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A digital response system to mitigate overtourism. The case of Dubrovnik

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ABSTRACT

In order to design effective responses to the complex phenomenon of overtourism, the tourism carrying capacity (TCC) of a destination is an essential reference point. This paper provides in-depth analysis of this correlation through the case study of Dubrovnik. The study applies a TCC calculation model that is able to quantitatively include the main effects of overtourism. The paper illustrates how these results can be used to automate specific decongestion policies by conceptualising a digital response system for real-time intervention to mitigate the undesirable effects of overtourism.

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Introduction

Although the concept of overtourism is far from new, the topic has become increasingly cited in recent academic discourse. There are numerous studies on unsustainable tourism growth which analyse typical symptoms of overtourism, such as the gentrification of urban city centres, congestion in attraction areas, and the overcrowding of popular seaside destinations and UNESCO world heritage sites. While overtourism has become increasingly commonplace, it is volatile and highly influenced by external factors that cannot be controlled or predicted and which limit the mobility of people. These include earthquakes, tsunamis, terrorist attacks and, most recently, pandemics. The topic of overtourism appears in most journals and new publications on tourism (see the excellent review of the debate by Koens et al., 2018); it has also caught the attention of policymakers worldwide (Peeters et al., 2018; UNWTO, 2018).

An awareness of both the positive and negative effects of tourism, and its propensity to be unsustainable, has been around for several decades. In a book by Young (1973) entitled *Tourism: Blessing or Blight*, published in 1973, and a work of Krippendorf (1987) with the title *The Holidaymaker* (1989), the potentially devastating effects of tourism on destinations are described in great detail. Here, the discussion focused predominantly on the environmental and social damage that (excessive) tourism could inflict on host communities. Van der Borg (1991) and Van der Borg et al. (1996) look at heritage cities in general, and the Italian city of Venice in particular, to illustrate the equal importance of the economic impact of tourism.

As explained below, in Van der Borg (1991) and Van der Borg (2011) it is argued that the net contribution of tourism to the local economy and community tends to vary, just as the positive and negative impact of tourism varies over Butler's TALC (1980). This means that the sustainability of tourism also differs. The foundations for the present debate around sustainable tourism development and (clearly unsustainable) overtourism can be traced back to these and other publications in the eighties and nineties.

Strangely, the overriding narrative surrounding tourism development did not change significantly until very recently. For decades, tourism remained the means to boost social and economic development in rural and urban environments and in developed and developing countries (Ashworth & Page, 2011; Edwards et al., 2008; Robinson & Picard, 2006; Sharpley & Telfer, 2015; Theobald, 2012; Van der Borg et al., 1996). Tourism development policies and tourism business models happily embraced this rather simplistic narrative, which focuses on quantities rather than qualities and on the interests of the industry rather than of visitors. However, the discussion is finally shifting towards new, more sustainable tourism development paradigms. A recent description of this trend can be found in (Fayos-Solà & Cooper, 2019) (see also Aall & Koens, 2019; Buhalis, 2000; Liu, 2003; Saarinen & Rogerson, 2014; Sharpley, 2000; Williams, 2004).

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The debate on overtourism has accelerated the aforementioned shift. This debate is fuelled by the seemingly continuous growth in the number of tourists worldwide and cases that testify to the critical limits of tourism development (Amsterdam, Barcelona, Berlin, Bruges, Dubrovnik, Florence, Prague, and, obviously, Venice). Tourism carrying capacity (TCC) plays a central role in the overtourism debate, and is particularly prevalent in policy-driven attempts to address the phenomenon (see for instance, Capocchi et al., 2019; Cheung & Li, 2019; Gonzalez et al., 2018; Koens et al., 2018; Milano et al., 2019; Namberger et al., 2019; Wall, 2020).

The concept of overtourism is relative, as explained for example, by Gonzalez et al. (2018) or Namberger et al. (2019). It is not simply a matter of millions of people visiting a place. In fact, a small, sensitive host community may very well experience what can be termed overtourism when visited by just a few tourists. Moreover, as illustrated by Bertocchi et al. (2020), the quality of the visitors determines the attitude of the local community towards tourism. The TCC helps to give a concrete foundation for this discussion: when the TCC is surpassed by the actual number of tourists and there is a discrepancy between the optimal and the actual quality of the visitors, overtourism is a fact. Obviously, small and sensitive host communities in central Africa will have a modest capacity to host visitors, while megacities like Shanghai will have a huge capacity to accommodate visitors. But in both cases, *too much is too much*, and the measure of TCC remains a key element in planning developed for a destination (Saveriades, 2000).

This variability means that issues of overtourism and TCC may become even more important when global tourism recovers from the pause instigated by the 2020 pandemic. The absolute number of tourists worldwide may not reach pre-COVID-19 levels right away, but in many destinations there will be a crucial discussion on the extent to which public space, public facilities and public infrastructure should be made available to visitors, and how much should be reserved for inhabitants and other users. This is especially relevant as social-distancing norms are likely to become a feature of daily life. This means that much of the analysis related to the phenomenon of overtourism will become more relevant; as will the potential solutions which are discussed and are proposed in this paper.

The purpose of this paper is to illustrate the role of the TCC in instances of overtourism and to discuss the policy implications of the relationship between these two concepts. This will be done through analysis of the case study of Dubrovnik, an iconic destination where the debate around overtourism has become very intense in the last few years. The city's historic centre has been pushed to experiment with different solutions to mitigate the effects of overtourism, from regulatory to more technical interventions.

First, the following section presents conceptual evidence for the relationship between overtourism, TCC, and policy on the basis of a literature review.

