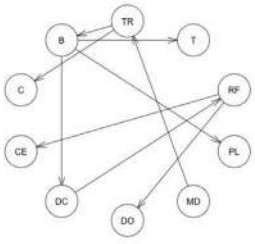
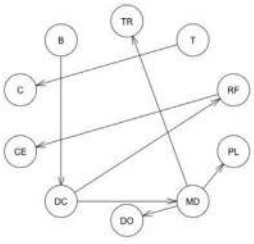
(M10) -522.0605958 [B][PL][T][C|T][DC|B][RF|DC][CE|RF][DO|RF][TR|RF][MD|TR] 	(M11) -524.8840612 [C][DO][MD][PL][T][TR|C][B|TR][DC|TR][CE|DC][RF|DC] 	(M12) -526.1012981 [B][MD][PL][T][TR|MD][C|TR][DC|TR][DO|TR][CE|DC][RF|DC] 
(M13) -517.126813 [B][C][DO][PL][T][DC|B][CE|DC][RF|DC][TR|RF][MD|TR] 	(M14) -531.6963744 [PL][T][C|T][TR|C][B|TR][RF|TR][CE|RF][DC|B][DO|RF][MD|DC] 	(M15) -527.3729879 [B][DC|B][C|DC][MD|DC][RF|DC][TR|DC][CE|RF][DO|RF][T|C][PL|DO] 
(M16) -530.1548123 [B][DC|B][T|B][PL|DC][RF|DC][DO|RF][TR|RF][C|TR][MD|TR][CE|MD] 	(M17) -530.3505663 [DC][CE|DC][MD|DC][RF|DC][TR|DC][B|TR][C|TR][DO|RF][PL|MD][T|B] 	(M18) -527.3428835 [B][DC|B][C|DC][TR|DC][MD|TR][RF|TR][T|C][CE|RF][DO|RF][PL|MD] 
(M19) -528.3939493 [PL][MD|PL][TR|MD][B|TR][DC|B][T|B][C|DC][CE|DC][RF|DC][DO|RF] 	(M20) -529.9446029 [MD][TR|MD][B|TR][C|TR][DC|B][PL|B][T|B][RF|DC][CE|RF][DO|RF] 	(M21) -531.4081897 [B][T][C|T][DC|B][MD|DC][RF|DC][CE|RF][DO|MD][PL|MD][TR|MD] 

Table 4
Four models with the best network scores are presented.

Score	Arc Strength (x2)	Arc Strength (mi)	ci.test (mi)	ci.test (x2)
(M13)	B- > DC	B- > DC	ci.test("CE",	ci.test("CE",
−517.13	4.51E-06	8.86E-06	"DC",c("B"),	"DC",c("B"),
	DC- > CE	DC- > CE	test = "mi",	test = "x2",
	2.98E-06	6.83E-04	data = data1)	data = data1)
	DC- > RF	DC- > RF	*data: CE ~ DC |B*	*data: CE ~ DC |B*
	1.35E-13	1.01E-06	*mi = 21.477,*	*x2 = 19.145,*
	RF- > TR	RF- > TR	*df = 12, p-*	*df = 12, p-*
	8.59E-07	1.55E-05	*value = 0.04381*	*value = 0.08509*
	TR- > MD	TR- > MD		
	1.66E-06	1.41E-04		
(M7)	B- > DC	B- > DC	ci.test("CE",	ci.test("CE",
−517.35	4.51E-06	8.86E-06	"DC",c("B"),	"DC",c("B"),
	DC- > C	DC- > C	test = "mi",	test = "x2",
	8.69E-03	3.01E-03	data = data1)	data = data1)
	DC- > CE	DC- > CE	*data: CE ~ DC |B*	*data: CE ~ DC |B*
	2.98E-06	6.83E-04		
	DC- > RF	DC- > RF	*mi = 21.477,*	*x2 = 19.145,*
	1.35E-13	1.01E-06	*df = 12, p-*	*df = 12, p-*
	DC- > TR	DC- > TR	*value = 0.04381*	*value = 0.08509*
	3.09E-08	1.01E-05		
	TR- > MD	TR- > MD		
	1.66E-06	1.41E-04		
(M4)	B- > DC	B- > DC	ci.test("CE",	ci.test("CE",
−519.09	4.51E-06	8.86E-06	"RF",c("DC"),	"RF",c("DC"),
	DC- > RF	DC- > RF	test = "mi",	test = "x2",
	1.35E-13	1.01E-06	data = data1)	data = data1)
	RF- > CE	RF- > CE		
	3.37E-07	3.50E-04		
	RF- > DO	RF- > DO	*data: CE ~ RF | DC*	*data: CE ~ RF | DC*
	3.92E-09	8.80E-04	*mi = 15.966,*	*x2 = 25.327,*
	RF- > TR	RF- > TR	*df = 12, p-*	*df = 12, p-*
	8.59E-07	1.55E-05	*value = 0.1928*	*value = 0.01335*
	TR- > C	TR- > C		
	2.17E-03	3.03E-03		
(M8)	B- > DC	B- > DC	ci.test("CE",	ci.test("CE",
−519.87	4.51E-06	8.86E-06	"RF",c("DC"),	"RF",c("DC"),
	DC- > C	DC- > C	test = "mi",	test = "x2",
	8.69E-03	8.69E-03	data = data1)	data = data1)
	DC- > MD	DC- > MD		
	2.16E-09	7.31E-04		
	DC- > RF	DC- > RF		
	1.35E-13	1.01E-06		
	DC- > TR	DC- > TR	*data: CE ~ RF | DC*	*data: CE ~ RF | DC*
	3.09E-08	1.01E-05	*mi = 15.966,*	*x2 = 25.327,*
	RF- > CE	RF- > CE	*df = 12, p-*	*df = 12, p-*
	3.37E-07	3.50E-04	*value = 0.1928*	*value = 0.01335*
	RF- > DO	RF- > DO		
	3.92E-09	8.80E-04		
	MD- > PL	MD- > PL		
	2.37E-16	1.08E-02		

