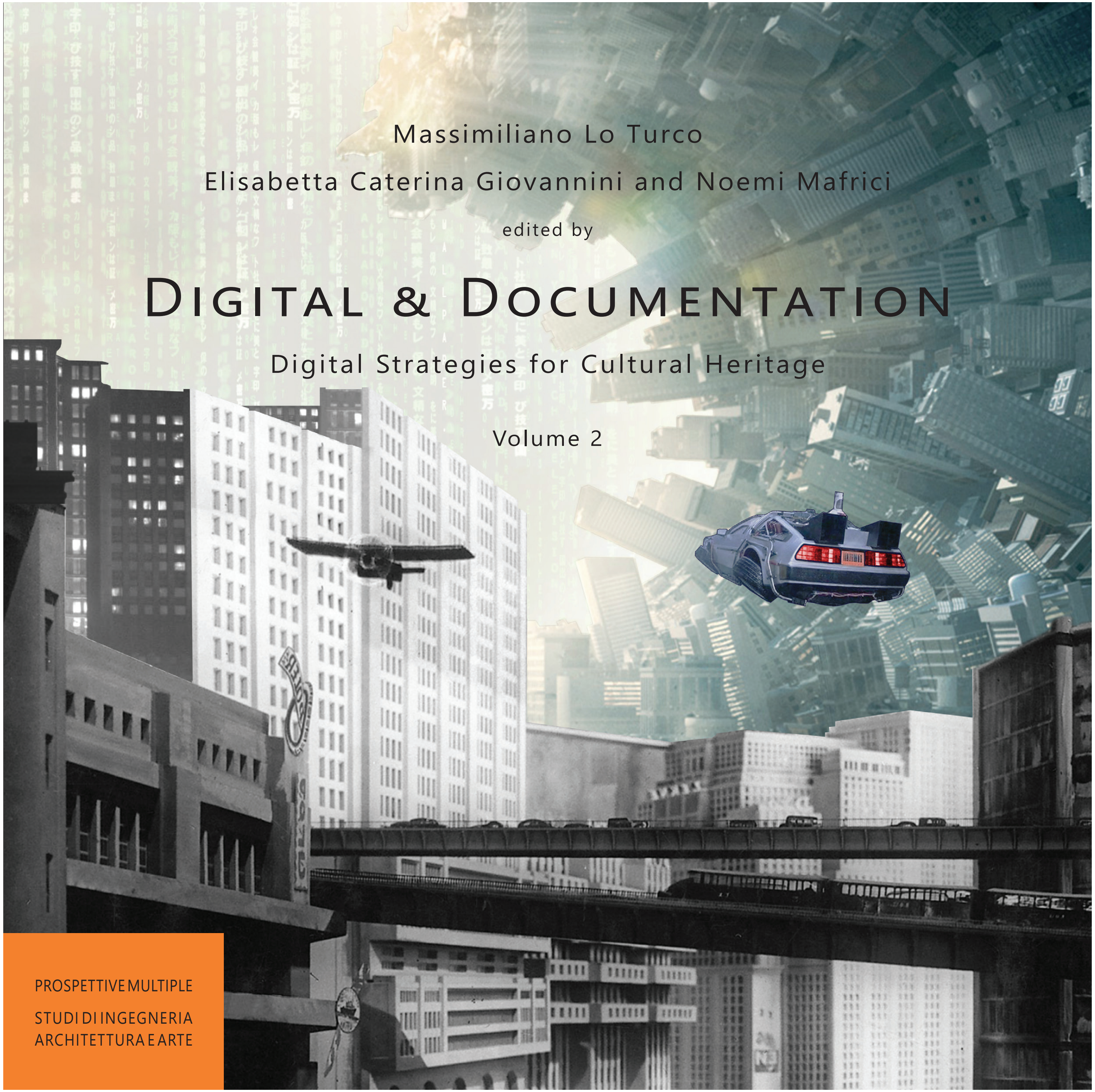
AI: Architectural Intelligence. Deep learning and heritage environments