The tourism carrying capacity (TCC): a literature review

An understanding of the tourism carrying capacity can be gained by examining the relationship between the collective costs and benefits generated by tourism; recalling Butler's Destination Life Cycle Theory (TALC); and by considering the consequences induced by a deliberately uncontrolled tourism development (Van der Borg, 2011). This section summarizes the principal results of that study.

Today, a great deal of tourism literature revolves around the notion of sustainability. Yet, much of this literature is focused on how sustainable tourism is implemented in rural or non-urban areas. Only recently has the scope for sustainable tourism widened to include urban environments, specifically heritage cities (Coccossis & Mexa, 2017; García-Hernández et al., 2017; Gonzalez et al., 2018; Parpairis, 2017; Rudsari et al., 2019; Zhang et al., 2017). How the concept of sustainable tourism development is implemented in reality is more difficult to understand.

Wall (1995) has asserted that tourism alters a local community permanently and that the sustainability of these alterations is dependent on whether they are perceived as acceptable. If the way in which tourism has altered the community is acceptable, then it is sustainable. While the local society develops and changes, so does the location's tourism; the development process of a tourist site may be depicted as cyclical. Butler's life-cycle theory of a tourist destination can easily be linked to the notion of overtourism and its carrying capacity (see Butler, 2019; Russo, 2002), although it is sometimes criticized and alone cannot represent a holistic understanding of the phenomenon (see for example, the articles of Choy, 1992, or Haywood, 1986). In fact, Butler's model is nothing more than an evolution of the product life cycle that has often been used in economic literature to depict the changes in sales volume of any given consumer product. Butler's TALC replaces the amount of products sold with the total number of visitors as the indicator for the development stage of the destination.

In its most elementary form (see for example, Butler, 1980; Morrison & Mill, 1985), TALC explains that the total number of visitors changes cyclically. Initially, the locality that stimulates tourism experiences a very slow rise in

the number of visitors. In the second stage, tourism booms. In the third stage, growth stagnates and eventually turns into decline, entering the fourth stage. Van der Borg (2011) argues that in addition to the changes that occur in the volume of visitor flows, a change also occurs in the composition of the visitors (i.e. the combination of visitor types).

The variation in types of visitors translates into a variety of costs and benefits, the net effect that tourism generates will vary over the different stages of the cycle. Growth in tourism demand will positively affect income and employment levels of a relevant part of the population. At the same time, increasing numbers of visitors will generate negative effects. These are "costs" typically borne by the physical and cultural environment, the local population, and the visitors themselves. By comparing benefits and costs in each heritage city, it is possible to determine whether tourist flows are either insufficient or excessive. In reality, assessing the benefits and costs of tourism is difficult, because there are various stakeholders involved who perceive benefits and costs in a different manner.

The concept of sustainability – in terms of desirable or acceptable change, as suggested by Wall (1995) – and the cyclical development of a tourist destination are closely related. In fact, as Van der Borg (2011) suggests, if tourism development remains stuck in the initial stage, investments are unable to trigger the desired social and economic change. There are too few visitors, and the opportunities that tourism offers are not fully utilised. Also opportunity costs are high. However, if tourist numbers grow to such a level that attractions are compromised (in terms of accessibility, quality etc) then society, and eventually tourism itself, will suffer. Change is no longer acceptable. In this instance, the number of tourists exceeds capacity and, instead of providing growth, threatens to overwhelm the community and society it is a part of. Developing tourism in a sustainable manner thus means trying to use a destination's finite resources optimally for tourism's purposes. This safeguards the interests of current and future inhabitants, tourists, and the tourism industry (see also Coccossis & Nijkamp, 1995; Fossati & Panella, 2000).

Referring to Butler's TALC, Van der Borg (2011) demonstrates that in a destination's development process it will go through sustainable and unsustainable stages. Van der Borg et al. (1996) developed this approach further with the help of a cost-benefit analysis. Generally, the early stages of a location's development as a tourist destination are barely profitable. This is because the costs of the initial investment are substantial compared to modest returns. Therefore, developing tourism is only sensible if the number of tourists can be expected to grow sufficiently in order to make the investment in facilities and attractions worthwhile. The saturation stage typically means a net loss for the local community as negative externalities – such as congestion and pollution – outweigh benefits.

With regard to mature heritage sites and cities, Van der Borg et al. (1996) suggested that the most relevant limit to tourism development is the maximum level of development, which is closely linked to what is more generally known as the TCC. When this limit to development is exceeded, negative externalities usually appear. The TCC aims to indicate this perimeter by designating the maximum number of tourists that a destination can host. UNWTO defines the TCC as the "maximum number of people who can visit a tourist destination at the same time, without causing the destruction of the physical, economic and socio-cultural environment and an unacceptable decrease in the quality of visitor satisfaction" (UNWTO, 1981). This also underlines the extent to which the limits of tourism development involve multiple dimensions (physical, economic, socio-cultural, etc).

The multiple capacities of the TCC, as highlighted by Getz (1983), refer to six elements which may affect a destination: physical, economic, perceptive, social, ecological, and political capacities. This approach was subsequently adopted by several authors (Coccossis & Mexa, 2004, 2017; Widz & Brzezińska-Wójcik, 2020), and led to the creation of three more succinct, well-known, and distinct dimensions of the carrying capacity: the physical-ecological, socio-demographic, and political-economic dimensions.

These parameters can be used to determine whether the number of visitors to a destination should be limited. These reasons can be summarised as follows. First, because the physical environment of a destination is jeopardised; this corresponds to what is usually called the physical-ecological carrying capacity (see Abernethy, 2001; Buckley, 1999; Martin & Uysal, 1990; Papageorgiou & Brotherton, 1999; Zacarias et al., 2011). Second, because the local community loses its character; this corresponds to what is normally called the social-anthropological-demographic carrying capacity (see Graymore et al., 2010; Mathieson & Wall, 1982; Prebensen et al., 2014; Saveriades, 2000). Third, because the local economy becomes overly dependent on tourism, corresponding to what is usually called the social-economic carrying capacity (see, among others, Sowman, 1987; Swarbrooke, 1999).

