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Original article

An approach to assess the value of industrial heritage based on Dempster–Shafer theory

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A B S T R A C T

Industrial heritage associated with political, economic, cultural, social, scientific, technological, and architectural fields has been a crucial concern to nations and governments, since it reveals the way our ancestors lived, records technical progress and realizes cultural continuity. Thus, conserving and reusing industrial heritage is a vital decision-making issue. Studies on multiple criteria provide a series of methods to assist; however, they confuse uncertain with unknown, whilst most of them are not applicable due to uncertain reasoning. Here, an evaluation system of the value of industrial heritage is built using the analytic hierarchy process (AHP) and fuzzy sets used for translating comments from experts. Then, we present the Dempster–Shafer theory (D-S theory) to classify industrial heritage based on an evaluation system of the value of industrial heritage. Taking industry type, year, development process, immediate surroundings, and remains into consideration, we select 16 industrial heritage sites as samples to verify the feasibility of D-S theory. The results suggest that D-S theory is effective in fusing evidences, and that the mass function is reliable for confirming conservation levels. The integration of AHP, D-S theory and fuzzy theory establishes a mathematical model that targets information fusing and reduces the uncertainty of evaluations, providing a new approach for confirming the level of heritage conservation.

1. Introduction

In the past century, a majority of factories and industrial buildings have been abandoned or idled, and some were listed as industrial heritage, which embodies both material heritage and intangible heritage. Until now, ~6% of the industrial heritage has been on the world heritage list [1], and the number of charters for the conservation of industrial heritage has proliferated all over the world. For settling the tension between protection and reconstruction, special attention should be paid to the value of industrial heritage.

Derived from cultural heritage, industrial heritage is regarded as a certain field of heritage. Therefore, the definition and value can refer to charters of cultural heritage. The Venice Charter defines historic monuments as buildings with civilization, historical relevancy and art [2]. The Granada Convention enacts statutory regulations and policies that could meet minimum conservation standards, which integrates public attitudes into the decision-making process [3]. As the container of memory, the scope of heritage extends to intangible heritage [4,5]. An authoritative document in the field of industry is The Nizhny Tagil Charter, which elaborates the definition, value, legal protection, maintenance and conservation of industry [6]. From the above content, we conclude that industrial heritage is comprised by the continuous cycle of multi-level space that carries the memory of the industrial age, including buildings, factories, sites, setting, technology, drafting and processes related with industrial activities.

The nature of resources is the value of the weight between the conservation and the development benefits it gains [7]. Every action that confines the developmental right of a historical building must compensate for it by promoting the economic-oriented incentive policy of heritage conservation [8]. Cultural charters suggest that a historical building with innovative, historical, social, cultural, artistic, economic, technological, and spiritual value can regarded as heritage [9–11]. Reekers emphasized the importance of conversing industrial heritage in his book "Industrial Archaeology," in which he builds a new discipline called industrial archaeology. Henceforth,

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more intensive research focused on industrial value has emerged. Compared with a cultural charter, an industrial heritage charter emphasizes scientific value [6]. Alois Riegl et al. define the value of industrial heritage, which includes historical, technological, artistic, aesthetic, social, economic, cultural, educational, industrial, spiritual, peculiarity and scarcity value [12–14]. The value proposition decides the function and the form of heritage, including an industrial museum, a post-industrial landscape, a creative industrial zone or a synthesized garden; thus, it is a decision process [15].

With respect to the stakeholders (government, public, investing enterprise, tourist, or property owner) of heritage, the complexity of the evaluation has grown and so has the number of Multi-criteria Decision Analysis (MCDA) on industrial heritage.

Considering that the objective value data cannot be acquired, it is inevitable to use subjective evaluations, requiring numerous experts with different specialties. Torre claims that quantitative data are more about causality but qualitative judgments are more about the relationship of feelings and scenes, thus bringing up a toolbox approach that puts all related values in a table [16]. The reuse of historical buildings requires the analysis of the causes and the environment of its degradation, as well as identifying its original materials, services conditions and the current state of decay [17]. The Delphi method helps experts convey opinions without interference, but the differences between experts cannot be shown [18]. Often combined with the Delphi method, AHP is a useful tool to identify industrial heritage value factors. It also divides the value system into synthetic levels, project levels and indictors with independent factors therein and solves multiple-criteria decision-making problems through the establishment of priorities [19–22]. However, the result will be hazardous due to the interdependency of criteria [23].

