The challenge of cultural heritage visitation: A problem demanding new approaches

Arthur Stewart[1], Chiara Eva Catalano[2], Eyad Elyan[1], Andrea Giachetti[3], John Isaacs[1], Michela Mortara[2], Peter Reid[1] and Helen Vosper[1]

[1]Robert Gordon University, Aberdeen, UK, [2]CNR IMATI, Genova, Italy, [3]University of Verona, Italy

ABSTRACT

Tangible cultural heritage includes assets dating across millennia characterising many of the world's major cityscapes and landscapes. In many cases massive and spectacular architecture has been re-purposed for mass-visitation from a burgeoning tourist economy creating wealth and employment across transportation, hospitality and heritage sectors. Historic building visitation is increasing at 6-7% annually, and however promising in the short term, such a trend is ultimately unsustainable. Limited space, and queueing and close packing of visitors diminishes the quality of the visitor experience and degrades the built environment via pressure of numbers and reduces personal safety both for visitors and employees. However, the problem is much more complex and must also address the challenge of visitor experience for different users, financial, legal and operational constraints and a profoundly changing visitor-demographic which clearly identifies that past practice will not be suitable for operating such heritage sites in the future. Added to such known unknowns are the unknown unknowns concerning the uncertainties of future travel, economic demands placed on visitor attractions, and political and security uncertainty. Rationalising possible solutions to managing visitors in the 21st and subsequent centuries demands the description and parameterisation of a complex-sociotechnical system such as SEIPS 2.0. This must first identify the known domains, and seek approaches, data and innovative future research to inform policy sufficient to persuade authorities locally, nationally and internationally that the cost of doing nothing is too high a price to pay for the legacy which so many of us enjoy.

KEYWORDS

Cultural heritage visitation, socio-technical systems, 3D simulation, pedestrian dynamics, crowding

Introduction

Tourism is central to the economy of multiple countries worldwide, accounting for over 10% GDP in Europe and forecast to expand (World Travel and Tourism Council, 2018). Global demographics are undergoing substantial change, with those over the age of 65 forecast to exceed 30% in some countries (United Nations, 2019). A major pillar of global tourism is the quest for authentic cultural heritage experience, particularly ancient buildings which define the character of many of the world's major cities and landscapes. Increasingly tourists have become heritage consumers, with annual visitation increasing 7% in the UK (Association of Leading Visitor Attractions, 2018) and 12.5% in Italy (The Local, 2017). The scale of such visitation (Edinburgh Castle: 2m; Rome Colosseum 4.2m) raises serious questions over long term sustainability, even without additional adverse factors. However, a number of elements will have an increasing influence in the future which require urgent consideration in order to protect our heritage for generations to come.

Visitor flow

Visitor flow through heritage sites is likely to be limited by available space, designated pathways, and bottlenecks which restrict flow. Direct observation, video (Johansson et al., 2008) and self-mapping (Rainbolt et al., 2012) can describe visitor flow, which may be affected by queuing strategies or time-limited visits. Flow may also be modelled using a variety of mathematical and simulation approaches, (see Gupta and Pundir, 2015 for a review). Briefly, these include treating individuals as cellular automata (Guo, 2018), particles (Manenti et al., 2011) applying a gas lattice or social force model. These can predict pedestrian flow and model behaviours, obstacle navigation (Nicolas et al., 2017), building evacuation (AlShboul and Al-Tahat, 2007) group behaviour (Federici et al., 2014). and escape panic (Helbing et al., 2000). Despite their sophistication, models generally treat all members of a crowd as agents with similar able-bodied capabilities, whereas in reality this is a significant misrepresentation of the public at large.

Morphological and kinematic factors

In large open sites such as museums, body size or speed minimally affect crowd movement. However, in dense crowds or restricted space, slower and larger people become increasingly influential. Obese adults have shorter stride length, greater lateral displacement and typically move at a speed of two thirds that of non-obese individuals (Spyropoulos et al., 1991) impacting flow where crowd density is high or lateral width is limited. Consequently, the worsening obesity pandemic has profound implications for crowd movement. Firstly, the tripling of obesity prevalence (body mass index ≥ 30 kg.m^{-2}) (Swinburn et al., 2011) means typical visitor size is increasing, reducing clearance space wherever width is restricted. Counterflow and passing will become more problematic and narrow apertures will take longer to negotiate. Secondly, super-obese individuals (body mass index ≥ 50 kg.m^{-2}) have become ten times more prevalent in the same timeframe (Strum and Hattori, 2013), with implications for rescue-evacuation, and potentially non-navigable visitor paths. In addition, the rapid expansion of the senior visitor market (Jang et al., 2009) has consequences for slower movement, difficulty in negotiating stairs (Verghese et al., 2009) and affecting the speed of those behind them (Stewart et al., 2017). Additionally, decrements in vision and balance particularly affect older visitors, for whom attempting to move faster than comfortable is a fall-risk.