Naturally, it is not necessary to investigate these dimensions separately. Instead, a multi-dimensional lens should be used in which all three components influence and define the TCC. Close relationships are often formed between the different analytical

dimensions, in particular between the social and economic aspects. This leads to complications that affect the local population in particular. Residents play a vital role in the tourism system and are a fundamental ingredient for the "hospitality" of all destinations. The social impact of tourism on the local community is understood through the reaction of the city's inhabitants to tourism. This thus determines the social-anthropological carrying capacity of the destination. The social-economic TCC can be defined as the maximum number of visitors that can enter the city without undermining the functioning of the city. This number is closely related to the idea of "crowding out", an idea first described by Prud'homme (1986) and further elaborated by Russo (2002). Overtourism tends to dominate, if not suffocate, the urban economy: it pushes other economic activities or social functions from the centre to the peripheries. Centrally located and high value space becomes even more expensive while congestion and pollution erode the quality of life in the city, for both families and businesses. Together, these factors fuel the, often irreversible, process of crowding out.

Implementing TCC and the necessary tools

Glasson et al. (1995) have shown that the carrying capacity of a tourist destination is a nuanced and complicated phenomenon. The scale on which carrying capacity can be measured varies, from that of a single attraction to the location in its entirety. In practice, local characteristics and peculiarities determine the most relevant level of analysis. For example, a number of in-depth interviews conducted with managers of various attractions in Venice have shown that the smaller-scale attraction level is of less relevance to Venice, as most visitors do not visit the city's attractions but instead spend their time walking the historic streets in the centre (Visentin & Bertocchi, 2019; Bertocchi & Visentin, 2019). A parallel situation exists in heritage cities that have been carefully conserved such as Bruges (Neuts & Nijkamp, 2012), Rothenburg, and Salzburg (Buonincontri & Micera, 2016), which are attractions as a whole.

Overall, the positive and negative effects of tourism in a location will be measured differently, as the perception and behaviour of the destination's residents, visitors and tourism industry change. Therefore, time is also an important factor for consideration. The dynamism of the TCC concept is evident when looking at how the perceived acceptability for certain phenomena caused by excessive tourist pressure can change from destination to destination. These depend on the type of tourist and also, *ceteris paribus*, on the intensity of use, the fragility of local resources in specific areas, and the many different and specific management techniques that affect them (Coccossis & Mexa, 2004; O'Reilly, 1986).

Notwithstanding frequent criticism of carrying capacity as a planning instrument (see for example, Lindberg et al., 1997; Priestley & Mundet, 1998), it is hard to continue to repudiate that tourism development does not have an upper limit, given the profound and sustained rise in global tourism demand. In fact, the concept has proven its value for visitor management in Venice, Malaga, Dubrovnik, and other important destinations of (urban) tourism. Despite serious limitations, the concept of carrying capacity remains a useful concept for environmental management, in particular in providing insights into the interaction of human activities with the environment (Papageorgiou & Brotherton, 1999; Zacarias et al., 2011) and it "enables the preservation of the high quality and quantity of coastal resources while meeting not only the current needs, but also securing long-term economic and ecological benefits for future generations" (UNEP/PAP, 1997, p. 8).

Coccossis and Mexa (2004) have also examined TCC as a valuable tool for planning and management, while Martin and Uysal (1990) argue that TCC is impossible to ignore and, together with the tourism life cycle, generates a more feasible blueprint for tourism management.

The calculation of TCC for tourism planning has multiple implications: it provides space for initiatives to manage tourist flows through balanced redistribution and segmentation of the demand; the creation of alternative itineraries or new tourist attractions, and the introduction of regulations or system reservations (Buckley, 1999; Matias et al., 2007; Riganti & Nijkamp, 2008).

Moreover, social marketing can play an important role in changing consumer attitudes and behaviours (Kotler & Keller, 2006) and "demarketing" in reducing or shifting demand (Kotler et al., 2007). Both are useful tools in the field of sustainable tourism in response to the need to operate within TCC limits (Pomering et al., 2011). To this end, alternative success criteria must be established to ensure that the goal of tourism marketing is not simply to attract a certain number of tourists, but rather to achieve high satisfaction rates between tourists and residents (Ryan, 1991). Strategic marketing can also be useful for allowing destinations to achieve desired policies by avoiding the excessive exploitation of local resources (Buhalis, 2000).

The use of smart and digital solutions can help to make marketing strategies effective, enabling destinations to successfully achieve the desired goals (Gretzel et al., 2000). The digital revolution has also transformed the tourism industry by changing business patterns and business models (Gretzel et al., 2000) and influencing the behaviour and decisions of tourists (Buhalis & Law, 2008;

Schwanen & Kwan, 2008; Wang et al., 2012). In particular, mobile technology has allowed companies to reach consumers without time or spatial constraints (Grant & O'Donohoe, 2007); this has enabled tourists to better manage their activities and quickly personalize their journey by taking advantage of connectivity (Ling, 2004). From a consumer perspective, smartphones have taken on the role of guides by recommending new attractions and experiences to tourists while meeting their needs (Haldrup & Larsen, 2006). Concurrently, technology has become a useful tool for destination organizations to correctly manage the tourist phenomenon through monitoring and implementing tourism planning based on the needs of tourists (Moscardo & Murphy, 2014).

