

highly relevant, raise challenges for scaling up existing MCDA sorting and ranking approaches to large data sets (Doumpos and Zopounidis, 2011, 2018), (Leyva et al., 2016).

- Multicriteria recommender systems represent an exciting and constantly changing research topic. Multicriteria recommender systems integrates MCDA techniques to consider a set of criteria that provide information on different aspects of the items to be recommended. These systems have not yet been studied extensively, and more research is necessary. Recommender systems have mainly integrated utility-based techniques. Although the outranking model has had a great impact in the MCDA field and has many applications, it has not been sufficiently introduced in recommender systems (Del Vasto, et al., 2016), (Lakiotaki et al., 2011).

Challenges

The hybridization of Big Data and MCDA brings about as a series of theoretical, methodological and operational contradictions and inconsistencies. For example, the problem of semantic heterogeneity caused by different meanings of data, terminologies, and models used in Big Data and MCDA is one of the key challenges in advancing research on integrating Big Data and MCDA. To this end, transparency issues are particularly troublesome to the Big Data-based decision making. For example, decision maker participants and Big Data experts often mix-up fundamental concepts of MCDA such as the notion of value structure, goal, criterion, objective, and attribute without recognizing similarities and differences. It has been only recently that some considerations have been given to how the problem of semantic heterogeneity inherent in Big Data - MCDA affects the quality of the decision-making process. Research into Big Data - MCDA has so far tended to concentrate on the technical questions of how to integrate Big Data and MCDA. Our understanding of the benefits of such integration is limited by the lack of research on conceptual and operational validation of the use of Big Data - MCDA in solving real-world decision-aiding problems. More research about modeling and human-computer interaction is needed to understand the way analysts and decision makers can employ Big Data - MCDA as a decision support tool.

Concluding remarks

The process of merging different disciplines requires a close collaboration among researchers and practitioners with different areas of expertise. Unfortunately, the collaboration between the two disciplines involved in integrating Big Data and MCDA has been rather limited. Most of the contributions to Big Data - MCDA research have come from disciplines outside the MCDA community. Specifically, the integration in one direction has dominated the approaches for interfacing Big Data and MCDA. Also, most of the Big Data - MCDA applied research has been done without any participation of the MCDA researchers and practitioners. The topic of a tighter collaboration between the Big Data and MCDA communities is of critical importance for advancing research and practices in Big Data - MCDA.

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Multicriteria Methodologies for the enhancement of the Cultural Heritage

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The importance of enhancing the cultural heritage

In the last decades, the conceptual and the policy framework for the cultural heritage has massively evolved due to the awareness of the benefits for the economy, the society, the culture, and the environment (CHCFE project, 2015).

Nowadays, the cultural heritage has been identified by government authorities as a tool for the sustainable development (Council of the European Union, 2014), for the economic growth, to reconvert cities, to enable integration and inclusion processes and as a pillar for the identity of the nations (Arfaoui and Heid 2016).

Many cities have already recognized the role and importance of cultural and creative industries in local development. Preserving and enhancing the cultural heritage is integrated into urban agendas and local development strategies in a variety of sectors such as innovation, branding, tourism and social inclusion (Blake, 2000).

Indeed, the protection and enhancement of cultural values (tangible and intangible) start to have a recognizable role in the urban regeneration processes. For example, when the cultural actions (e.g. reuse of the building, reclamation of open space, arts 'festivals', events and public art) are the core of a local policy aimed at urban renovation, the processes are defined as cultural-led regeneration (Evans, 2005; Vickery, 2007).

Even more, strategies that want to enhance cultural heritage can generate positive interlinked impacts on context. On the other hand, the dimension of these synergistic effects depends on the process activated and the capacity to create a shared and inclusive social representation of a context, that respect the identity and the local values (Ferilli et al., 2017).

Therefore, local and international agencies, such as the European Commission, and the 2030 Agenda for Sustainable Development Goals of the UN General Assembly and UNESCO's Governing Bodies, encourage the public awareness of cultural heritage, motivating governmental institutions to act for the preservation of the local and the national heritage (e.g., McKercher et al., 2005).

The use of multicriteria methods in the cultural heritage context

Despite the increasing interest in enhancing the cultural heritage, due to the increasing lack of public funding in the current economic context, is necessary to rethink the strategies to deal with such huge quantity of heritage to preserve (Yau, 2009). In this sense, emerges the possibility of supporting decision makers with appropriate methodologies that aim at classifying, prioritizing and selecting the appropriate strategies to preserve and enhance cultural heritage (Fusco Girard and De Toro, 2007; Fusco Girard et al., 2014). To support such complex decisions, those methodologies need to deal simultaneously with all these aspects building a participative and sharable decision.

In the past, the MCDM methods have been used in the context of cultural heritage in different case studies (e.g., Hong and Chen (2017), Dutta and Husain (2009), Giove et al. (2011)). However, given the complexity of the problem, it seems that the natural evolution of these methods is the integration of those MCDM methods in appropriate frameworks. Some attempts in this direction have been made for MCDM Methods that have been used together with GIS environment (see e.g. Tarragué et al. (2012) or Oppio et al. (2015)).

In this perspective, a versatile framework for the evaluation and the subsequent selection of interventions for the

preservation of the cultural heritage has been proposed by Ferretti and Comino (2015). They consider both qualitative and quantitative values, to help decision makers in developing urban strategies. They stress the necessity of interacting with the different stakeholders in a transparent process, to prioritize the most important elements in the context of the cultural heritage and to support the choices of public and, eventually, private stakeholders.

Recently, a further aspect has been introduced in the literature that considers the choice of the interventions in the cultural heritage context as a portfolio of choices to be made altogether in order to take into account potential synergies among the different projects to implement. An attempt in this direction has been made by (Nestico et al., 2018) that propose to apply MCDM methods to generate a plan that chooses a portfolio of interventions to be made altogether.

