Roofing tiles or slates? A network analysis of factors influencing architect choice

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Abstract. Tiles and slates are the two most commonly used roofing materials worldwide, yet many customers and construction professionals are frequently unsure about which product to choose. In this article, a network analysis based on a Bayesian machine learning approach was used to identify which are the main factors and how they influence architect decision about roofing tiles or slates. For that, the information collected from a survey conducted to 429 architects working in the Spanish construction sector was used to create a Bayesian network model that represents the conditional dependencies of the variables considered when the decision is taken. The results obtained allow to unveil aesthetic as the main factor conditioning architect decision for roofing tiles. In turn, the decision is more complex when roofing slates, since architects apart from the price they strongly considered the ability of installers in the decision process.

1 Introduction

An intense public debate always exists when it is required to decide whether use tiles or slates as roofing material. The roof is the outermost layer of a building and has a protective function by providing shelter from the cold and rain. The list of commercially available roofing materials is very extensive and it continues to grow due to the manifold possibilities of composite materials [1]. However, slate and ceramic title have traditionally exceled from the others.

Roof tiles are made of ceramic from antique times, where the earliest documented proofs date from archaic Greece between 700 and 650 BC [2]. Ceramic tiles (terracotta) replaced thatched roofs because of their insurmountable fire-resistance and longer lifespan [3]. At present, these properties still maintain tiles as a leading roofing material, existing also varieties made from concrete or plastic. Nevertheless, the possibility to produce titles from different materials offers multiple commercial solutions in terms of colors and designs (e.g., flat, pantiles, roman, imbrex and tegula) [4]. Other advantage of tiles is their price. Roofing a building with ceramic tile costs under normal conditions around € 30 per square meter. On the downside, tiles are not recommended on steep roofs and maintenance can be necessary relatively often, especially if the customer pretends to keep the original color. Additionally, roof tiles are sensitive to temperature changes that may produce cracks where mold caused by humidity can reduce their lifespan.

Slate is a fine-grained metamorphic rock composed mainly of quartz, muscovite and illite, but other minerals such as chlorite, biotite, hematite or pyrite are typically present. More than 80% of Europe's natural slate used for roofing derives from the Slate Industry in Spain [5]. One of its main advantages is that slate is a natural stone with two lines of breakability (cleavage and grain) which make possible to easily split the rock into thin slabs. After being broken in the extraction process it keeps its natural appearance and is easy to stack. The fact that slate is a natural stone implies less processing costs. However, the price of roofing a building with slate is higher than using tile. On average, the purchase and installation of slate roofs costs around € 55 per square meter.

Slate is an extremely suitable material for roofing due to its high impermeability, having a water absorption index of less than 0.4% [6]. Moreover, slate can be very durable, lasting a hundred of years with little or no maintenance. Aesthetically, its dark color is very well appreciated by many customers, architects and designers, which gives a point of elegance to the roof of any building. In the following picture is shown the installation process of a roof with slates and tiles. The difference between the color and the design of the sheets completely defines the style of the building.

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Fig. 1. Installation process of slates (top) and tiles (bottom)

From a commercial point of view, slate is more used in cold climates, having the great advantage of not accumulating snow when compared to tiles. It is also noteworthy that slate may have different fixing systems. In Spain slate sheets are typically fastened with nails or hooks, whereas in UK the used of double nails onto timber battens is a common practice. Some architects place special importance on that owing to the required ability from installers to achieve an optimum result.

2 Materials and methods

The main goal of this study is to determine which are the main factors conditioning the architect choice between tiles and slates. In order to carry out this analysis, this article proposes the development of a network analysis based on a Bayesian network structure (machine-learnt from the data) that captures the probabilistic relationships between the variables involved in the decision making process. For that, data were gathered from interviews and questionnaires conducted to architects and building professionals in the Spanish construction sector to depict the conditions under which architects opt for tiles or slates.

