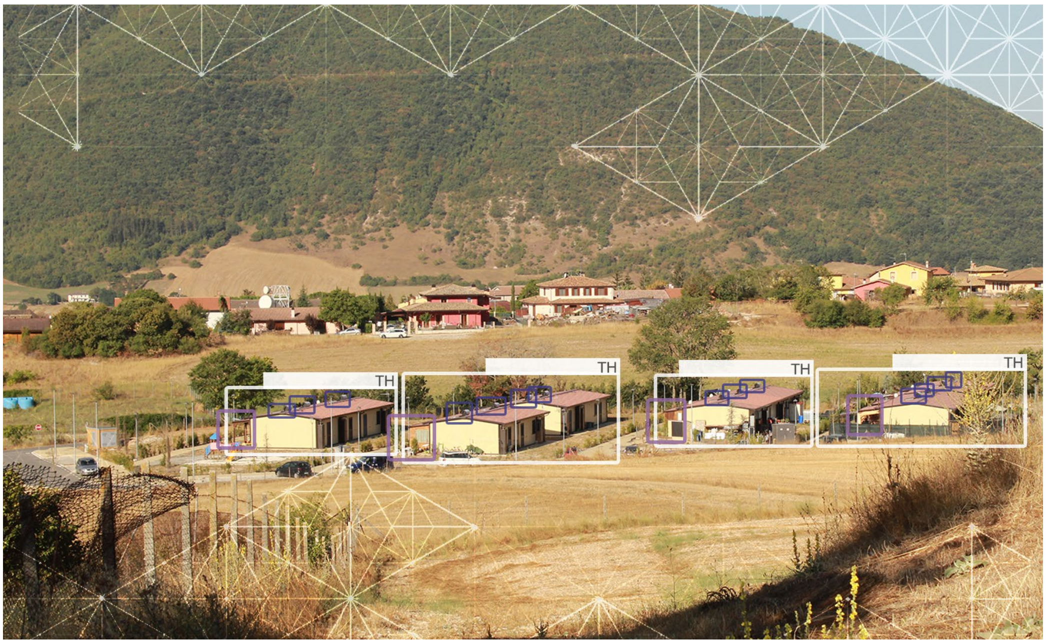
Augmented Intelligence In Built Environment Projects

Camilla Pezzica

Abstract

Ever-increasing levels of digital connectivity and ubiquitous sensing capacity offer opportunities to rethink traditional design and planning practices towards delivering more sustainable and resilient futures. Within this context, the chapter discusses how digital representation, Artificial Intelligence and collaborative processes can enable coping better with uncertainty by informing design and environmental management moves. Through two distinct examples, one in the UK and one in Italy, it illustrates how data about the built environment can be collected, networked, and operationalised to deal better with complexity and make informed decisions which consider alternative courses of action and challenge pre-existing assumptions. Both cases presented highlight the importance to establish a two-way link between digital and physical infrastructures and the people.

Keywords
AI, architectural design, decision-making, digital representation, modelling, urban planning.



doi.org/10.3280/oa-845-c194

Towards the People-Smart Sustainable City

Cities are considered hubs for the transformative change required to protect the prosperity of present and future generations [Golubchikov 2020]. In fact, they can support a larger social and infrastructural webbing and promote civic innovation and people-centred design and management, through the integration of sensors and Information and Communication Technologies (ICTs) and the development of Artificial Intelligence (AI) applications [Duarte, Ratti 2021; Kandt, Batty 2021]. However, technology-centric and narrow-focused smart city approaches oversimplify problems and wrongly assume that these can be solved solely by having access to smart infrastructure [Boykova et al. 2016]. Digital platforms are often built to promote profit rather than open information sharing and relationality [Barns 2021] and some smart city projects risk generating a loop in which more of the same is delivered.