model, all of them satisfy the technical requirement. Fig. 10 shows the Hamiltonian MCMC diagnostics for the two coefficients of the cultural evolution variables in M13. All of the technical measurements indicate a convergence of the posteriors.

5. Discussion

5.1. Technical implications

The current research first and foremost carries a huge implication for the application of Bayesian analysis in the study of culture and social anthropology. Its methodology diverges from the mainly qualitative approach of the literature on Franco-Chinese influence in Southeast Asian architecture as well as in Vietnam (Dinh & Groves, 2006; Hartingh et al., 2007; Herbelin, 2016; Le, 2013; Nguyen, 2014; Nguyen, 2016; Phan et al., 2017; Tran Hau Yen The, 2011; Tran & Nguyen, 2012; Truong, 2012; Vietnam Associations of Architects, 2003; Vongvilay et al., 2015; Walker, 2011). It also supplements the computational movement toward Bayesian-based research on cultural evolution in Asia (Higham & Higham, 2009; Kumar et al., 2008; Lee & Hasegawa, 2011; Long & Taylor, 2015; Thouzeau, Mennecier, Verdu, & Austerlitz, 2017).

Through the Bayesian networks analysis, the study shows that, despite a small volume of data and coding of highly representative variables, it is nonetheless plausible to find the impacts of certain cultural elements on the aesthetics, architecture decisions of people at that time. What should be emphasized here is the subjective probability characterization in judging the architectural feeling of the house façade. This is in fact a position underlying almost all Bayesian work, where prior information is often subjective due to the inclusion of the researchers' experience, intuition, theoretical ideas, or personal observations (Gill, 2002). This process in itself implies a limited number of observations, but in no way undermines the statistical analysis that follows. By giving equal value to every input in judging the Franco-Chinese or hybrid modern feeling of a house façade, the study takes the mean or mode in Bayesian posterior distribution, ruling out the possibility of any "expert opinion" being more valuable. This approach is in line with the probabilistic interpretation of regularization in Bayesian statistics, and thus, shows its rich potential in social sciences studies as a whole (Kruschke, 2015; La & Vuong, 2019; McElreath, 2016; Vuong et al., 2018b; Vuong & La, 2019).

It is important to note here that, although the findings do not confirm the presumed model (Fig. 2), the in-depth technical analysis confirms the plausibility of judging the aesthetics, architecture, and designs of the house façade in Hanoi to find traces of cultural evolution in the early 20th century in Vietnam. By highlighting ornamental features that are highly representative of French and Chinese cultures as well as their hybridity, the study was able to construct an efficient Bayesian model that draws out the association and correlation among different variables.

5.2. Social anthropology implications

5.2.1. The flow of cultural evolution

Among the notable findings, the study confirms that there is indeed a strong cultural evolutionary signal in the architecture of the house fronts in Hanoi. In the two models with the highest BIC scores, there is a high probability of the CE variable taking the value 'strong representation of cultural evolution' (CE_E). This result is best understood once the old houses are situated in the right historical context. Vietnamese society in the early 20th century was at a crossroad of ambiguity, both in terms of political and cultural identities, due to the intense competition among the deep-seated roots of the Three Religions (Confucianism, Buddhism, and Taoism) as well as Chinese and French influence. Phan et al. (2017) noted that, although 80% of the inhabitants in the Western quarter in Hanoi were Vietnamese,[1] since the first half of the twentieth century, there had always been a large number of foreign inhabitants, such as Chinese, Indian, and the biggest group of all – French (Tran Hau Yen The, 2011). Given that the house, especially its façade, represents the face of the family and its biggest asset, its architecture inevitably reflects the cultural influences of the time. Against this background, it becomes clear why houses built during this period exemplify the Vietnamese souls that were torn between the traditional Confucian path and the liberal French style. On the evolving architecture in Vietnam, Herbelin (2016) also pointed out that, besides the urbanization, the cityscape in the early 20th century had changed dramatically because the French eradicated many laws on limiting household expenditure that were issued by the Nguyen dynasty earlier. As the people got to freely build two-storied houses and decorate them to their liking, these neoclassical designs were the results of influence from both France and China, where the East-West architectural fusion also took off strongly at the time (Herbelin, 2016).