2.1. Data description

A total of 429 architects, project managers and building professionals participated in the study. All participating professionals were asked about general challenges and particular technical issues they have to tackle when deciding which material use in a building roof. Despite that in many cases the decision of roofing tiles or slates may not depend exclusively from the architect viewpoint, being highly conditioned by customer preferences, the main factors that these professionals consider can be summarised as follows:

- Aesthetic: it represents the beauty of the roof as a whole (for the specific building under construction), depending on the material (tile or slate) chosen.
- Price: it is the cost of the material together with the cost of installation. Depending on the geometry of the roof and the slope the final price may vary considerably.
- Installation complexity: this factor involves the size and the slope of the roof. Steep and narrow roofs are more complex, which may trigger different material decisions.
- Worker specialization: it counts the company responsible for the installation process and the technical skills of the employees. This factor can be important especially when the roof design is complex.
- Maintenance: it considers the expected maintenance from the material chosen (tile or slate).
- Expected problems: this factor has into account the long turn challenges that can appear related to the weather (location) and type of building based on material chosen (tile or slate).

All the participants were asked to fill in a questionnaire where they had to answer from 1 (low influence) to 5 (high influence) how the aforementioned factors influence their decision. As a consequence, it is important to remark that those architects who place more importance to some factors may consider others less important. This aspect is fundamental to understand afterwards how preferences change among them, trying to unveil hidden patterns that condition their choice.

2.2 Model creation

Bayesian networks are probabilistic graphical models with the capacity to portray a number of variables and their conditional dependencies through a Directed Acyclic Graph (DAG). Therefore, a BN represented with a DAG is formed by a collection of nodes and arcs that represent, respectively, the variables and the conditional dependencies of the problem domain. Network theory is responsible for the study and representation of symmetric and asymmetric relationships between objects as a part of graph theory, which goes one step beyond trying to understand the mathematical structures to optimize network problems.

Bayesian statistical methods make use of Bayes' theorem to calculate and update probabilities when new data is accessible. Mathematically, Bayes´ theorem is stated as:

$$p(\varepsilon|X,\sigma) = \frac{p(X|\varepsilon,\sigma)p(\varepsilon,\sigma)}{p(X|\sigma)p(\sigma)} \qquad (1)$$

Where X is the sample, ε the parameter of the data point's distribution (conditional probability) and σ the prior distribution (hyperparameter). Bayes' theorem expresses the conditional probability of an event based on prior information or beliefs about the conditions related to the event. Despite that Bayes´ theorem dates back to 1763 [7], the term of BNs is relatively new, being introduced by Judea Pearl in 1985 [8], opening the door to renovated probabilistic approaches in Artificial Intelligence (AI). Bayesian networks were originally cultivated as a knowledge representation formalism, where human experts provided the only source of information available. Nowadays, there exist efficient algorithms that can machine-learnt the structure of a network (DAG) directly from data collected from the problem domain. This approach is very useful in problems like the one exposed here, where it is necessary to model the factors leading to a particular decision. In consequence, in this study an unsupervised Bayesian network was machine-learnt from the data gathered in order to portray the conditional dependencies existing when architects make a decision regarding the use of tiles or slates. For that, AI software BayesiaLab v. 8.0 was used [9]. This package contains a wide set of algorithms for machine learning, knowledge modeling, diagnosis, analysis and simulation, built upon a powerful

graphical structure that allows researchers to easily interpret complex problems.

2.3 Reasoning under uncertainty

Once the Bayesian model was built, one of the possibilities of Bayesian networks is to carry out inference. Simply put, the network created can be used to ascertain the knowledge of the state of a subset of variables when other variables are observed under specific conditions. This strategy was used to determine how architect perception changes when the influence of certain factors is high. Moreover, the evaluation of different scenarios through intercausal reasoning provides valuable insights about how the uncertainty is propagated through the different nodes in the network.