In response to this, Andreani et al. [2019] suggest to achieve the required socio-technological hybridization and recover the human scale by adopting a design-oriented approach, considerate of the complexity and diversity of contemporary urban environments. For delivering socially oriented solutions which generate value for all, setting up the right conditions for the exploitation of digital technologies in the design and management of built assets seems certainly critical. To this end, the chapter suggests developing intelligent pathways, which facilitate collaboration among the many actors involved in the shaping and conservation of contemporary urban landscapes and support their decision-making process. This requires adopting a decision-driven approach aimed at producing nuanced information to answer specific questions rather than at generating unidimensional solutions; what implies looking at existing data and collecting new ones.

The chapter illustrates the potential value of this proposition through two distinct cases in which digital representation and AI were used to support problem understanding, via modelling and analysis, as well as the development and evaluation of alternative design and planning decisions. These belong to two recent research experiences, one in the UK and one in Italy: (i) the "Shelf-life" project, funded by the Arts and Humanities Research Council, which focused on the Carnegie libraries of Britain [Prizeman et al. 2018]; and (ii) a fully-funded PhD research about Temporary Housing (TH) post-disaster [Pezzica 2021].

The goal of these projects was, in order, to foster intelligent conservation and Building Back Better practices and they both carefully considered time and change as part of their discourses. These two cases adopt different perspectives and provide a variety of real-world examples, which enable a broad ranging discussion about the use of digital representation and AI in built environment projects, including their application in supporting decision-making and scenario exploration. Although they differ in several aspects, these projects have in common a focus on social and environmental sustainability and they both propose using digital representation and AI to generate digital models, rich in useful information, which help grounding complex decisions in theoretical reasoning and critical reflection while promoting open sourcing and collaboration.

Promoting Intelligent Conservation Practices: Shelf-Life Project

When Carnegie libraries were built around 100 years ago, through the uniquely controlled procurement of the homonymous steel magnate and philanthropist and his trust, electric lighting was expensive and heating cheap. These buildings were engineered to capture daylight as a priority to benefit readers, e.g., via the use of large skylights, glazed ceilings and partitions. The libraries were also naturally ventilated to safeguard public health via the use of ventilation turrets and grilles, vaulted ceilings, and domes, among other elements, as protecting the public from airborne diseases was a key concern at the time. Since their design aimed to satisfy energy performance requirements which are diametrically opposite to current ones

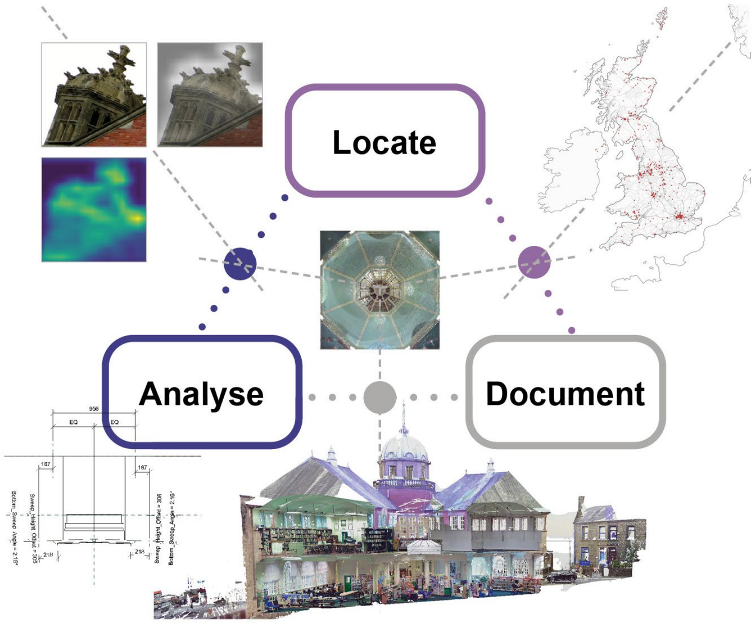


Fig. 1. Shelf-life project framework.

[Prizeman 2017], Carnegie libraries are increasingly being sold and re-purposed. To date, their characteristic features have often been made redundant and are seen as contributors to the buildings' reduced thermal efficiency and increased risk of water leakage. The fact that most of them have been granted heritage status is often perceived by local administrators as an additional problem, and current imperatives of energy use reduction and requirements for physical accessibility put these libraries at risk of closure.