Defining the problem

Many heritage sites designed for defence or other functions have been re-purposed for mass visitation and require large numbers of individuals to navigate convoluted layouts, narrow passageways, uneven surfaces and steep staircases. Increased seniors' tourism brings increased likelihood of reduced or impaired mobility and global obesity prevalence increases typical and excessive body size. These factors all restrict free-flowing movement, diminishing the visitor experience via queuing and close-packing, which in turn increases contact with surfaces degrading building fabric, and also adversely affects public safety. This problem is manifest via a 'slow creep' of increasingly unfavourable factors, together with the greater probability of adverse events which, however unlikely, have potentially disastrous consequences for visitors and the industry as a whole. If such a problem represents normal operation for cultural heritage, then in a medical emergency or full building evacuation, the implications are much worse. Such a perfect storm of adverse factors which conspire against user experience and personal safety demands creative solutions across multiple domains. The scope of this paper is to propose a methodological approach developed for healthcare and to apply it in a novel way to this sector.

Historic sites and their management can be viewed as complex sociotechnical systems and systems analysis frameworks may be useful for exploring how interactions between the different elements give rise to outcomes (for example financial viability, preservation, staff and visitor satisfaction). The model developed (adapted from Holden, 2013; see Figure 1.) can be used to design interventions which support system optimisation and human wellbeing and can be useful to support enhancement of the experience for those considered to be 'boundary users' such as the elderly, mobility or cognitively-impaired whose capacity to engage with the site may be limited. Where solutions preclude modifications to historic architecture, it will become increasingly important to address a more complete inclusiveness agenda as the visitor demographic changes over time.