3 Results and discussion

From the data collected through the questionnaires and interviews carried out to the 429 professionals who participated in the study, 175 missing values were detected during the data cleaning process. This lack of data constituted about 1.20% of the dataset, which was solved by using a dynamic completion approach through the application of an Expectation-Maximization (EM) algorithm in BayesiaLab software [9]. After that, the Bayesian model was machine-leant from the data.

3.1. Network representation

Having into account the analysis of both tiles and slates, 12 variables were used in total to create the Bayesian model. For that, the unsupervised learning algorithm Maximum Weight Spanning Tree (MWSP) was used, where the Minimum Description Length (MDL) [9] score was employed to obtain a threshold that ensures to obtain a network that maximizes correlation at an acceptable level of structural complexity. The resulting network is shown in the following figure with nodes referring to slates and tiles in blue and orange respectively.

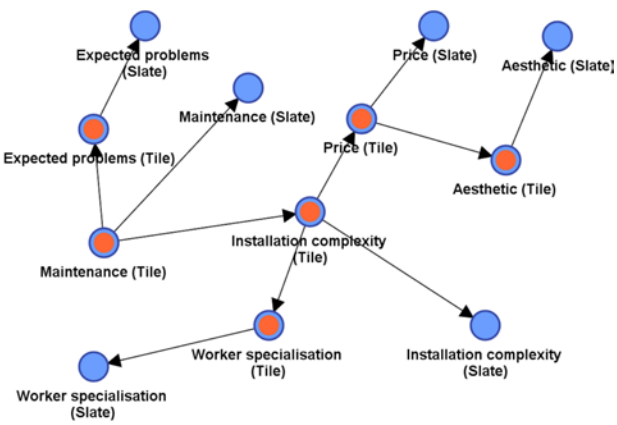

Fig. 2. Unsupervised Bayesian network representing the conditional dependencies between tiles and slates.

MWSP is a fast learning algorithm based on a key constraint that implies the generation of a Bayesian network model where each node is restricted to have exclusively one parent node. This approach reduces notably the time required to produce several models in a short period of time, avoiding the introduction of V-structures.

Conceptually, the model obtained (Fig. 2) offers a good representation of how the dependencies among variables are established. In this regard, *installation complexity (tile)* occupies a central position in the network, from which different branches are formed. The central situation of this variable in the model clearly remarks its influence in the decision making process. The complexity of the roof design inevitably influences the installation process, therefore, it is understandable that this factor may constitute a trigger for architects when it comes to decide whether roofing tiles or slates. In general, there exists a clear association duplicity for the variables in the network, that is reflected for *price*, *aesthetic* or *worker specialization*. As a result, it can be concluded that from the installation complexity, architects move to think on the price, aesthetics or the work specialization required.

3.2. Factors determining architect decision

After building the Bayesian model, the next step is to exploit its informative content. One of the strengths of Bayesian networks is the possibility to infer the state of certain variables when others are observed. As an example, in Table 2 are shown the main values obtained in the questionnaire for the six factors considered both for tiles and slates. This result is benchmarked with the mean value of the factors when hard evidence is set for aesthetic, that is P(Aesthetic=5)=100%.

Table 2. Mean value of the factors in the model and the variation resulting from the inference of roof aesthetic.

Factors	Mean (Title)	Mean (Slate)	Inference (Title)	Inference (Slate)
Aesthetic	3.974	4.140	5 P(5)=100%	5 P(5)=100%
Price	3.741	3.991	4.073 (+0.331)	4.266 (+0.275)
Installation complexity	3.495	3.892	3.071 (+0.205)	4.054 (0.162)
Worker specialization	3.653	4.187	3.777 (+0.124)	4.254 (+0.067)
Maintenance	3.533	3.609	3.659 (+0.126)	3.708 (+0.099)
Expected problems	3.580	3.659	3.672 (+0.092)	3.726 (+0.067)

Under normal circumstances, *aesthetic* is the factor architects have more into account when choosing tiles or slates. In second place, *price* (M_t=3.741) is more relevant for tiles, whereas for slates they seem to prioritise *worker specialisation* (M_s=4.187) above *price*

(M_s=3.991). However, it is important to remark that even if the price appears to be more important in tiles, when analysing the mean score in both materials the mean score is higher for slates (M_s=3.991) than for tiles (M_t=3.741). This tendency is slightly reduced when *aesthetic* is considered as a top criterion (M=5). At that time, architects focus especially on the *price*, having *installation complexity* an important rise in importance.