The Shelf-Life project poses that the conservation management of public buildings should be informed by both technical and historical understanding and that quantitative indicators used for audits should be qualified by nuanced and context-based readings of design and operational intent. Thus, it combined a broad range of digital methods and tools to reflect systematically about the re-vitalisation of thousands of Carnegie library buildings across the UK and the USA, and formulate critical approaches to their refurbishment, so they can continue promoting culture and wellbeing. The project specifically explored functional and morphological relationships between single architectural components and the whole building. This enabled promoting a wider and deeper understanding of the libraries' original design and environmental performance drivers and augmented the legibility of technology and construction systems which might have potential for reappraisal [Prizeman, Pezzica et al. 2020].

Linking Digital Representation and AI: Architectural Scale

The research followed the three-steps framework shown in Figure 1. Initially, all the surviving Carnegie library buildings in Britain were mapped (Locate). This required using many information sources (e.g., scientific publications, archival documents and historical maps) and then confirming their status through a physical survey, during which all surviving buildings were digitally photographed (Document). The images collected were used to assess the quantity and relative incidence of common features using a deep classifier (Analyse). A group of 23 libraries was selected to be digitally recorded using terrestrial laser scanning and photogrammetry to produce a 3D dataset with the metric information required to create a set of parametric families of typical architectural components in Historic Building Information Modelling (HBIM). To facilitate the association of architectural and construction histories to the 3D models, it was proposed to exploit image classification methods again to match illustrations with pictures or corresponding elements, as there is scope to use adverts to link some of the libraries' characteristic components to manufacturers that are still in operation [Prizeman 2015]. This workflow enabled correlating data (e.g., build date, architect, plan configuration, listing designation status, notes on condition, materials, components, location etc.) for all the Carnegie libraries of Britain. The output digital resources include a GIS interactive application, a semantically tagged photographic gallery, a deep learning model for the classification of selected architectural features, and a set of HBIM families, all accessible at [Prizeman, Pezzica 2020].

Subsequently, publicly available energy data was collated and analysed using an interactive dashboard to challenge current assumptions about the libraries' presumed poor energy performance [Prizeman, Boughanmi et al. 2020]. To this end, a whole building model supporting Life Cycle Analysis (LCA) calculations was also created, and a few others were used to study the functioning of Carnegie libraries' natural ventilation system via Computational Fluid Dynamics (CFD) analysis.

Aspects of Technical Implementation: "Shallow" vs Deep Models

In the Shelf-Life project digital representation and AI were used to draw and share the advantages of generalisable results, by looking at standardised architectural components. To this end, in [Pezzica, Schroeter et al. 2019] the performance of a high-end Machine Learning ($F1_{ML}$=0.56) and two Deep Learning classification models ($F1_{CNN}$=0.78, $F1_{FPN}$=0.82) was comparatively assessed for 4 classes of features using their mean F1-scores. This study concluded that deep learning, and particularly a Feature Pyramid Network model, is preferable in this application. The test involved training 3 supervised classification models using the image data collected in the survey phase: 424 photos of external façades and 224 of libraries' interiors, generating ~4,000 photo crops which were labelled using 4 keywords. Random samples of backgrounds were also used to train the model (using the tag "other") while several copies were generated for each image, following random transformations as part of a data augmentation process. This, and the availability of a critical mass of observations, enabled a sensible model sizing and training, overcoming risks of poor performance due to overfitting.

Deep learning models present an end-to-end architecture, i.e., they train simultaneously representation learning and classification, tailoring the learning of features to the needs of the classification task at hand. Thus, differently from traditional machine learning methods, they do not require generating input features independently of the training process. Moreover, they help overcoming common issues in image datasets such as distortions and occlusions even with no hyper-parameter tuning; what makes them a better fit when using imperfect (collaborative) data. Although a downside is that deep classifiers are seen as black boxes, explainable AI tools can be used to understand the underpinning of their internal decision-making processes. To provide a degree of control over the classification results, in this project coarse localisation maps were generated from Grad-CAM to check what visual information the FPN model used to classify an object correctly.