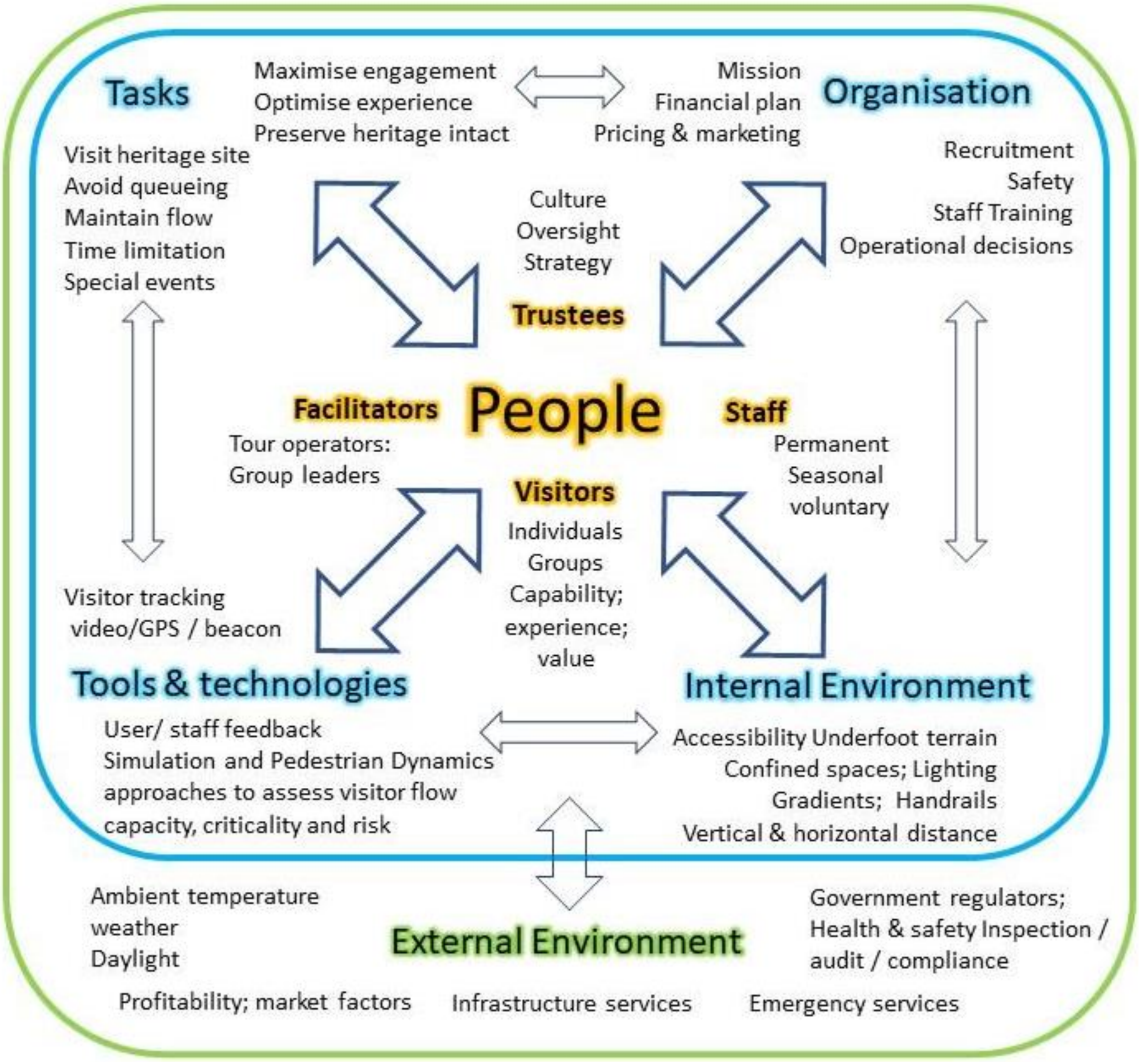

Figure 1: Entities and factors considered relevant to a cultural heritage sociotechnical system, adapted from the SEIPS 2.0 model of Holden et al. (2013).

A systems framework

Most systems frameworks are designed to be used in two directions: retrospectively for adverse event analysis, and prospectively for designing new or improving existing systems. Improvement of existing systems is particularly challenging, especially where systems have evolved organically over time, like many historic buildings. The SEIPS 2.0 model was designed to take these additional complexities into account. Several challenges faced by healthcare systems are echoed in historic site systems. Of the available systems frameworks, the Systems Engineering Initiative for Patient Safety

(SEIPS) 2.0 (Holden et al., 2013) has much to offer. The interactions between the work system elements can be viewed as inputs which are transformed by human performance to yield outputs (including user satisfaction and safety). SEIPS 2.0 focuses on these transformations, dividing them by type (physical, cognitive and/or social/behavioural) and in terms of the participants (professional-only, patient-only and patient/professional collaborations). This consideration of individual and collaborative working is the key for considering historic sites as systems – engagement of a visitor with a site relies not only on interaction with staff, but increasingly on the extent to which they engage with interactive displays. The design of these (usability and accessibility) can significantly impact the user experience, pre-empting guided discovery, and may also convey important safety information.

Consideration of these domains reveals some of the critical inter-dependencies which exist. For instance, time-limited visits or incorporating special events within some sites may particularly affect those with small children or mobility issues. Prevailing legislation and safety culture of the organisation determines permitted numbers in parts of the site (for example, a church tower) determining rules and safety signage. The legal framework and its enforceability are also major challenges for operational staff in dealing, for instance, with non-native speakers, safety-critical decisions or unprecedented events. While this illustration might seem complex, it is far simpler than the reality of the interdependencies of any large heritage facility. Applying this analysis to make cultural heritage future-proof will require intelligent modelling predictions of what that future will involve and continual comparison with the trajectory of the model constraints going forward.

Aside from the simplicity of previous models which fail to adequately convey these inter-relationships, the paucity of existing knowledge base is a further challenge. Research evidence is spread across multiple disciplines which share a dialogue which is at best incomplete. In addition to published evidence and available data, it may be very difficult to extract information from organisations who may not identify with ‘the problem’ and/or not wish to share data. Likewise, experienced operational staff may rely on knowledge which may be undocumented. This creates a knowledge management issue which may be difficult to overcome due to organisational structure constraints. In some cases, organisations and operational staff may be slow to appreciate how the real risks which threaten their continued success have changed in recent years. Added to fire, flood and damage-degradation are an increasing risk of adverse health events, and more worryingly, malevolent chemical or weapon attack. The reality is that until major disasters actually occur, there is very limited appreciation of the underlying risk, and, potentially, a misplaced complacency.