[1] In 1948, there were 150,000 Hanoi inhabitants. The figure rose to 300,000 in 1951 and to 643,576 in 1960 Nguyen V U (2016) *Hà Nội nửa đầu thế kỷ XX [Hanoi in the first half of the XX century]*. Third edition edn. Hanoi: Nha xuat ban Ha Noi.

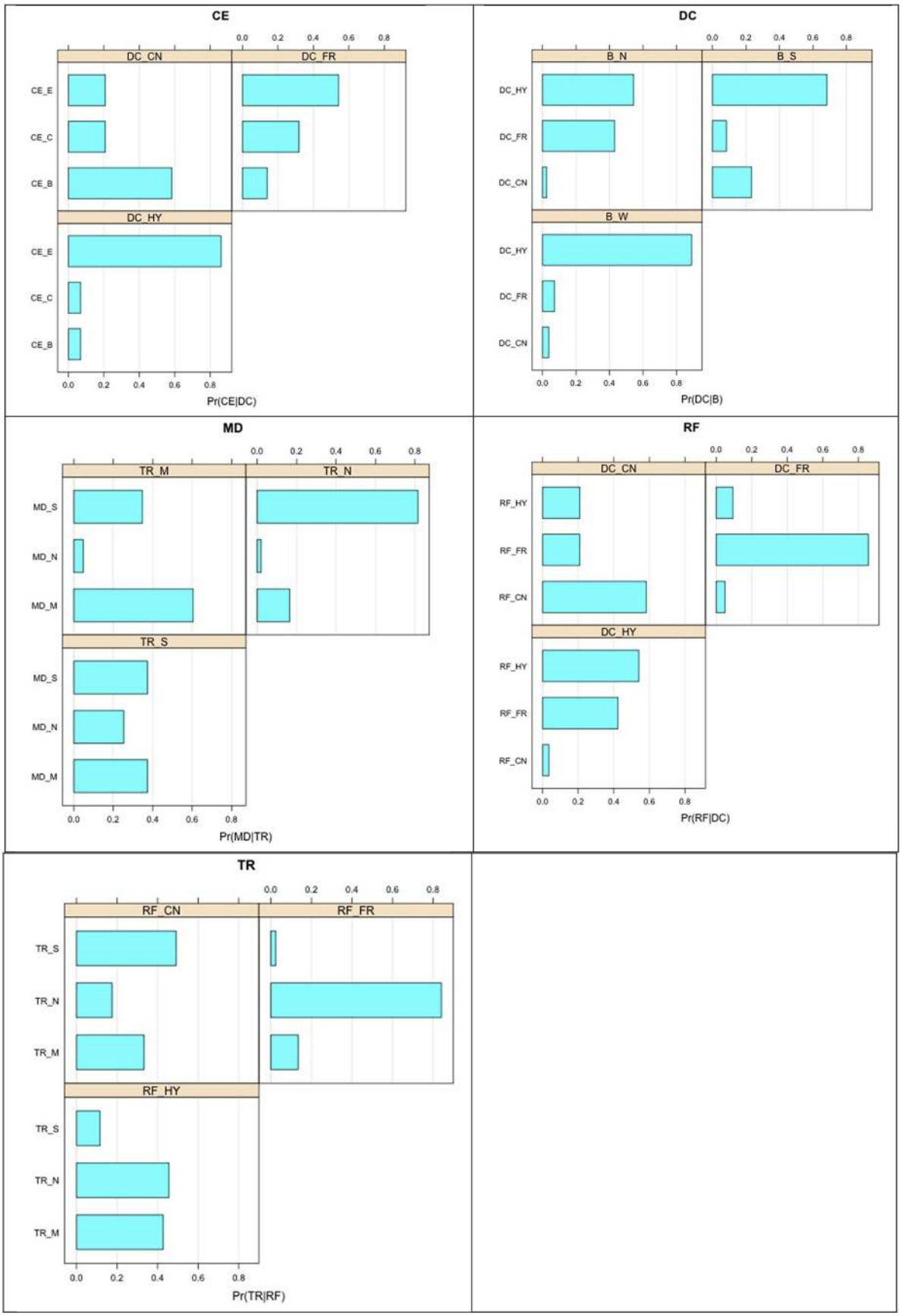


Fig. 5. Probability distribution of the categorical variables in model M13 given different evidences.