Building Back Better: TH project

TH assistance projects are commonly delivered after disasters, in conditions of uncertainty and time pressure. Although easier to implement in this context, one size fits all TH solutions have often proved unsuccessful and short-sighted, detracting resources from development [Borsekova, Nijkamp 2019].

In Italy, after the criticisms of the centralised and top-down response to the 2009 L'Aquila earthquake, local administrations have been given increasing responsibilities over the delivery

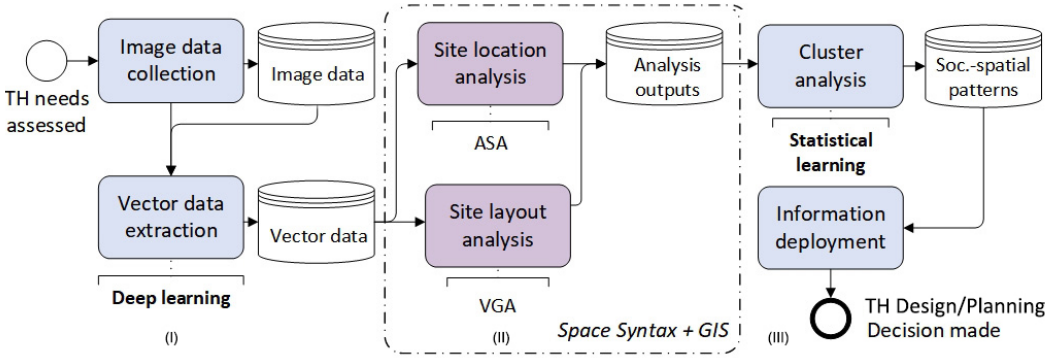


Fig. 2. TH project analysis framework.

of TH plans, including proposing and evaluating the location and layout of the TH sites. Yet, in the aftermath of the 2016-2017 Central Italy earthquakes, they were offered only limited support and generic guidance (e.g., select sites close to the destroyed city, limit land consumption, favour terraced housing arrangements) to undertake the task. Furthermore, the TH planning and delivery process, which was set up centrally, allowed room for discretionary decisions and little space for bottom-up inputs, leaving unresolved problems concerning damage assessment and the choice of TH sites' location and layouts [Pezzica 2021].

The TH project poses that enabling an equitable and developmental disaster recovery requires the adoption of well-informed and place-sensitive TH planning practices. Therefore, it seeks to mainstream the generation of digital information packages relevant to the design and planning of TH sites, which enable a formal verification of TH outcomes in the medium- and long-term, at multiple levels. The proposal is tied to action and involves methods to rapidly harvest and mine data produced though collaborative mapping by civic activists and volunteers. The project exploited the opportunities offered by the diffusion of low-cost imaging devices, increasingly accessible digital technologies and software solutions (collaborative platforms), as well as open data and code produced to support post-disaster humanitarian operations. It combined digital representation and machine learning to: (i) help document disaster-affected towns; and (ii) visualise changes in patterns of urbanisation and transportation as part of scenario-based assessments. The scenario production and auditing required modelling and analysing the spatial configuration of TH plans at multiple scales and times, considering various network centrality and resilience indices.