The integration of all the above elements can be retrieved in the work proposed by (Barbati et al., 2019). The methodology integrates a MCDM method and the resolution of a portfolio problem. It is characterized by the continuous interaction with the different stakeholders involved and it also allows to consider potential synergies and possible linked effects in the urban context.

Discussion and insights

From the analysis of the evolution of the way of dealing with the cultural heritage, it seems that a new paradigm could and is being developed in which decisions are taken, with the support of structured methodologies, considering multiple aspects of the problem, multiple stakeholders, multiple criteria and the relevant restrictions, including the not economic ones. The decision processes tend to become more inclusive and, consequentially, the procedures to evaluate the potential intervention requires the use of participatory and collaborative approaches that support the interaction between the actors involved, and identify possible ongoing improvements.

Moreover, reducing funding encourages the councils to look for new ways to fund the culture policies (cultural, educational, social activities, preservation of cultural heritage, local engagement, and enterprise, etc.) and to optimize the available resources. Furthermore, it is important to consider that a cultural enhancement strategy could be implemented in very different periods, where the conditions could change quickly and the enabling context can be identified.

More in detail, when dealing with decisions in the cultural heritage system, several aspects need to be considered as:

- Several stakeholders are involved in the decision-making process of the strategy to adopt (Yung and Chan, 2013). Indeed, the cooperation between public, private and nongovernment sectors is important to start and carry out projects but also to sustain the places over time (Macdonald and Cheong, 2014);
- Several points of view need to be taken into account and integrated in order to reach an agreement among the several stakeholders involved (Fusco Girard et al., 2014);
- Citizens want to be fully informed of the decision to be made, therefore a clear and transparent procedure to get

to the decision must be adopted (Dutta and Husain, 2009);

- Awareness of the identity shared values of the different local communities should be promoted (Cerreta and Panaro, 2017);
- Economic aspects can be revitalized as for example the promotion of tourism (e.g., McKercher et al., 2005), local entrepreneurship and local businesses (e.g., Tuan and Navrud, 2008);
- Monetary aspects need to be considered together with other elements (Wang and Zeng 2010) such as improvement of the environment and the urban landscape (Veldpaus et al., 2013), protection of place identity and heritage values, sustainability, well-being and life quality of citizens (Tweed and Sutherland, 2007);
- Indeed, this type of processes cannot be planned in each aspect. It is necessary that the local communities feel part of the same vision, participate, cooperate and even compete together.

Therefore, it is crucial that methodologies that support decisions in the cultural heritage context are characterized by:

- Integration of different methods and tools, structuring multi-methodological and hybrid decision-making processes;
- Versatility and easiness of adaptation in different complex problems;
- Consideration of the different interventions as interlinked and not isolated;
- Efficiency in monitoring the impacts of the selected actions in the urban context;
- Capability of handling dynamic aspects such as unforeseen changes in the economy;
- Ability to deal with uncertainty and risk conditions;
- Capability to stimulate cooperation between different actors, reducing conflicts.

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MCDA Research Groups

Decision analysis at University of Trento

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Research on decision analysis methods has been carried out in the University of Trento since the late Eighties, mostly

thanks to the initiative of **Mario Fedrizzi**, now Emeritus Professor. The research group initially focused on preference relations, consensus and their representations with fuzzy sets theory. In that period, fruitful collaborations were established with other researchers such as Hannu Nurmi (University of Turku, Finland), Janusz Kacprzyk (Polish Academy of Sciences), José Luis Verdegay (University of Granada, Spain). During the Nineties the research group, then called MEDIA (Multi-Expert Decisions and Interactive Aggregation), was composed also by Michele Fedrizzi and Ricardo Alberto Marques Pereira and developed mathematical models to describe consensus in the case when the preferences of decision makers are fuzzy.

After the Italian University reform in 2010, and until present days, the research in MCDA in Trento has been carried out by different researchers in three different departments.

Michele Fedrizzi and **Matteo Brunelli** (Dept. of Industrial Engineering) have studied cardinal preference relations, especially with respect to the condition of consistency. This led to some studies, both theoretical and numerical, on inconsistency indices, i.e. indices commonly used to quantify the degree of inconsistency of a set of preferences. Some of the results spotted how seemingly different measures of inconsistency are, instead, functionally related, and thus equivalent. Furthermore, more axiomatic studies have been proposed in order to study the mathematical structures of inconsistency indices by means of an analysis of their properties. In this context it was shown that a number of well-known indices fail to satisfy some properties and therefore their use as inconsistency indices remains questionable. Other research directions include fuzzy sets theory and, more recently, the optimization and management of maintenance operations.

Silvia Bortot and **Ricardo Alberto Marques Pereira** (Dept. Of Economics and Management) have research interests related to aggregation functions, especially the Choquet integral and the ordered weighted averaging (OWA) functions.

The Choquet integral was applied, for instance, in the context of project management and properties of OWA functions have been studied in the light of their binomial decomposition.

Additionally, among their proposals there is that of using the binomial decomposition of OWA functions to study the non-additive structure of some well-known welfare functions and inequality indices like those introduced by Gini, Bonferroni and De Vergottini.

Finally, they have proposed an extension of the AHP in which aggregation was defined on the basis of 2-additive Choquet integrals sensitive to inconsistency, and they have investigated the general algebraic representations of the mean particularly in relation with the AHP framework of pairwise comparison matrices.

Finally, **Stefano Benati** (Dept. of Sociology and Social Research) has conducted research in game theory and portfolio optimization. Among his proposals there is the use of the median, instead of the expected mean value, to make portfolio optimization more robust. His current research on