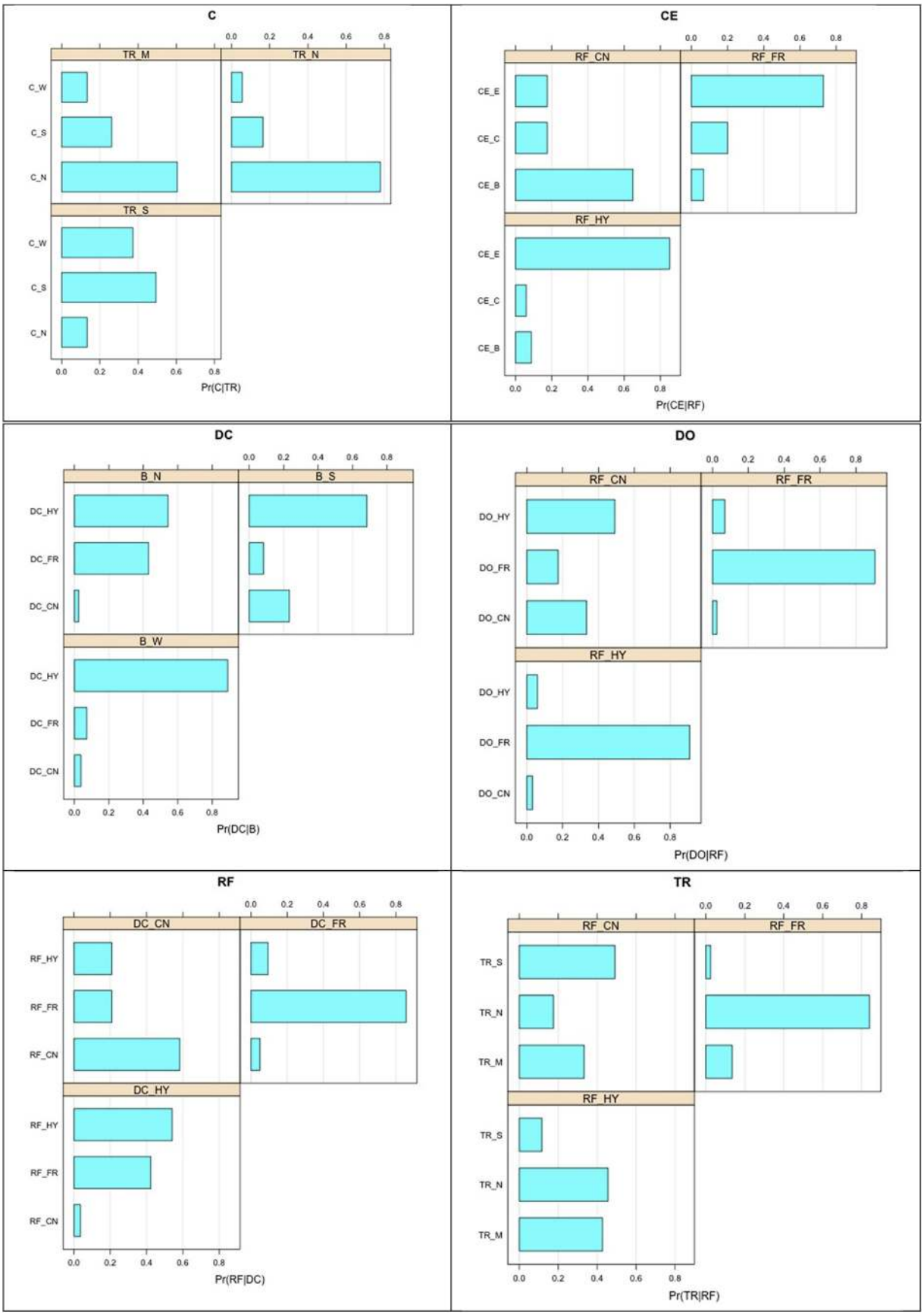


Fig. 6. Probability distribution of the categorical variables in model M4 given different evidences.