Massimiliano Lo Turco
Elisabetta Caterina Giovannini and Noemi Mafrici
edited by

Digital & Documentation

Digital Strategies for Cultural Heritage

Volume 2

PROSPETTIVE MULTIPLE
STUDI DI INGEGNERIA
ARCHITETTURA E ARTE

Massimiliano Lo Turco
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Digital strategies for Cultural Heritage

Volume 2

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The volume consists of a collection of contributions from the seminar "Digital & Documentation: Digital Strategies fo Cultural Heritage", realised at the Politecnico di Torino on June 14th, 2019. The event, organized by the "BIM Acquisition as Cultural Key TO Transfer Heritage of ancient Egypt For many Uses To many Users REplayed" - B.A.C.K. TO T.H.E. F.U.T.U.RE. Project - team of DAD - Department of Architecture and Design of Politecnico di Torino, promotes the themes of digital modeling and virtual environments applied to the documentation of architectural scenarios and the implementation of museum complexes through communication programs of immersive fruition.
The event has provide the contribution of external experts and lecturers in the field of digital documentation for Cultural Heritage. The scientific responsible for the organization of the event is Prof. Massimiliano Lo Turco, Politecnico di Torino.

This publication is made with the contribution of DAD, Department of Architecture and Design of Politecnico di Torino, through the "BIM Acquisition as Cultural Key TO Transfer Heritage of ancient Egypt For many Uses To many Users REplayed" - B.A.C.K. TO T.H.E. F.U.T.U.R.E. Project, in collaboration with Fondazione Museo delle Antichità Egizie di Torino. The project is one the winner of the call "Metti in rete la tua idea di Ricerca" partially financed by Compagnia di San Paolo.

The event "Digital & Documentation - Vol. 2" has seen the participation of professors, researchers, scholars and private institutions

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Institute for Heritage Sciences of the National Research Council

University of Camerino

University of Ferrara

Free University of Bozen

The event is promoted by Unione Italiana del Disegno (U.I.D.)

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07 AI: ARCHITECTURAL INTELLIGENCE. DEEP LEARNING AND HERITAGE ENVIRONMENTS

Valerio Palma

Abstract

An unprecedented computing power and the vast datasets recently available have boosted machine learning techniques, featuring algorithms that can "learn" from experience. These are gaining importance in many disciplinary fields, dealing with computer vision and object recognition problems. Nevertheless, the applications of such tools in the fields of architecture and cultural heritage are still limited, as well as the spread of public datasets to encourage experiments and research.
This contribution presents a project on artificial intelligence (AI) technologies aimed to support the management and accessibility of both architectural heritage and the connected multimedia information. Original developments of a deep learning model based on convolutional neural networks are employed in a smartphone app to recognize monuments framed using the camera. AI recognition works from different viewpoints and does not need any reference image stored on the device. Once the monument is identified, the app provides the user with information previously downloaded from the web. The Central Archaeological Area in Rome has been a test field for the first experiments.
The app prototype shows that AI offers a chance to enhance existing digital archives and deal with open issues in managing spatial information.

Grazie a potenze di calcolo senza precedenti e alla disponibilità di vasti dataset, le tecniche di machine learning, che prevedono algoritmi capaci di "imparare" dall'esperienza, sono applicate a problemi di computer vision e riconoscimento di oggetti in molti ambiti disciplinari. Tuttavia, l'uso di questi strumenti nel campo dell'architettura e dei beni culturali è ancora limitato, così come la diffusione di dataset pubblici per stimolare ricerca ed esperimenti.
Il contributo presenta un progetto che studia le tecnologie dell'intelligenza artificiale (AI) per supportare la gestione e l'accessibilità del patrimonio architettonico e delle informazioni multimediali connesse. Un modello originale di deep learning, basato su convolutional neural networks, è impiegato nello sviluppo di un'applicazione per smartphone capace di riconoscere i monumenti inquadrati attraverso la telecamera. Il riconoscimento tramite AI può funzionare da diversi punti di osservazione e senza la necessità di immagini di riferimento memorizzate sul dispositivo. Una volta individuato il monumento, l'app rende disponibili all'utente le informazioni precedentemente scaricate da una piattaforma web. Il primo esperimento completato ha riguardato i monumenti dell'Area Archeologica Centrale di Roma.
Il prototipo mette in luce come l'AI offra opportunità per valorizzare gli archivi digitali esistenti e dare nuovi contributi ai problemi aperti sulla gestione dell'informazione spazializzata.