Koens and Postma (2017) conducted a survey among several European capitals (Amsterdam, Barcelona, Berlin, Munich, Lisbon, Copenhagen) from which the following 10 overarching strategies emerged: 1) spreading visitors around the city and beyond; 2) time-based rerouting; 3) regulation; 4) creating itineraries; 5) visitor segmentation; 6) making residents benefit from the visitor economy; 7) creating city experiences that benefit both visitors and local residents; 8) communicating with and involving local stakeholders; 9) communicating with and involving visitors; 10) improving city infrastructure and facilities.

The ability to detect critical problems, caused by excessive tourist pressure, is crucial in determining which policy interventions are suitable to mitigate said problems, and how these would be best implemented. Therefore, both a monitoring system (Buckley, 1999) and an efficient calculation of the TCC are essential to make all interventions useful in practice (Simón et al., 2004).

However, the scientific research and testing of systems which combine these fields for TCC management has not yet been conducted. As a result, there is a methodological and operational gap that needs to be addressed so that many cities can mitigate the effects of overtourism.

The purpose of this research is to illustrate a model capable of combining necessary activities to tackle the phenomenon of overtourism. These are likely to be highly relevant in the aftermath of COVID-19, when it will be critical to avoid overcrowding and congestion for the purposes of social-distancing and public-health. The activities outlined in this paper are necessary to calculate and limit the use of a destination or its infrastructure (in this case through the TCC), monitor tourist flows and their impacts on the city, and the promotion and marketing of other, lesser-known and visited attractions or territories.

Materials and methods

The study aimed to use carrying capacity criteria to determine the sustainable limit of tourists and visitors, to share this insight with policymakers, and to conceptualise a digital response system. This system should be capable of mitigating the threat of overtourism and redistributing visitor flows. The digital response system was designed to better structure the mitigation of overtourism with three steps: 1) the calculation of a limit regarding the pressure of visitors or the growth of the tourism sector in a destination; 2) the monitoring of this limit through indicators and data; 3) the implementation of strategies to reduce the number if that limit is exceeded. As discussed previously, one of the most common ways to establish limits for the maximum number of visitors is to study pressure on urban destinations and cultural sites using the carrying capacity concept; this forms the first step of the methodology.

One of the primary reasons to use the methodology to calculate the carrying capacity outlined below is its applicability to destinations such as art and historical cities. The model was first developed by Costa and Van der Borg (1988) and refined by Canestrelli and Costa (1991) for the city of Venice and was recently updated by the authors, also for Venice. The two cities of Venice and Dubrovnik are considered to be similar case studies, which have faced negative externalities due to overtourism in recent years. In addition, the model is based on the limits and rates of use, and therefore responds well to limitations on the number of daily visitors within the walls of Dubrovnik's old town. In 2016, UNESCO warned the city that its World Heritage Status was at risk and recommended that the city restrict visitor numbers to 8,000 per day (see Panayiotopoulos & Pisano, 2019; Simmonds, 2017). Furthermore, the current situation of both city centres clearly illustrates the "touristification" of historic city centres and the consolidation of a tourism monoculture (Bertocchi & Visentin, 2019; Stecker & Hartmann, 2019).

Applications of the carrying capacity concept often focus on the search for an optimal number of visitors (Canestrelli & Costa, 1991; Coccossis & Mexa, 2004; Van der Borg et al., 1996). According to Mowforth and Munt (2003, p. 223), "[t]he result of carrying capacity measurements will always depend on the context of the situation being measured and … this context will vary not just with the physical and social environments, but also with the values of those asking the questions and establishing the conditions for measurement." To adapt the calculation of the carrying capacity limit to different contexts, Bertocchi et al. (2020) developed a fuzzy linear programming approach for the physical carrying

capacity of an urban destination which is capable of suggesting a sustainable range of destination visitors instead of an exact number. This "fuzziness" is included in the result of the model, expressed as a range of different users (tourists sleeping in hotels, tourists sleeping in Airbnbs or similar accommodation, and daily visitors) instead of an exact number. It is also included in the elaboration of constraints (physical limits of the tourist subsystems) and the behaviour of users (usage rates of every single profile related to the constraints). Once a limit on people or limits on the growth of a particular tourism asset (e.g. an accommodation system) are set, it is possible to understand the current situation of the destination and the rate of overtourism and touristification of the area through the use of indicators.

Some indicators related to overtourism at a macro level were developed by Peeters et al. (2018) in a report for the European Parliament; other indicators refer to lower levels, such as the European Tourism Indicators System (ETIS) or those developed by Bertocchi and Visentin (2019) for Venice. During this process, technologies, big data, real-time data, and ICT can support monitoring. New sources of data, such as sensors, cameras, telco data, and data from connected objects (the internet of things), can be used to construct new indicators. Together, the monitoring system able to detect when capacities are exceeded, and a control system capable of activating specific policies, strategies and actions, make it possible to mitigate the negative externalities of tourism. These include congestion, overcrowding, depopulation, loss of tradition, and the worst scenario: the development of a tourism monoculture. Actions can be taken to manage visitors and flows or to protect and preserve attractions, cultural sites, and historical centres. They can also consist of strategic plans such as the demarketing of tourist hotspots and major destinations, or policies and laws to reduce pressure on heavily used destinations.

The model first considered the TCC calculation made by Canestrelli and Costa (1991) and the updated values from Bertocchi et al. (2020). According to these contributions, the calculation of the TCC can be conceptualized as a problem of benefit maximization under the constraint of the maximum stress (caused by overtourism in our case) that tourism subsystems of a destination can bear. This must not be exceeded by the entire system. Such a problem can therefore be formalized in a linear programming problem whose canonical form is:

$$\begin{cases} \max\limits_{x}(cx) \\ Bx \leq d \\ x \geq 0 \end{cases} \tag{1}$$

where c_i are the coefficients of the objective function, $b_{i,j}$ the technical coefficients, and d_j the second side coefficients.