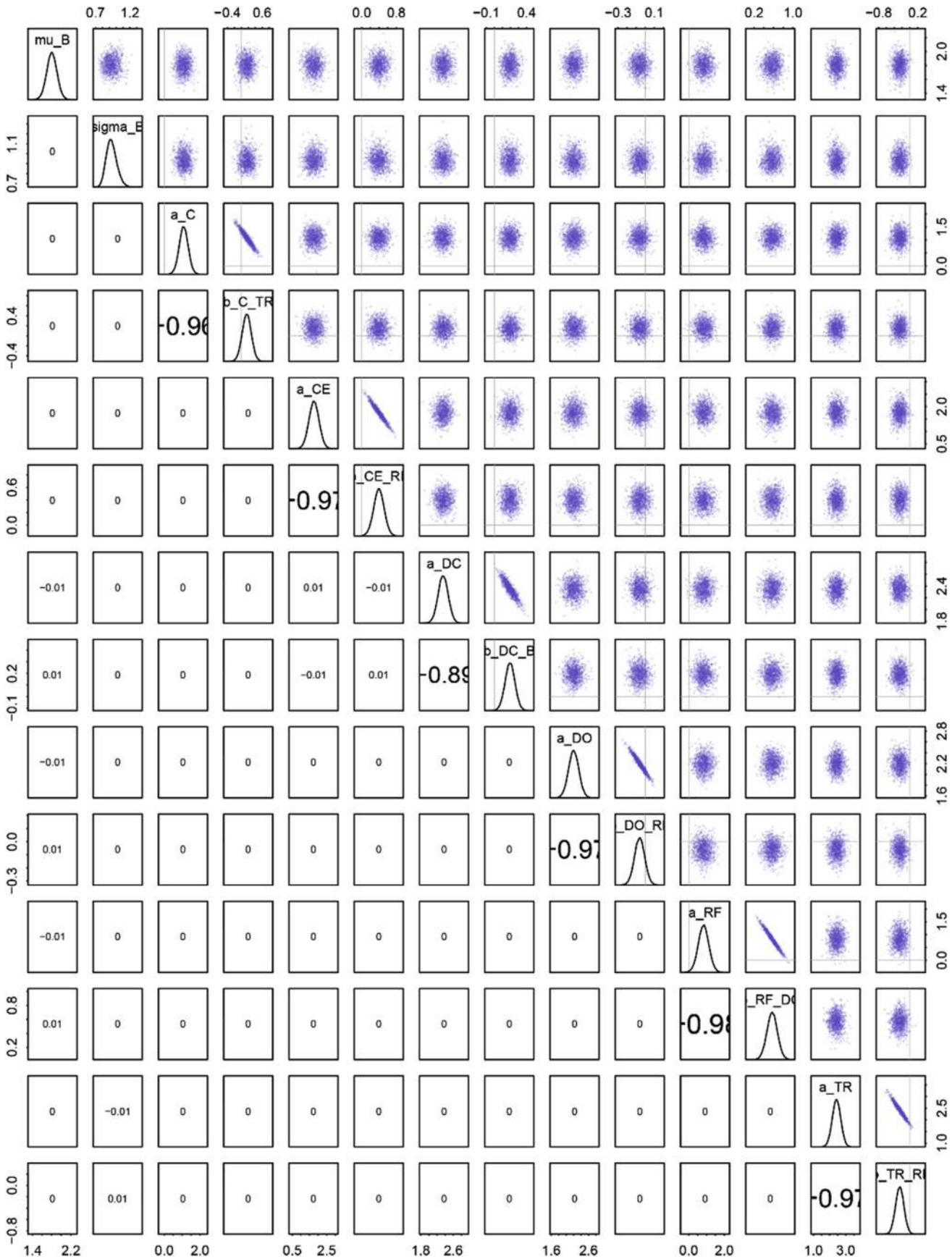


Fig. 7. M4's coefficients' posterior distribution.

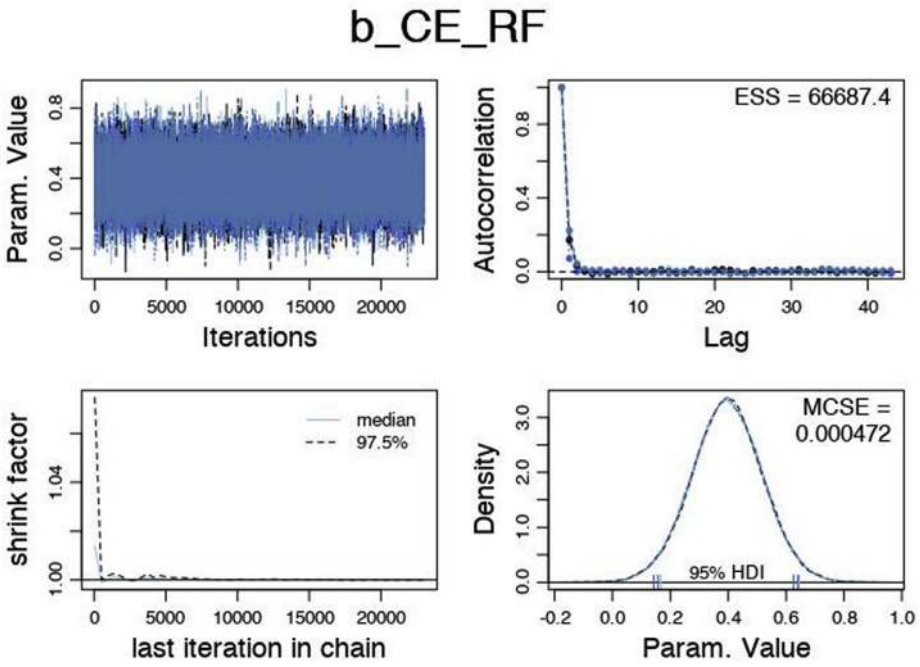


Fig. 8. Hamiltonian MCMC technical validations for $\beta_{\{CE \cdot RF\}}$ in model M4 using Stan codes.