Accessing space, accessing information

The digital world is permeating and altering the readings of the city and the experience of architectural heritage. Constantly evolving tools are nurturing information gathering, and datasets are growing in size, detail and complexity. However, care must be taken not to mistake the sprawl of analytical layers and the amount of data with the understanding of heritage and the capacity to manage it and plan its role in the contemporary city. Information and communication technologies (ICTs) can help to trace clear paths through digital environments and facilitate access to documents and data, but landmarks are needed to navigate across information and organize a growing knowledge.

The present contribution introduces a project on the use and accessibility of cultural heritage (CH) sites, the targeted employment of ICTs and the effective management of information on the built space. The project is carried out at the Future *Urban Legacy* Lab[1] (F*UL*L) of Politecnico di Torino, as part of a research stream on heritage technologies.

As a first challenge, we address the lack of proportion between the cultural role played by architectural heritage and the resources allocated. Italy has 49 cultural sites on the UNESCO World Heritage Sites list. Despite this, only the 0.7% of Italian GDP is allocated to culture[2]. Sites such as the Imperial Fora in Rome or Pompeii and Herculaneum host millions of visitors each year but can't provide appropriate informative services on site, and face management and maintenance problems. At the same time, due to low tourist flows, many small, isolated or less known historical and archaeological sites cannot afford surveillance and maintenance, and thus are not accessible. We need to optimize the available resources in order to guarantee the protection of cultural heritage and enhance its value.

Another challenge is to manage the new kind of information the technology is making available. Thanks to an unprecedented development of the tools, the city is now producing brand new information about itself. We have to continuously redefine the networks of relationships between documents and data, according to updating needs and contents.

Under the hypothesis that the physical form of the built environment plays a key role in the construction of new data models, tools like those of digital survey, spatial information modelling, augmented reality (AR) and artificial intelligence (AI) can synergistically work together to improve our knowledge of the strata that make up the city, and their interaction. These techniques do not have clear boundaries and many overlaps and interactions are possible, especially through the fast development they are experiencing.

We have begun to study these connections from AI, as a means to make data networks and digital environments accessible from the physical space. On the one hand, we try to imagine a platform to get in contact with a digital archive of texts, models and images on architectural heritage. On the other hand, we aim to enable easy search for information, a stronger link between data and localization, interactions with documents for different users and different purposes.

Of course, many tools already connect single artworks to related information. Nevertheless, solutions such as audio tours and QR codes require site-specific design and a physical infrastructure, which can be easily perishable and not compatible with complex information flows.

We think that mobile computing technologies can overcome the limitations of such traditional media and allow novel interactions with monuments and works of art. An inspiring and worth to note fact is that widespread devices like our smartphones can already connect large databases and a direct experience of the city. We just ask, and a *smart* voice assistant listens to music, recognizes it and connects us with further information and services.

What if we could ask "*hey phone, what am I looking at?*". The idea is to frame a monument with the camera

Fig. 1 - Temple of Saturn and Temple of Vespasian and Titus in the Central Archaeological Area, Rome. Credits: Sarah Nichols (CC BY-SA 2.0).

and get access to a data network that is linked with that architectural object, its position in the city and its spatial characteristics.

As a first experiment, we produced a prototype mobile app for the Archaeological Central Area in Rome, which includes the Imperial Fora. Here, a practical need arises: providing an appropriate, precise and complete informative service — for different kinds of visitor, different languages, different levels of detail — with limited impacts on the site and its maintenance.

We pursued the development of a lightweight app to be used offline, thus making it suitable for a large number of users and many sites, even where wireless connectivity is not available.