3.3. Prediction of preferences

After the results obtained in the previous section, it is intended to go one step further when trying to predict the preferences of building professionals under specific circumstances. The Bayesian network built (Fig. 2) offers the possibility of reasoning under uncertainty by setting observations for the variables included in the model.

Apart from aesthetics, customers have always put the spotlight on roof maintenance. For this reason, in Fig.3 is shown the inference result of maintenance when price has a strong influence (M=5). In this case, architects have higher expectations from slates than tiles, so it can be concluded that a consideration of a high price in the roof material involves a preference for slates since the expected maintenance in the long turn is smaller.

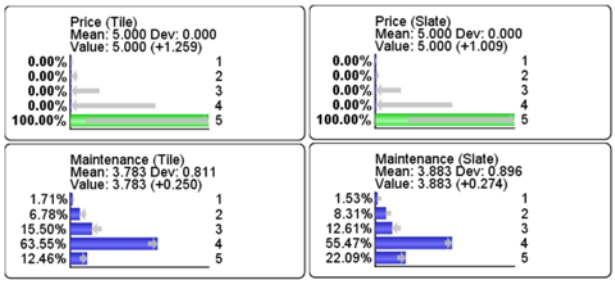

Fig. 3. Inference results for maintenance given a maximum price influence.

When the complexity of the installation is high and architects place high importance on it, the degree of relevance they assign to the specialisation of workers may vary among the material chosen. As it can be seen on Fig. 4, when installation complexity is high (M=5), architects give more importance to workers´ specialisation when roofing slates than tiles. This result maximizes, particularly for those architects who place high influence (M=5) to worker specialisation, with a 72.02% in slates versus a 48.11% in tiles.

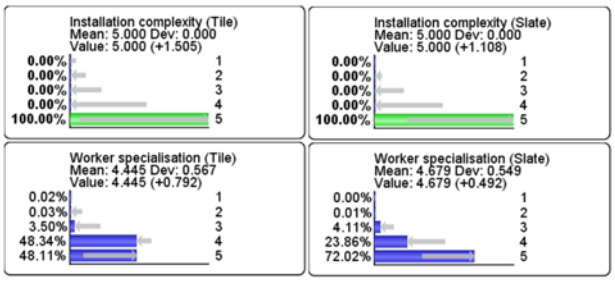

Fig. 4. Inference results for worker specialisation given a maximum influence of installation complexity.

A reason for that could be found on the different fixing systems that slate may have, which represent a point of complexity to achieve an optimum final result.

4 Conclusion

In this article a network analysis based on a Bayesian construction machine-learnt from the data was used to discover architect preferences when choosing tiles or slates as roof material. From a total of 429 interviews and questionnaires carried out to architects, project managers and building professionals it was built a dataset, defining a set of factors that characterize the architect choice. The factors and their conditional dependencies were depicted through the creation of an unsupervised Bayesian model, which enabled to spot how they are interlinked. In general, *aesthetic* and *price* are the two principal factors conditioning the most architect choice, although *worker specialization* is even above *price* for slates. Additionally, *maintenance* is a differential factor for slates over tiles when the *price* has the same top influence. The same tendency was identified for *worker specialisation* when the *installation complexity* has a maximum influence in both materials. Finally, it must be highlighted that this study reflects architect preferences, which in many cases might differ considerably with the taste of the client.

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