It is perhaps the longing for this past that makes Bui Xuan Phai's oil paintings about Hanoi Old Quarter appealing. The artist himself is a product of the politics and culture of the time, having been born into a Confucian family but educated at the *École Supérieure des Beaux-Arts de l'Indochine (*Indochina College of Fine Arts*)*, the former name of the Vietnam University of Fine Arts (André-Pallois, 2016). As the war against the French broke out, he then joined the cultural front to produce propaganda poster art in 1945; he relocated to the countryside in 1958 for manual labor with the peasants under a Party policy, but by 1966 had decided to pursue artistic expressionism free from any political agency (Bui & Tran, 1998; Naziree, 2006). His experiences translated into his paintings of Hanoi—the resilience of the time shown in the houses that may appear wobbly but have stood there for decades. In his paintings, the streets of Hanoi came alive in simple brushstrokes of bold borders and mundane gray and white colors. The cityscape in Phai's paintings, often understood in three periods of 1960–1970, 1970–1980, and 1980–1988, appeared in a familiar and simple form with subtle signs of evolution: the two-storied houses, attached to one another like stacking matchboxes with the same dark brown brick roofs, were old and undecorated, their doors perpetually shut; then as the 1970s–1980s came, the houses' shuttered windows were painted in more details instead of in one black brushstroke and the first sign of modernity emerged in the form of a lamppost. In other words, Phai had captured the angst, poverty, and aesthetics of wartime Hanoi, all the while exemplifying the resilience and somewhat helplessness of Vietnamese people then when facing intense foreign cultural influences.

The findings here also highlight one aspect of cultural evolution – its direction. If the architecture in Hanoi is still evolving, presumably toward modernity, one question arises: will the Chinese influence retain as China, a close neighbor to the north of Vietnam, rises in the world? The current research implies that China cannot possibly reverse the flow of cultural evolution in Vietnam, in this case, its architecture. Yet, one fact that will not change regardless of the geopolitics is the inexplicable Vietnamese affection for hanging Chinese characters on their house façade or in their home. Vietnamese people lining up to buy calligraphy during the Lunar New Year (*Tết*) is not just a scene representing the lively modern economic life but also a behavior that signifies the nostalgia and the embrace of tradition (Pham, 2018).

5.2.2. The strong signals of Buddhist decorations on the house façade

Regarding the elements that most affect the Vietnamese perception on cultural evolution of Hanoi architecture in the early 20th century, the Bayesian networks investigation into Hanoi architecture indicates a strong influence of Buddhism over the decorations of the house façade. In the top 5 networks with the best BIC scores and small *p*-values, the variable DC always has a direct probabilistic dependency on the variable B. Given the predominance of Confucianism in Vietnamese culture (Vuong, 2016; Vuong, Vuong, Nguyen, & Ho, 2019; Vuong & Tran, 2009), this result is quite interesting. Two possible explanations could account for this finding. First, the lack of Confucian presence is attributable to the end of *Hán* script in academic and official settings in 1919 and the elevation to national status of *Chữ Quốc Ngữ* in Vietnam in 1945 (Chiung, 2007; Trinh, 2000). Second, it is possible that some of the French architects who were involved in the planning and building of Hanoi at the time had been influenced by Buddhism during their work with the *École Française D'Extrême-Orient* (EFEO), the French School of Asian Studies founded in 1900. As Clementin-Ojha and Manguin (2007) noted, in 1920, the EFEO established a full Archeological Service and Charles Batteur was tasked with the restoration of Vietnamese antiquities. In 1922, Charles Batteur helped restore the Pagoda of the Single Pillar (*Chùa Một Cột*) in Hanoi and numerous other pagodas that were damaged by a typhoon in 1929 (Clementin-Ojha & Manguin, 2007). The architects' involvement in preserving and restoring the Buddhist pagodas may help explain the somewhat prominent feature of Buddhist decorations in the house façade in Hanoi.

The strong signal of Buddhism on the house façade in the 20th century is also an interesting finding given that Buddhist pagodas and Buddhist office buildings in North Vietnam were either destroyed or confiscated during the 1950s and 1960s, known as the "cultural revolution" (Werner, 2015) and also after the victory of the war in April 1975 (Buswell, 2003, p. 170; Schwenkel, 2017; Tran, 2013). The result hints at a quiet, subtle undercurrent of cultural evolution, of Buddhist influence always lurking in the Vietnamese culture even when it was not officially allowed or publicly declared. The re-emergence of Buddhism in Vietnam took place after 1986 when Vietnam began implementing economic reforms, known as *Đổi Mới*. The rise in popularity of Buddhism, however, does not mean Vietnam has become a religious country. Some statistics still put Vietnam as "one of the least religious countries in the world" as