Cultural aspects of visitation and safety: Identification of the knowledge gap

Several regulations and guidelines define the procedures for operating cultural monuments (Calò et al., 2018). Specifically, guaranteeing visitor safety on sites or ruins is paramount, since these are commonly located in challenging topography, in many cases precluding safe pathway design and visitor routes. In response, nations have adopted multiple standards that generally impose minimal interventions on cultural heritage, that may differ widely between countries. For instance, under Italian laws (Legislative Decree n.112/98), in compliance with European Directives, the rules on the safety of historical sites deviate from the traditional deterministic/prescriptive approaches in favour of a security strategy tailored to individual situations. However, the regulations neither address problems related to the visitor demographics nor the related risks and conservation challenges. Much of our existing knowledge is historical and factual. Visitor numbers, recorded demographics and adverse events may exist but may not be accessible to researchers for further investigation. Pedestrian dynamics approaches which optimise visitor flow are largely theoretical and untested in ancient buildings. As a result, it is unknown how many people each heritage site can accommodate safely, and how will this change over time. Such knowledge is crucial to informing future policy which will make visitors and staff as safe as possible. However, this step requires engagement between operators, regulators and academics to share knowledge, concerns, approaches and vision.

Avenues for future research – a need for creative approaches

How can new technologies help advance the search for optimal cultural heritage visitation? We envisage flow simulation and machine learning as pivotal tools to reveal safety-critical scenarios, and serious gaming as promising means to inform administrators and staff of these, and to engage the public. Simulation is most useful and reliable when reality is represented in a rich and detailed way. Hence the need not only to model realistic visitor morphology and motion, but behaviours and feelings as well.

Capturing real visitor flow requires tracking multiple trajectories and speed inside the historical building. Indoor positioning cannot reliably use GPS due to the signal attenuation, so alternative solutions derive these data via proximity to anchors strategically placed throughout the path. These techniques are based on wi-fi or Bluetooth communication between anchors and smartphone devices and positioning is typically determined on the smart device using its internal sensors (accelerometer, gyroscope, etc.). Bluetooth Low Energy technology allows tracking individual visitors using a network of receivers (beacons) – small, easily-installed low cost radio transmitters with a 10-30 m range and positional accurately to 1 m.

Some museums (for example the National Slate Museum, Snowdonia, Wales) already use beacons for visitor engagement rather than for data collection, enabling visitors to learn about a particular artefact based on its location, in a range of modalities (for example audio, video, augmented reality) as well as game applications with location-based ‘pop up’ clues. Beacons’ versatility enables them to be used for different purposes because any device can find them, and any app can use them to trigger content. Therefore, the same infrastructure can serve both for enhancing the cultural experience and for within-site navigation in normal and emergency conditions. An app on the visitor’s device can then convey personalised location-based alert signals, give dynamic route suggestions or direct appropriate evacuation directions. By themselves, beacons can only detect that a Bluetooth-enabled device has entered its zone. This basic information can be used to model a smart environment, where areas of the building detect how many visitors are present (notwithstanding privacy issues). However, for capturing visitor flow, personal trajectories are essential. The challenge is to design methodologies and architectures to acquire expressive data while safeguarding the visitor privacy.

Device-based tracking has a limited ability to determine accurately position of subjects and cannot analyse other variables like body type, actions, carried items, etc. In principle, these variables could be captured using computer vision tools. Several approaches based on classic vision methods and on convolutional neural networks detect and track people in video sequences (Brunetti et al., 2018). Vision can be used also to detect subjects’ pose (Güler et al., 2018), to detect and predict actions (Kong and Fu, 2018), and pedestrian attributes (Wang et al., 2019). Video tracking is inevitably field-of-view limited, although approaches have been proposed for person re-identification in different sequences (Barbosa et al., 2018). Beyond subjects’ trajectories, vision-based methods can also detect actions, gaze, and attributes such as personal gait signatures (Singh et al., 2018), which could be validated using laboratory gait analysis. This could be used to train a system able to assign body and gait models to people detected in videos. Statistics on visitors’ behaviour captured in videos could also be used to estimate parameters of human agents populating virtual worlds simulating heritage sites, enriching models of crowd dynamics.

Another important aspect is the emotional and subjective response of visitors to a specific situation, as is the case of crowd acceptance. Several studies suggest that virtual environments have the potential to provoke immersion and are best suited to making humans feel part of the digital world, as if it were real (for example Mestre and Fuchs, 2006). Immersive experiences can assess the acceptability of queuing and crowding in the exploration of the cultural site (Pelechano et al., 2008) simulating places of interest without personal risk and compliment previous work on comfort and behavioural intentions during crowding. Even where the virtual environment is imperfect due to navigation issues, the effects of crowding and environmental layout on users' feelings can be studied (Alawadhi and Yoon, 2016; Dickinson et al., 2019).