While the extended form is:

$$\begin{aligned} &\max_{x} c_1 TH + c_2 NTH + c_3 E \\ &TH \leq d_1 \\ &TNH \leq d_2 \\ &b_{3,1} TH + b_{3,2} NTH + b_{3,3} E \leq d_3 \\ &b_{5,1} TH + b_{5,2} NTH + b_{5,3} E \leq d_5 \\ &b_{6,1} TH + b_{6,2} NTH + b_{6,3} E \leq d_6 \\ &b_{7,1} TH + b_{7,2} NTH + b_{7,3} E \leq d_7 \\ &TH, NTH, E \geq 0 \end{aligned} \tag{2}$$

where TH, NTH, and E represent the type of users, respectively hotel tourists, non-traditional hotel tourists (e.g. tourists at B&Bs and Airbnbs), and excursionists (day trippers). The intention is to calculate the optimal number to master the objective function given their budget levels c_1, c_2, c_3 respectively;$b_{i,j}$, d_j are the left- and right-side constraints coefficients of each tourism subsystem (here set at seven).

The following steps were undertaken to calibrate the problem on the target destination:

1. identify the tourism subsystems of a destination, especially in terms of tourism facilities and services;
2. classify the type of users that often utilize those subsystems;
3. determine the level of usage of these subsystems by user profile;
4. proceed with a quantitative analysis using a fine scope to maximize the revenue of the destination through understanding the daily expenditure of each profile.

The indexes on the usage rate of the tourism subsystems and the spending capacity of each profile were collected through interviews and questionnaires developed thanks to the Interreg Med AlterEco project. Interviews were conducted to acquire information regarding the behaviour of the following three profiles: tourists in hotels, tourists in Airbnbs, and excursionists. In the model, values obtained through various simulations represent the median, minimum, and maximum values for defined profiles, scored according to their impact on the tourism subsystems. In this context, the spending capacity of tourists is represented as an average between those who are luxury tourists (4 and 5 stars) and of those who choose low-budget accommodation (1 and 2 stars).

This is also applied to the excursionist (or day tripper) profile: the visitor who stays overnight in another

location or in their place of residence. The values used in the model represent the average of the respondents' spending capacity, where there are users who say they do not spend anything during the day (very few) and high-expenditure excursionists.

The calculation of averages and minimum and maximum values is also a way to account for the different visiting behaviours and peculiarities of many profiles (for example, excursionists who do not spend money, visitors who do not visit the old town, domestic or international tourists).

In this way, the usage rate of the various tourist subsystems, which includes the most fragile (in our case the historic city centre), is the average of visitors' usage rates of one or more tourist subsystems. This ranges from several times a day to once during their holiday, to not at all.

Once the optimal range of users per typology is calculated, it is possible to monitor the situation of the destination using data and indicators. If the limit is exceeded, it is possible to act promptly to mitigate problems of overtourism and stressful situations.

Study area

Dubrovnik is a globally recognized destination with rich heritage and scenic attractions. The city centre was designated a UNESCO World Heritage Site (WHS) in 1979 and is renowned for being a living heritage site, which should be preserved. The beginning of the 21st century brought a strong surge in mass tourism that was addressed in the city's 2014 annual UNESCO report. The study expressed concerns, citing "threats which could have deleterious effects on its inherent characteristics," meaning that the site currently "meets the criteria for its inscription on the List of World Heritage in Danger." A year later, UNESCO and the ICOMOS mission to Dubrovnik drafted a report with findings and recommendations in line with operational guidelines. This report unfortunately did not sufficiently explain, describe, or understand the TCC. Accommodation capacity in the city is 27,600 beds, with a trend of rapid growth in the now leading household/apartments segment. In the last decade, this segment increased threefold, while hotel capacity grew by only 15% (Dubrovnik Tourist Board), and has strongly contributed to the existing touristification trends and pressures:

- increase in commercial and low-cost flights due to the expansion of Dubrovnik airport's facilities;
- increase in cruise tourism, especially with regard to the size of the ships;
- increase in road traffic, undermining residents' mobility (the existing road network struggles with 40% to 60% more traffic than capacity allows for during the high season).

There is no clear data on the ratios of newly constructed tourist apartments versus existing ones. The conversion of residential apartments into tourist-orientated lets has added approximately 10,000 bed spaces in the last decade, significantly reducing the available accommodation stock for the local population. Between 2014 and 2018, overnight stays grew from 3.1 to 4.1 million and arrivals from 864,000 to 1,272,000 in the context of a resident population of 42,000. Overtourism not only exists in Dubrovnik but is possibly out of control.

Unsurprisingly, this has generated tensions between tourism and the resident population, who have increasingly negative perceptions of both the industry and visitors. These are only occasionally researched and documented, both in scientific research (Olya et al., 2019; Seraphin et al., 2019) and in newspaper articles (Coldwell, 2017; Diaz, 2017; Dickinson, 2018; Hughes, 2018; Morris, 2017). An in-depth overview of Dubrovnik's infrastructure reveals that attitudes will continue to deteriorate as the impacts of touristification on the city's environmental management and infrastructure become increasingly evident:

- the water supply is struggling with a number of issues, including high losses;
- the wastewater system is mostly outdated and porous;
- waste management does not meet EU standards (separation, recycling, landfilling);
- electricity consumption is creating peaks that are problematic for the energy system (production, transmission);
- air pollution from traffic is evident with limited progress in monitoring;
- noise pollution intensely affects residents in the WHS.