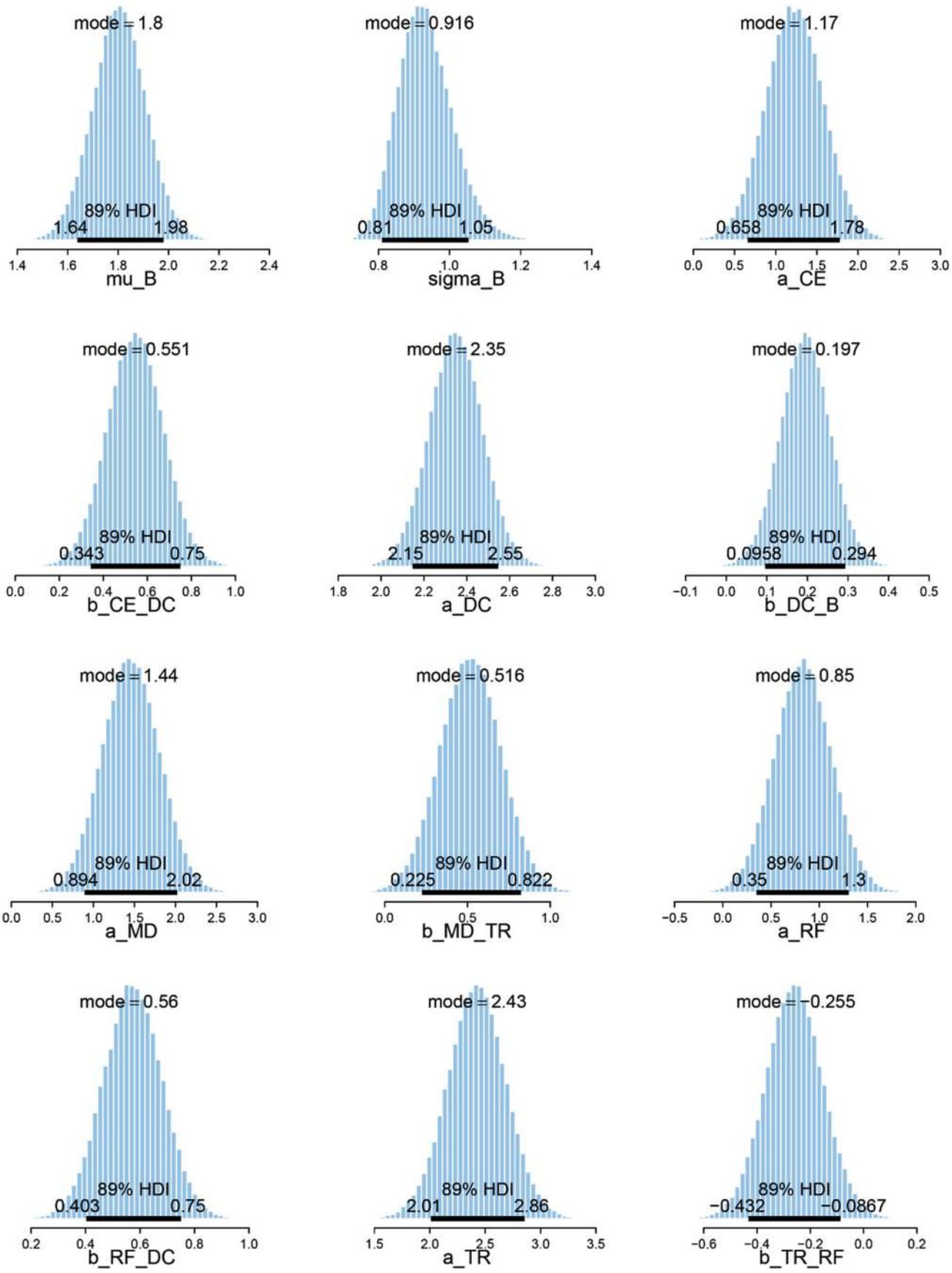


Fig. 9. M13's coefficients' posterior distribution.