Other promising fields of research are machine learning and deep learning which have been used in areas including image classification, video analysis and face recognition. Despite progress in the area of processing and analysing large volumes of unstructured data (videos, sensory data, etc.), very little work has made use of such advanced methods in the area of crowd modelling, behaviour analysis and evacuation. An exception is generative adversarial neural networks which have been used to detect abnormalities in crowd movement from video footage (Ravanbakhsh et al., 2017) – training their models using normal scenarios, and then flagging anything outside their scope. Other intelligent methods have included mathematical agents trained to simulate crowd evacuation from an area under bomb terrorist attack. The agent was trained using data extracted from virtual reality experiments with the human 'in the loop', establishing a direct relation between the crowd population, causalities, congested areas and the best exit routes (Shendarkar et al., 2006).

Crucial aspects in any learning experience are motivation, user engagement and identification (Mortara et al., 2014). Serious games (those not designed primarily for entertainment) engage the player in the experience, motivate learning, and encourage task persistence. In particular, role-play games set in a virtual environment offer active, situated learning enhanced by identification. Identification also stimulates empathy, and this mechanism is adopted in games for raising awareness. Indeed, a virtual environment with effective game mechanics becomes *"an environment where content and gameplay enhance knowledge and skill acquisition, and where game activity involve problem solving spaces and challenges that provide players/learners with a sense of achievement"* (Qian and Clark, 2016). In this context, serious games can 1) enhance the visitor experience, engaging with the visit and motivating learning about the heritage site; and 2) support managers and regulators to raise operational awareness regarding the problems due to crowding and queuing, and to assist the training of staff regarding movement optimisation, egress and emergency procedures.

Conclusion and future research

Future research is required to characterise buildings typical of geographical regions, and modelling agents enriched with specific behaviours and characteristics to reflect the changing demographic. The additional risk exposure imposed by future visitors will become pivotal to understand, not only for the individuals concerned but all stakeholders. New approaches including and beyond those described here require engagement which is interdisciplinary, interorganisational and international. Creative dialogue between academics, regulators and operators is required to realise the benefits of this research effort which moves beyond current risks and embraces a future trajectory. Application of this systems ergonomics model to the problem will uncover a totally new set of risks which have yet to be systematically investigated and applied. Registering the gravitas of a new set of risks in the consciousness of stakeholders shall take us one step closer to providing the sector with the means to address the problem and minimise the risk of the perfect storm.

References

Alawadhi, A., Yoon, S. Y. (2016). Shopping behavioral intentions contributed by store layout and perceived crowding: An exploratory study using computer walk-through simulation. Journal of Interior Design, 41(4):29-46.

AlShboul, A., Al-Tahat, M. D. (2007). Modelling of public building evacuation processes. Architectural Science Review 50:37-43.

Association of Leading Visitor Attractions (2018). http://www.alva.org.uk/details.cfm?p=423 visited 20/6/18.

Barbosa, I. B., et al. (2018). Looking beyond appearances: Synthetic training data for deep cnns in re-identification. Computer Vision and Image Understanding, 167:50-62.

Brunetti, A., et al. (2018). Computer vision and deep learning techniques for pedestrian detection and tracking: A survey. Neurocomputing, 300:17-33.

Calò, S., Malè, M., Tamburrino, E. (2018). Developed legal and regulatory framework for protection of medieval ruins – Ruins Project Deliverable D. T3.3.1.

Dickinson, P., et al. (2019). Virtual reality crowd simulation: Effects of agent density on user experience and behaviour. Virtual Reality, 23(1):19-32.

Federici, M. L., et al. (2014). An innovative scenario for pedestrian data collection: The observation of an admissions test at the University of Milano-Bicocca. In U Weidmann et al. (eds.) Pedestrian and Evacuation Dynamics 2012, Switzerland: Springer, 143-150.

Güler, R. A., Neverova, N., Kokkinos, I. (2018). Densepose: Dense human pose estimation in the wild. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (7297-7306).

Guo, R-Y. (2018). Potential-based dynamic pedestrian flow assignment. Transportation Research C 91:263-275.