Overtourism mitigation strategies

The main city documents related to tourism are the *Strategic Plan – City of Dubrovnik 2018–2020* and the *Strategy for Tourism Development and Regulations on Cruise Tourism for Dubrovnik Area Phase I*. Although it is not entirely clear how the strategic actions of the document should be formally implemented, the city authorities have engaged in various activities related to

sustainability indicators and touristification issues, such as:

- a Destination Sustainability Measurement Project conducted by the Global Council for Sustainable Tourism (GSTC), the City of Dubrovnik, and the Cruise Lines International Association (CLIA) – ongoing, to be completed in the first trimester of 2020.
- a Respect the City Project – ongoing.
- the Croatian Sustainable Tourism Observatory (CROSTO), a monitoring framework of 14 regional level indicators that was joined by the City of Dubrovnik in 2019 – ongoing.
- a study on the sustainability of tourism development and carrying capacity – ongoing, to be completed by early 2020.

Attempts to deal with overtourism have intensified in the second half of 2019 and aimed to inform the TCC, among other goals. However, the quality and reliability of outputs is yet to be determined. At the moment, city authorities and the Institute for the Restoration of Dubrovnik have begun to produce a Management Plan for the UNESCO World Heritage Site Old City of Dubrovnik (WHS Dubrovnik). Its conceptual and methodological framework considers aspects of overtourism. Many consider this to be a pivotal moment for responding effectively to touristification phenomena and improving the site's sustainability.

ICT, monitoring systems, and marketing strategies

The City of Dubrovnik developed a smart city strategy in 2015; since then, different projects and activities have been undertaken. Dubrovnik Visitors visitor counting system (hereafter called "Du Visitors") became fully operational in 2019 and provides information on the current number of people in the historic city centre, along with data on past trends. Essentially, the system is composed of cameras placed on the six city gates which count people entering the area (Figure 1). The system uses machine learning to calculate predictions and, as more data is gathered, it will be possible to conduct more precise forecasting of visitor flows. The Dubrovnik Card (hereafter called "DuCard") has been in use for the last 10 years and provides discounts, unlimited use of public transport, and access to the top nine attractions. It is a typical tourist card partnered with a mobile application, which notifies users via iBeacons when they are in the vicinity of the card's offers.

A pilot study was conducted which combined the Du Visitor and DuCard systems for a limited area in the old town. It sent push notifications to DuCard users in the most visited area (Figure 2) and when the number of people in the old town passed 4,000, notifications suggested alternative attractions (11 sites within UNESCO WHS) and routes, to avoid overcrowding.

Figure 1. Old City of Dubrovnik and the pilot area.

Figure 2. Map. The pilot project has selected the area in the core of the WHP as critical for the purpose of managing overcrowding.

There are other smart city web platforms and ICT solutions which address overtourism and could potentially aid with the implementation of solutions.

Dubrovnik Eye is an interactive web platform which enables direct communication between citizens and administrative bodies – largely municipal utility companies. Citizens report problems online by providing a photo, a problem description, and a location. The City then reacts, resolves the problem, and reports back on actions taken. Some of the reported issues relate to tourism, and there is a potential to upgrade the web platform to focus more directly on touristification.

The Rural Dubrovnik-Neretva web platform promotes 84 agrotourism destinations, including wine bars, restaurants, wineries, wine tastings, tasting halls, rural accommodation, souvenir shops, 15 events, and seven thematic trails from the region north of Dubrovnik. The network is still in the early stage of development and requires more users; tourists seeking alternative attractions to avoid the crowding of the WHS are a key target demographic.

A noise monitoring pilot study was conducted in collaboration with the Old Town district (part of the City's self-governance system), the Institute for Restoration of Dubrovnik, and the Institute for Tourism. During the period July–September 2018, noise measurements were conducted by 15 volunteers using a smartphone app and one professional sound meter (Sauter SU 130). A total of 1,522 measurements were recorded; these were taken throughout the day and night, recording values passing the formal thresholds of 55 dB (day) and 45 dB (night). The results are not equal to professional noise monitoring and mapping, but are highly informative nonetheless:

- the percentage of measurements exceeding the threshold was 81;
- heat mapping of measurements exceeding the threshold corresponded to the distribution of restaurants and bars.

This pilot study demonstrated the potential to improve both resident's living conditions and the ambient setting for tourists and visitors (Figure 3). It has the potential to become a monitoring tool for local authorities and/or integrated in platforms such as Dubrovnik Eye.

A mobile phone positioning data pilot study was conducted by Positium Ltd. for the Dubrovnik Development Agency DURA in 2017. The aim was to analyse data quality and provide a snapshot of visitor trends during the Christmas period in Dubrovnik Old Town. The analysis verified the high quality of the data; more specifically, roaming subscribers left on average 34 location events per day on the operator network. This pilot study proved that deep exploration and profiling of tourist behaviour can provide a near complete picture of trips to Croatia and Dubrovnik.

Figure 3. Recorded levels of noise above the legal limits, July-September 2018.

Improvements for effective mitigation

The policies adopted to date are well designed but segregated. They are also implemented sporadically and could benefit from a more continuous commitment to their implementation. This is why ICT and digital web solutions play such a critical role. As the cited examples demonstrate, there is significant potential to develop a comprehensive system which combines TCC threshold monitoring with diversification strategies. Use of ICT and the internet can bridge the gaps between disparate policies, but the various projects made it clear that these cannot substitute certain critical components, such as:

- data reliability and quality;
- the optimization of the flows, such as traffic redirection, which can lead to more crowds if managed ineffectively;
- alternative tourism offers, which need reliable quality assurance and marketing.