MCDA has undergone considerable technological development recently. Mousumi uses Multi-criteria Decision Making (MCDM) to grade heritage sites in Calcutta [24]. Giove presents a multiple criteria model to evaluate the redevelopment of built heritage in Italy, in which the operation at every node of the hierarchical tree is based on non-additive measures and the multi-linear aggregation function [25]. As every rash decision is significantly associated with extra work and cost, it is instructive to explore the feasibility of AHP and additive ratio assessment (ARAS) on heritage management [26]. The literature on the differences in the opinions of experts is not without its problems, so fuzzy modeling and structural analysis are designed to accommodate a historical building in Poland [27]. And an accessible way of tackling regeneration problems of derelict buildings is using MCDM under a fuzzy environment [28]. To yield a more effective result, Kim et al. propose Stochastic Analytic Hierarchy Process (S-AHP) to explain the priority problems of historical heritages and knowledge-based Experience Curve (EC) to reflect experts' criticisms on importance degree among factors [29]. Given decision-making also revolves around spaces and geographical location, Girard et al. introduce the term "territory" and "integrated assessment" and define "spatial integrated assessment (ISA)" that integrates AHP and GIS as pertaining to results that describe the importance of environment to decision-making [30].

In addition, the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) is proposed to improve decision quality [31]. Chen et al. evaluate buildings using cost-benefit analysis on the basis of costs and functional requirements [32], which is impractical for industrial heritage since costs and benefits are hard to evaluate. Considering that heritage is associated with social value and should therefore regard as a non-market product, Wantrup applies Contingent Valuation Method (CVM) to evaluate it [33]. Adapting the travel cost method and the Willingness To Pay (WTP) to the evaluation of historical buildings are methods to estimate their economic value, from which the reuse preference classification corresponds to the economic value is concluded [34]. The social value can be gained by social return on investment (SROI). It strengthens enterprise competitiveness and makes project more rewarding [35]. Wang use FDM method and ANP model to decide the reuse selection of historical buildings, which is demonstrated through two examples in Taiwan [36]. However, the aforementioned methods are not completely convincing, as there always be ambiguity with experts since there is not one exact answer to each question. They perform poorly in fusing opinions, especially when are conflicting expert opinions.

Fuzzy theory shows excellent superiority on the transformation of imprecise knowledge through membership [37,38]. The results are inscribed in a set and not a point, which is considered more appropriate and precise for modelling and results. Fuzzy modelling can take imprecise, uncertain and fuzzy information into consideration and apply the knowledge to the renewal of a historical building [27].

A further study on evidential reasoning is presented. It can be traced back to upper and lower probabilities raised by Dempster in 1960s [39] and later with his student G. Shafer's book [40]. J.A. Barnett applies evidential reasoning to artificial intelligence and denominates Dempster and Shafer's theory as D-S theory [41]. Mathon fuses metric data and experts' opinions by using the advantage of D-S theory that can simultaneously manage epistemic and aleatory uncertainty [42]. Paleari applies D-S theory to emotion recognition, increasing the recognition rate by 19% and the identification precision by 30% [43], which demonstrates the superiority of D-S theory.

Although there has been considerable research on industrial heritage, the value of industrial heritage combined with D-S theory has remained elusive. Due to the many advantages of D-S theory and fuzzy theory, they are suitable for the evaluation of industrial heritage. As a basic top-down weight method, AHP stratifies the target and can be applied to numerous fields. It enables decision-makers to improve their understanding of industrial heritage. Therefore, we evaluate the value of industrial heritage based on AHP, fuzzy sets and D-S theory that can integrate all suggestions that have been revealed as indispensable to settle differences [44]. We establish an evaluation system to valuate industrial heritage based on AHP, collect expertise to compute the weight of each value, apply fuzzy language on cases to translate quantified figures, and fuse evidence from different sources through D-S theory.

2. Research aims

The transformation from subjective evaluation to objective calculation proves that there is increasing attention paid to the evidentiary combination needed to resolve alternative choice, decision-making, risk assessment, disease diagnosis, and other related issues. These insights set a reasonable rationale to assess the conservation hierarchy of industrial heritage. Evaluating the level of industrial heritage is essential for social development, urban construction, economic growth and cultural inheritance. Plenty of MCDAs are used in industrial heritage, including selecting factors, deciding transformational forms, and evaluating industrial heritage. Thus far, most of MCDAs do not take fuzzy information into account.

The main objective is to build an efficient algorithm that combines AHP, fuzzy theory and D-S theory and verify the feasibility of the approach on industrial heritage through 16 cases from Shanghai. The cases contain factories that represent the development level of modern industry. Another objective is to build a value system for industrial heritage and obtain the weight of each factor, translate the complexity, subjectivity, and imperfect information. The aim of the study is to provide a comprehensive method for