Gupta, A., Pundir, N. (2015). Pedestrian flow characteristics studies: A review, Transport Reviews, 35:445-465.

Helbing, D., et al. (2000). Simulating dynamical features of escape panic. Nature, 407:487-490.

Holden ,R. J., Carayon, P., Gurses, A. P., et al. (2013). SEIPS 2.0: A human factors framework for studying and improving the work of healthcare professionals and patients. Ergonomics, 56(11) doi:10.1080/00140139.2013.838643.

Jang, S., Bai, B., Wu, C. E. (2009). Affect, travel motivation, and travel intention: A senior market. Journal of Hospitality & Tourism Research, 33:51-73.

Johansson, A., et al. (2008). From crowd dynamics to crowd safety: A video-based analysis. Advances in Complex Systems, 11:497–527.

Kong, Y., Fu, Y. (2018). Human action recognition and prediction: A survey. Journal of Latex Class Files, 13 (no. 9) arXiv preprint arXiv:1806.11230.

Manenti, L., et al. (2011). Towards an agent-based proxemic model for pedestrian and group dynamic. Proceedings of the 11th WOA 2010 Workshop, Dagli Oggetti Agli Agenti, Rimini, Italy, September 5-7, 2010.

Mestre, D. R., Fuchs, P. (2006). Immersion et presence. In Fuchs P, et al. (eds.) Le traite ́de la realité virtuelle. Paris: Ecole des Mines de Paris, 309-338).

Mortara, M., Catalano, C. E., Bellotti, F., et al. (2014), Learning cultural heritage by serious games. Journal of Cultural Heritage, 15:318–325.

Nicolas, A., et al. (2017). Pedestrian flows through a narrow doorway: Effect of individual behaviours on the global flow and microscopic dynamics. Transportation Research B, 99:30-43.

Pelechano, N., et al. (2008). Being part of the crowd: Towards validating VR crowds using presence. Proc. of the 7th Int. Conf. On Autonomous Agents and Multiagent Systems (AAMAS), Padgham, Parkes, Muller and Parsons (eds.), May 12-16 2008, Estoril, Portugal, 136-142.

Qian, M., Clark, K. R. (2016). Game-based learning and 21st century skills: A review of recent research. Computers in Human Behavior, 63, 50-68. DOI: 10.1016/j.chb.2016.05.023.

Rainbolt, G. N. et al. (2012). Visitor self-report behaviour mapping as a tool for recording exhibition circulation. Visitor Studies, 15:203-216.

Ravanbakhsh, M., et al. (2017). Abnormal event detection in videos using generative adversarial nets, 2017 IEEE International Conference on Image Processing (ICIP), Beijing, 2017, 1577-1581.

Shendarkar, A., Vasudevan, K., Lee, S., Son, Y-J. (2008). Crowd simulation for emergency response using BDI agents based on immersive virtual reality, Simulation Modelling Practice and Theory, 16, 1415-1429, ISSN 1569-190X.

Singh, J. P., Jain, S., Arora, S., Singh, U. P. (2018). Vision-Based Gait Recognition: A Survey. IEEE Access, 6:70497-70527.

Spyropoulos, P., et al. (1991). Biomechanical gait analysis in obese men. Archives of Physical Medicine & Rehabilitation, 72:1065-1070.

Stewart, A., et al. (2017). The effect of person order on egress time. Human Factors, 59:1222-1232.

Strum, R., Hattori, A. (2013). Morbid obesity rates continue to rise rapidly in the United States. International Journal of Obesity, 37:889-891.

Swinburn, B. A., et al. (2011). The global obesity pandemic: Shaped by global drivers and local environments. Lancet 378:804–814.

The Local. (2017). https://www.thelocal.it/20170911/2017-was-a-record-summer-for-italian-tourism visited 20/6/18.

United Nations. (2019). World Population Prospects the 2019 revision, custom data acquired from website https://population.un.org, United Nations Department of Economic and Social Affairs Population Division.

Verghese, et al., (2009). Self-reported difficulty in climbing up or down stairs in nondisabled elderly. Archives of Physical Medicine & Rehabilitation, 89:100-104.

Wang, X., et al. (2019). Pedestrian attribute recognition: A survey. Journal of Latex Class Files, 14 (no. 8) arXiv preprint arXiv:1901.07474.

World Travel and Tourism Council. (2018). https://www.wttc.org/-/media/files/reports/economic-impact-research/regions-2018/europeanunion2018.pdf visited 30/11/18.