Results and proposal for the city of Dubrovnik

To apply the digital response system for overtourism mitigation in the destination of Dubrovnik (Figure 4), the first step is to *calculate the limit of users for the destination*. For this calculation, the historical centre was used as a reference area and, following the model proposed by Bertocchi et al. (2020), seven tourism subsystems were taken into consideration:

• **Accommodation sector**: this was separated into two distinct parts: the hotel sector and the extra-hotel sector. The extra-hotel sector has experienced significant

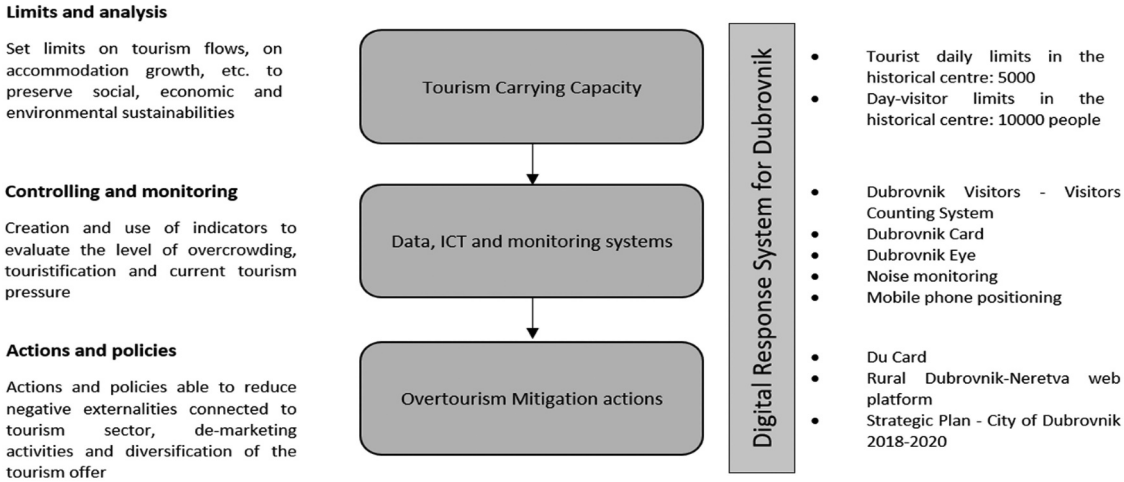

Figure 4. Conceptualization of a digital response system for Dubrovnik.

recent growth due to the sharing economy phenomenon in tourism, represented by platforms such as Airbnb;

• **Food and beverage sector**: in addition to visiting attractions, museums and churches, tourists need places to have meals. The food and beverage sector is an important element in the tourism system, and so it is valuable to record the performance (number of shifts per day) and capacity (number of seats) of the sector;

• **Mobility and transportation facilities**: This can be categorized into two groups: first, the capacity of the primary lines of public transport, and second, the number of parking spaces available in the destination itself and at the main entrances to the destination;

• **Environmental issues and waste management**: The collection and disposing of waste is significant due to the large number of additional city users;

• **Culture site** (regarding a cultural and urban destination): the main attraction of the destination must be calculated in terms of public space (e.g. main square). This is one of the primary reasons motivating tourists to visit a destination, and it is the main point of interest. For the purposes of this paper, this is the historic centre within the city walls.

To describe these tourism subsystems, we took advantage of the collaboration between our research group at the department of economics of Ca' Foscari University and the City of Dubrovnik during the activities of the European Project Interreg Med "AlterEco," in which both entities were partners. The AlterEco project was financed by the European Regional Development Fund to develop sustainable growth in the Mediterranean area by fostering the reasonable use of resources. In the field of tourism, AlterEco developed sustainable solutions to the use of destinations in the Med Area that have similar regional features, biodiversity, and tourism products (seaside and cultural cities) in common. Destinations included seven Member States, either partially (France, Portugal, Italy, or Spain) or fully (Greece, Malta, or Cyprus). The City of Dubrovnik provided data on its physical constraint limits and the usage rate per profile for the year 2019 (Table 1).

By applying the TCC calculation to Dubrovnik, using a linear programming method as formalized in problem (2), the following results and simulations were obtained.

Current situation

Every day, the destination can host 5,000 tourists sleeping in a hotel or independently in both traditional or non-traditional accommodation when $c_1 = c_2 = 210$, $c_3 = 70$ (value of c in euro), or in only traditional accommodations for levels of $c_1 = 210$, $c_2 = 145$, $c_3 = 70$ (as estimated by stakeholders in the MED area in the context of the AlterEco project). Total revenue generated is 1,050,000 euro.

Table 1. Dubrovnik tourism subsystem constraints.

Tourism subsystem	Constraints
Accommodation sector – Hotel	12,703 beds in hotels
Accommodation sector – Airbnb and similar	19,017 beds in Airbnb or similar
Food and beverage	35,385 places in restaurants
Mobility and transportation – parking spaces	119,652 parking spaces in the destination
Mobility and transportation – public transportation	2,425 places in public transportation
Environmental issues – waste management	20,000 tonnes managed daily*
Cultural site – main attraction	4,000** visitors

*Waste management does not currently meet EU standards. It is therefore considered here under the premise that it will be improved in the near future.

**The AlterEco project conducted pilot activities using a threshold of 4,000 visitors in the old town to send notifications and alerts on crowding.

Simulations

The study found that the two most restrictive subsystems are the "main cultural attraction" (which allows for only 4,000 people) and "waste management" (which permits a desirable value of 20,000 tonnes of waste managed daily). A decrease in the utilization rate of the "main cultural attraction" (while maintaining the same limits for 4,000 people) for each type of visitor was therefore simulated, alongside a relative increase in daily "waste management capacity."