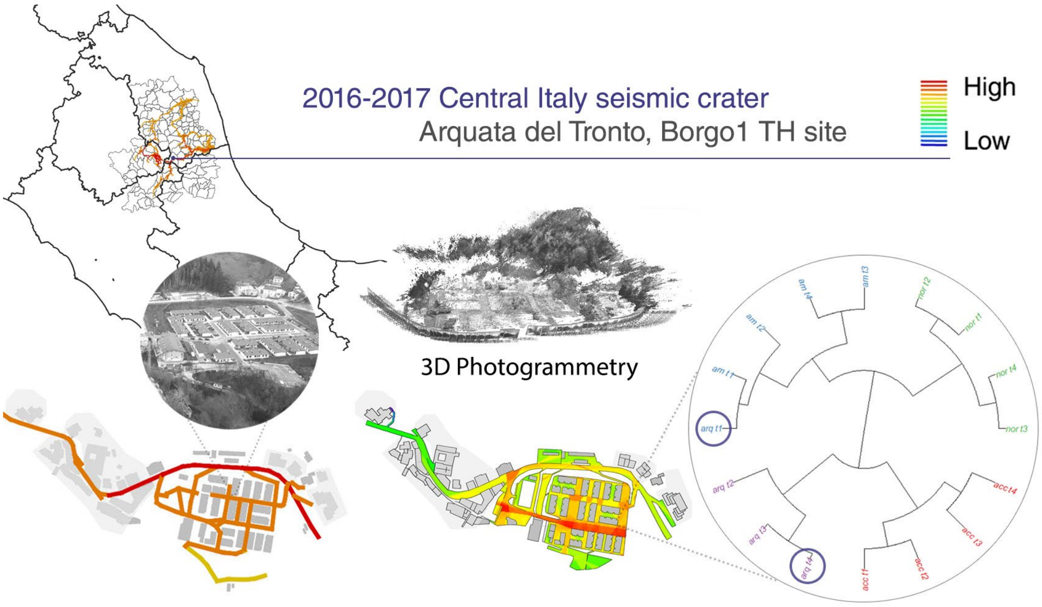
Linking Digital Representation and AI: Urban Scale

Figure 2 shows the proposed decision-driven TH analysis framework. This is focused on answering practical design and planning questions and encompasses: (I) data understanding and preparation; (II) scenario modelling and analysis; and (III) results evaluation and interpretation for information deployment.

In part (I) the project examined the possibility to use street level images collected by citizen scientists during participatory photographic mapping initiatives to support 3D reconnaissance operations and TH spatial planning, through the rapid and economic construction of photogrammetric models and vector data/maps. It also explored under which conditions collaborative photogrammetry can empower local communities and promote ownership of results, fostering civic participation in recovery by means of recording buildings and urban structures. To this end, a test was done using 4 image samples of selected urban fragments, whose 3D outputs presented varying quality levels. A framework to draft better image capture guidelines for citizen scientists was then developed, besides suggestions for exploiting multi-sensor data integration within fit-for-purpose digital documentation workflows [Pezzica, Piemonte et al. 2019]. Additionally, it was proposed the use of AI-powered image classification models (similar to those explored in the Shelf-Life project) to support the images' semantic-enrichment and open-sourcing, i.e., the automatic extraction of geo-spatial vector data such as Points Of Interests (POIs) from them.

In part (II), collaboratively produced vector map data (mainly road centre lines, administrative limits and building footprints from Open Street Map) was used to set up different configurational analysis models, suitable to evaluate alternative TH planning and design options and propose corrective planning actions. The analysis evaluates primarily the sites' spatial accessibility (ASA, Pezzica et al. 2020) and the permeability of their layouts (VGA, Chioni et al. 2021) and adopts an established theory of space and society known as Space Syntax, which understands urban spaces as components of a wider network system. The geography of the destroyed city, and how this changed immediately after the disaster and following the construction of TH sites, are analysed with an eye to that of the city after the reconstruction, to assess modifications in their spatial logic. Thus, the multi-scale study of 4 towns hit by the 2016-2017 central Italy earthquakes produced a high-dimensional matrix of floating numbers, each describing a key network property of the different configurations (Fig. 3).

In part (III) machine learning was deployed to synthetise this multidimensional information, otherwise difficult to aggregate and systematically interpret, in a format suitable to inform urban design and planning decisions. After performing the necessary data preparation steps, a classical agglomerative Hierarchical Clustering (HC) algorithm was used to group together the urban street network configurations in an iterative way so that deeper analogies could be identified starting from the configurational values which were previously calculated [Pezzica et al. 2021]. At the neighbourhood level, a group of 20 TH sites' layouts was analysed to extract several indices useful to identify similar spatial patterns, beyond the simple typological distinction between detached, row-, and courtyard housing. Using the analysis data, 3 different clustering algorithms (HC, K-means, FCM) were adopted to explore within a dashboard how well the form of different TH sites' layouts matched their intended function in post-disaster recovery and reconstruction [Pezzica, Cutini 2021].