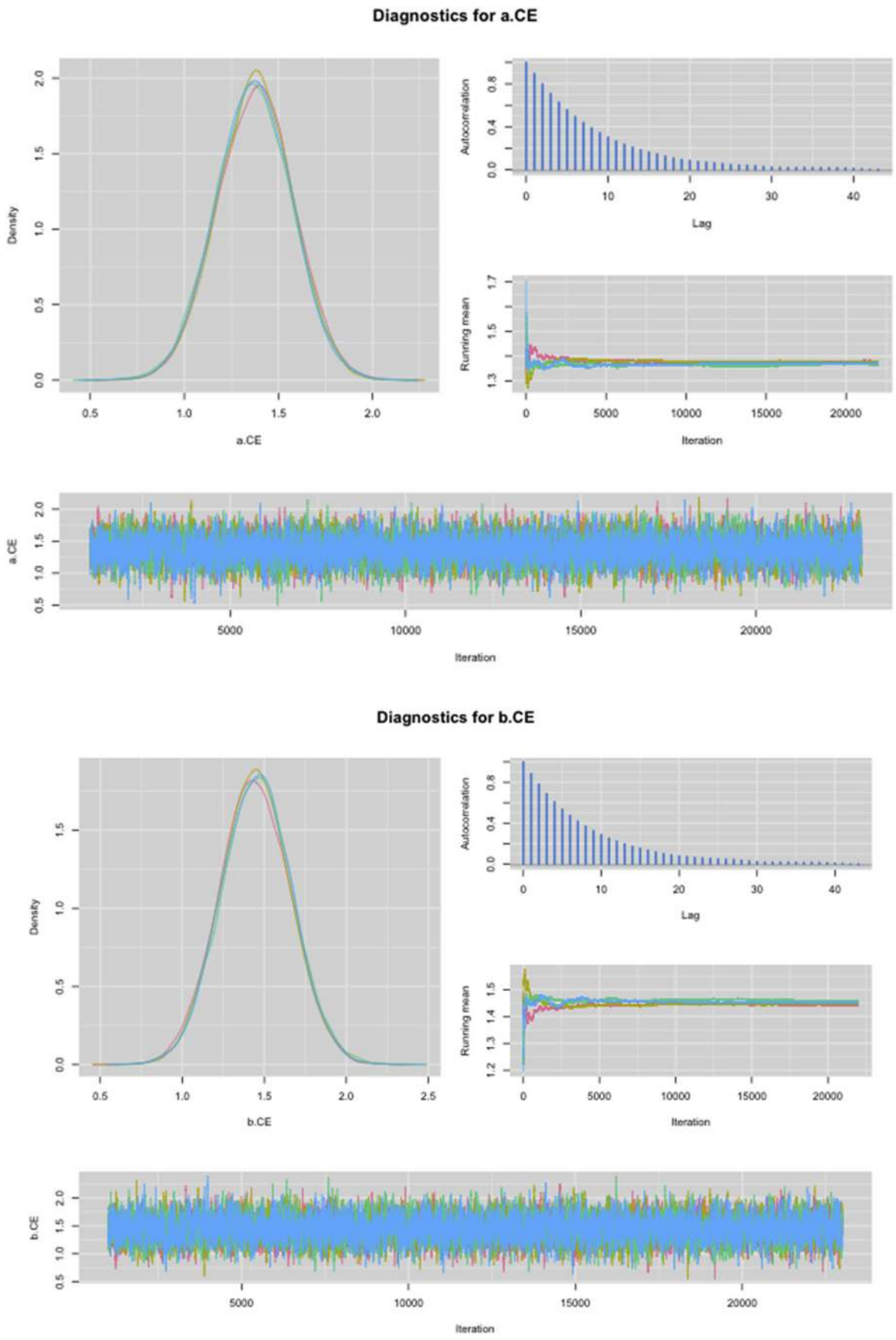


Fig. 10. Hamiltonian MCMC technical validations for $\beta_{\{CE\}}$ in model M13 using JAGS codes.

the majority of the population declares no affiliation with any religious institution (Hoskins & Ninh, 2017; Rots, 2017; Vuong et al., 2018b; Vuong & Vuong, 2018). Though lacking statistical backup, much of the academic literature on Vietnamese religious practices agrees on the highly fervent religious belief and worship in Vietnam, some even characterizing this phenomenon as "widespread re-enchantment" (Rots, 2017; Taylor, 2007). The revitalization of religious practices, particularly Buddhism in the house designs, has gone hand in hand with the country's socioeconomic modernization (Rots, 2017). In fact, thanks to the increasing wealth of a certain class, constructing Buddhist pagodas, or known in Vietnamese as "spiritual tourism destinations," has almost become a profitable business. Bai Dinh Pagoda (*Chùa Bái Đính*), located in the northern province of Ninh Binh, southeast of Hanoi, is a vivid example of a Buddhist pagoda complex renovated in all its grandeur with the new money—its cost was estimated at USD45 million (Thanh-Nga, 2016).

6. Conclusion

The inquiry into the house façade of Hanoi's Old Quarter has brought sharp focus onto the ornamental features and their cultures of influence. The topic itself, as this study shows, has been the subject of numerous qualitative research, yet none has applied Bayesian inference to systematically and rigorously document the selection of such ornamental designs and the perceived source of cultural influence. This study, therefore, opens up a new approach for social sciences in general and for the study of cultural evolution and architectural transformation in particular.

If Vietnamese fine art has intrigued myriad art collectors and researchers for its mixture of Southeast Asian artistic traditions since the early 20th century—such as the use of bright colors and dominant themes of farmland and countryside (Taylor, 2009)—and French colonial legacy (Vuong et al., 2018a), then its architecture has also captivated artists and ordinary people alike. Inspired by the spirit of Bui Xuan Phai and his immortalized paintings of Hanoi old streets, this study hopes to invite scholars of Vietnam studies as well as the international community to join the discussion on novel quantitative methodology in architecture studies and social sciences at large.

For closing this inquiry, the paper would like to end with a linocut painting by the artist Bui Quang Khiem (Fig. 11). The picture, based on an actual photo taken by the artist for this research, shows the façade of an old house on Cau Go street in Hanoi that exemplifies the mixing of many features of different architecture styles, such as the prominent Chinese characters at the center of the pediment, the two lotus flowers on the top columns, the art décor window and balcony iron railings, the French shuttered windows, to name a few. Just as the house in this linocut print stands immortalized on paper, the 500 photos taken for this research project (of which 278 were used) have locked in the shape and form of Hanoi houses at a specific point in time. In a city that is bustling with constant movements, the photos freeze Hanoi and its unique fusion of foreign architectural elements in time just enough for this academic inquiry to set off.

Fig. 11. A linocut painting by courtesy of Bui Quang Khiem.

Conflict of interest

The authors declare no conflict of interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssaho.2019.100001.

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