First simulation: all excursionists are not allowed to visit the historic centre ($b_{7,3} = 0$). Result: Dubrovnik can tolerate more visitors (5,000 tourists and 10,000 excursionists per day), and the total revenue rises to 1,750,000 euro.

Second simulation: all tourists are encouraged not to visit the historic centre, causing a decrease in the utilization rate of the subsystem of the "main cultural attraction" ($b_{7,1} = 0{,}5$, $b_{7,3} = 0{,}5$ and $b_{7,3} = 0$) – *for example, by promoting alternative itineraries as in the case of the digital response system* – and all excursionists are not permitted to visit the historic centre. As a result, Dubrovnik can accommodate up to 8,000 tourists and tolerate 4,000 excursionists, while further increasing total revenue to 1,196,000 euro. Furthermore, with an increase of about 20% of the daily waste management capacity, Dubrovnik could achieve a total revenue of 2,253,533 euro with 8,000 tourists and 8,100 excursionists. Also, if non-traditional hotel tourists would simultaneously further decrease their use rate of the "main cultural attraction" subsystem, total revenue would settle at 2,291,500 euro and a more heterogeneous tourist flow would occur. This would consist of about 7,600 hotel tourists, 1,150 non-traditional hotel tourists, and 7,300 excursionists (even when the non-traditional hotel tourists' daily budget is lower than hotel tourists' daily budget).

The simulations therefore show the effectiveness of interventions (e.g. promoting alternative routes) to alleviate tourist pressure in the historic centre, while allowing an increase in total revenues generated by the destination as a whole.

Although excursionists have a limited impact on the general income of the destination, their behaviour can have a significant impact on the capacity of the subsystems (excluding accommodation); this is felt most critically by the constraints related to the cultural site and transportation. Two simulations (the second presents multiple scenarios) attempted to mitigate their impact, explained by the hit-and-run model, by favouring other tourist profiles (such as Airbnb). This model of carrying capacity calculation does not translate operationally into denying access to the city and banning visits. Instead, it becomes a fundamental part of tourism flow management, and the control of tourist congestion, when implemented within a system which utilises the technologies and digital systems described.

With these results, it is possible to establish carrying capacity limits and monitor these through several activities developed by the City of Dubrovnik, such as DuVisitors, the DuCard, and the Dubrovnik Eye. Indeed, the Du Visitors real-time counting system for people and the DuCard mobile application seem to be highly compatible. If the intention is to integrate the Dubrovnik Visitors system with the Dubrovnik Card, the entire system will need to be able to calculate the TCC thresholds for Dubrovnik as a whole. Currently, the project aims to send a message to *every* Du Card user-tourist if the number of people visiting the monitored area reaches the threshold of 4,000. This message would suggest visiting other areas of the city which are usually not overcrowded: places like the nearby beaches, the island of Lokrum, and other points identified as the best hotspot substitutes for the historic centre.

However, as demonstrated by the simulations, other interventions could achieve even more profitable outcomes if interventions are extended to encompass the entire destination area and target specific visitor demographics. The integration of the three mechanisms (TTC calculation, DuVisitors, and the DuCard) into a single digital response system could therefore improve the overall management of the destination.

Conclusion

Destinations struggling with the negative effects of overtourism could benefit from the use of technologies to both monitor and measure overtourism, while promoting alternative offers for tourists in and around overcrowded main attractions. Some technological solutions not only enable the passive monitoring of these effects, such as measuring overcrowding in a certain area, but also become critical to the mitigation of certain unacceptable situations, if they are properly combined with other tools. Obviously, the acceptability of stresses caused by tourism varies according to different interest groups and cannot be determined by a universal measurement. However, as the experience of some European cities shows, measuring TCC can undoubtedly contribute to improving tourism planning by addressing the excessive pressure of tourist flows.

This paper has highlighted the usefulness of combining quantitative tools to calculate the TCC with other tools designed to implement real responses to the effects of overtourism. TCC has been conceptualized as a mathematical benefit maximization problem, defined by the constraint of maximum stress bearable by the tourism subsystems of a destination, which must not be violated by the entire system. Subsequently, an estimate of the maximum number of tourists that the city of Dubrovnik can bear was obtained and segmented on the basis of three visitor types (tourists in traditional hotels, in non-traditional accommodation, and excursionists). Simulations varied the use rate of the "main cultural attraction" subsystem for each segment of the tourist demand, taking into account the tolerance limit of the "waste management system," and demonstrated the relevance of applying diversification strategies to tourist flows. Such strategies have already been considered by the city of Dubrovnik, who invested in the Du Visitors and Du Card projects to try to spread the flow of visitors to less crowded parts of the city. The unification of these tools into a single "digital response system" could improve the efficacy of the system.

Finally, this study makes it possible to present useful indications for the planning of the city of Dubrovnik in the short term. The measurement, monitoring, and intervention system proposed in this paper requires an effort to coordinate and integrate different technologies. Reinforcing Dubrovnik's existing smart strategies and investing in future technology should therefore be a key concern for the city's development. On the other hand, the study and simulations of specific tourism-environmental subsystems have revealed some critical issues that require further investigation. Consequently, future work must consider the impact of touristification on the community's environmental management and infrastructure, since the water supply, wastewater system, and waste management are currently substandard. Furthermore, overtourism is creating pollution that is often overlooked, such as emissions from traffic and noise pollution within the residential areas of the UNESCO WHS.

The global tourism market is slowly recovering from the COVID-19 crisis; consideration of overtourism in general, and TCC in particular, will only increase in importance as destinations are required to respect social distancing and public health issues. The better allocation and management of public space, public facilities, and public infrastructure between inhabitants and visitors is necessary for both the sustainability safety of these desirable destinations.

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