ASA (*NAIN Rn*) *Spatial accessibility*

VGA (*Visual Integration*) *Layout permeability*

HC (*k* = *4*) Urban Level *Configurational clusters*

Fig. 3. Configurational analysis of Borgo1 site, Arquata del Tronto.

Discussion and Conclusions

The chapter discussed some of the opportunities and practical challenges of using AI and digital representation for augmenting intelligence in built environment projects and argued that their successful exploitation in design and planning requires well-informed and action-oriented – not simply data-driven – decision-making.
Specifically, the experience of the Shelf-Life project suggests that digital representation tools and AI methods can support the construction of cost-efficient knowledge sharing structures, which promote sensitive and economic approaches to the rehabilitation and re-use of historic buildings. In fact, they enable mapping families of common architectural components, through the automated recognition of features relevant to HBIM, and then pooling useful resources at scale. Besides help counting the instances of selected elements, they can inform 3D modelling and semantic enrichment processes. This enables exploring relationships among interrelated architectural elements which operate at a wider level as part of standardised systems, and which are characteristic attributes of a particular building typology, epoch, or geographic region. The proposal ultimately facilitates linking relevant technical literature, environmental models and HBIM components to identify buildings which share similar conservation issues and foster possibilities for mutual information exchange on best practice. It provides a valuable pathway for the organisation of relevant information in accessible and open formats and fosters the targeted dissemination of informed HBIM data, towards enhancing data exchange processes. What opens possibilities for codifying, identifying and informing intelligent conservation and repair strategies for several building typologies where architects specified similar features. Notably, as the quantity of features recorded becomes greater, so does the ability to infer historic design intent.

Changing context, the TH project indicates that digital representation and AI can contribute to enhance community advocacy and deliberation and foster a more longsighted and human-centered TH assistance delivery after disasters. Combined with the proposed spatial analytical approach, they can effectively support the comparative assessment of multiple TH planning scenarios and the proposition of fine-grain urban design adjustments, considering local patterns and temporal transformations. At the urban scale, this enabled differentiating between TH plans which are likely to initiate a process of urban decentralization (the relocation of commercial activities outside the historic city centre) and best practices, i.e., TH plans which contribute to increase the resilience of the local street network, without modifying the spatial logic of the destroyed city. At the neighbourhood scale, this enabled spotting a weak correspondence between TH sites' form and function, as well as inefficiencies in the use of physical resources in recovery and reconstruction. By facilitating a formal audit of post-disaster recovery trajectories, this approach can promote the construction of better TH schemes, which add to the resilience of local infrastructures and respond to the aspirations of local communities (e.g., by retaining in TH sites some of the visual and spatial permeability properties of the destroyed city). If combined with post-occupancy studies, the proposal offers opportunities to enhance strategic planning by supporting the definition of context-based socio-spatial performance targets to include in future framework agreements for TH supply and delivery.

References

Andreani Stefano, Kalchschmidt Matteo Giacomo Maria, Pinto Roberto, Sayegh Allen (2019). Reframing technologically enhanced urban scenarios: A design research model towards human centered smart cities. In *Technological Forecasting and Social Change*, 142, 2019, pp. 15-25.

Barns Sarah (2021). *Platform Urbanism: Negotiating Platform Ecosystems in Connected Cities*. Sidney: Palgrave Mcmillan.

Borsekova Kamila, Nijkamp Peter (2019). Blessing in disguise: long run benefits of urban disasters. In Borsekova Kamila, Nijkamp Peter (eds.). *Resilience and Urban Disasters: Surviving Cities*. Cheltenham: Edward Elgar Publishing, pp. 2-29.

Boykova Marina, Ilina Irina, Salazkin Mikhail (2016). The Smart City Approach as a Response to Emerging Challenges for Urban Development. In *Foresight and STI Governance*, 10 (3), 2016, pp. 65-75.

Chion Chiara, Pezzica Camilla, Cutini Valerio, Bleil de Souza Clarice, Rusci Simone (2021). Multi-scale configurational approach to the design of public open spaces after urban disasters. In *Proceedings of the 5th International Symposium Formal Methods in Architecture (5FMA)*. Lisboa: Springer Nature, pp. 171-183.

Duarte Fábio, Ratti Carlo (2021). What Urban Cameras Reveal About the City: The Work of the Senseable City Lab. In *Urban Informatics*. Singapore: Springer, pp. 491-502.

Golubchikov Oleg (2020). *People-Smart Sustainable Cities*. New York: UN.

Kandt Jens, Batty Michael (2021). Smart cities, big data and urban policy: Towards urban analytics for the long run. In *Cities*, 109, 2021, 102992.

Pezzica Camilla (2021). *Temporary Housing and Transitional Urbanism: Planning for Sustainable Post-Disaster Recovery under Uncertainty*. PhD Dissertation. Rel.: Cutini Valerio, Corel.: Bleil de Souza Clarice. Pisa: University of Pisa.

Pezzica Camilla, Chion Chiara, Cutini Valerio, Bleil de Souza Clarice (2020). Assessing the impact of temporary housing sites on urban socio-spatial performance: The case of the central Italy earthquake. In *ICCSA 2020 – LNCS*. Cagliari: Springer, pp. 324-339.

Pezzica Camilla, Cutini Valerio (2021). Linking space syntax and cluster analysis to design and plan temporary housing neighborhoods: A taxonomy of sites in Norcia. In *Journal of Design for Resilience in Architecture and Planning*, 2 (SI), 2021, pp. 89-114.

Pezzica Camilla, Cutini Valerio, Bleil de Souza Clarice, Chion Chiara (2021). Re-defining spatial typologies of humanitarian housing plans using machine learning. In *INPUT 2020 – LNCE*. Catania: Springer, pp. 319-327.

Pezzica Camilla, Piemonte Andrea, Bleil de Souza Clarice, Cutini Valerio (2019). Photogrammetry as a participatory recovery tool after disasters: a grounded framework for future guidelines. In *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W15, 2019, pp. 921-928.

Pezzica Camilla, Schroeter Julien, Prizeman Oriel, Jones Christopher, Rosin Paul (2019). Between images and built form: Automating the recognition of standardised building components using deep learning. In *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, IV-2/W6, 2019, pp. 123-132.

Prizeman Oriel (2015). HBIM and matching techniques: Considerations for late nineteenth- and early twentieth-century buildings. In *Journal of Architectural Conservation*, 21 (3), 2015, pp. 145-159.

Prizeman Oriel (2017). *Philanthropy and Light: Carnegie Libraries and the Advent of Transatlantic Standards for Public Space*. London: Routledge.

Prizeman Oriel, Boughanmi Mahdi, Pezzica Camilla (2022). Carnegie Libraries of Britain: Assets or Liabilities? Managing Altering Agendas of Energy Efficiency for Early 20th Century Heritage. In *Public Library Quarterly*, 41 (1), 2022, pp. 43-82.

Prizeman Oriel, Jones Christopher, Parisi Mariangela, Pezzica Camilla (2018). How can century-old architectural hierarchies for the design of public libraries be re-interpreted and re-used? In *Journal of Cultural Heritage Management and Sustainable Development*, 8 (4), 2018, pp. 481-494.

Prizeman Oriel, Pezzica Camilla (2020). CarnegieLibrariesOfBritain.
https://carnegielibrariesofbritain.com/ (21 January 2021).

Prizeman Oriel, Pezzica Camilla, Taher Ahmed, Boughanmi Mahdi (2020). Networking historic environmental standards to address modern challenges for sustainable conservation in HBIM. In *Applied Sciences*, 10 (4), 2020, art. 1283.

Authors
Camilla Pezzica, Welsh School of Architecture, Cardiff University, pezzicac@cardiff.ac.uk

Isbn 9788835141945