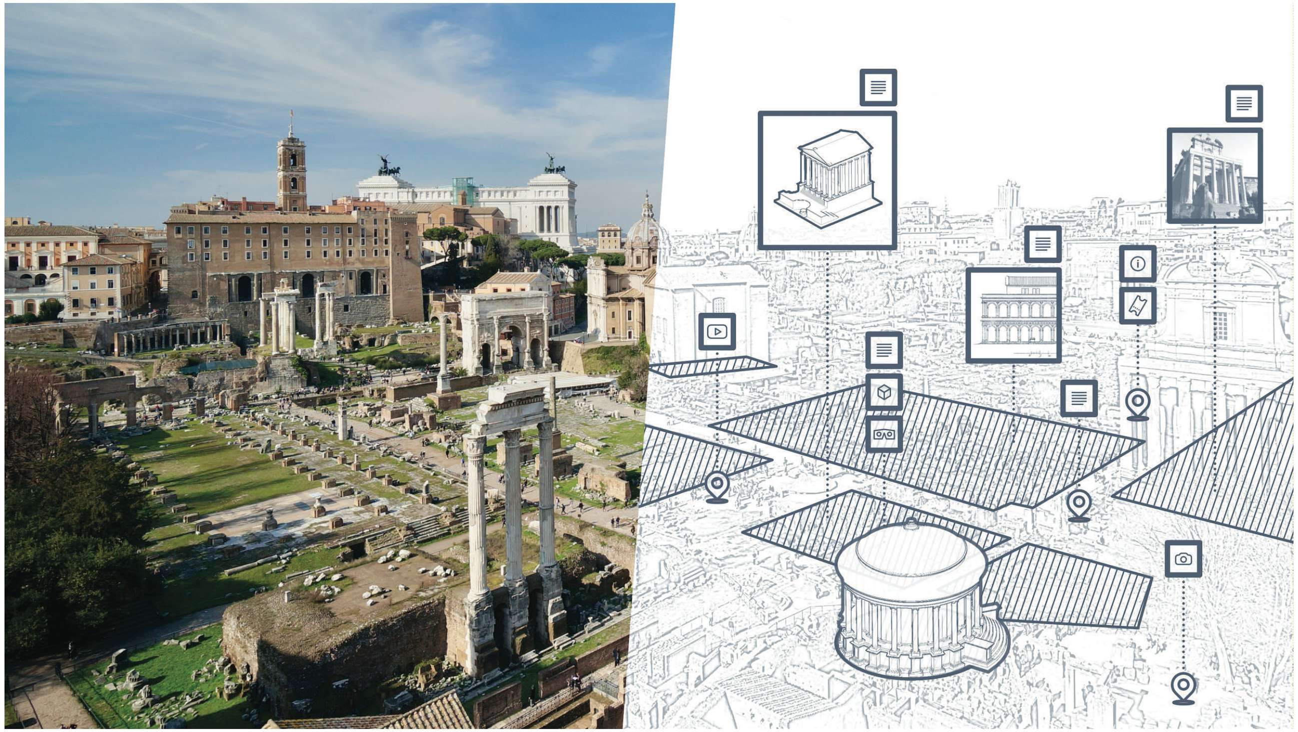

Fig. 2 - The project envisions the space of heritage sites as an access level to digital environments.
Credits: Future Urban Legacy Lab, Politecnico di Torino.
Original image: Andrew and Annemarie (CC BY-SA 4.0).

AI, heritage and spatial models

Thanks to the unprecedented computing power available, AI is now experiencing a very fast development. Deep learning (DL) is a subset of machine learning (ML) algorithms that has substantially improved the capacity of a machine to represent and interpret data[3]. These models, based on techniques dating back to the 1940s, were developed since the 1980s and are now exploiting the advantages of large-scale datasets and GPU computing, gaining a great industrial interest. DL algorithms can "learn" from experience and are capable to deal with "*complicated concepts by building them out of simpler ones*"[4].
Convolutional neural networks (CNNs) are popular and efficient DL models which have specialized architectures for computer vision, outperforming previously used algorithms and finding applications in many research fields[5].

Recent applications of CNNs to architectural issues include building façade segmentation[6], object detection and segmentation in street-level imagery[7] and architectural landmark classification[8]. However, much attention has still to be paid on finding an optimal model to classify architectural objects and features, and specific datasets for architecture- and heritage-oriented ML development still seem to be missing.

Since many works on the digitalisation of cultural sites and related archives have been conducted[9], the heritage field offers structured and ready-to-use sources of knowledge that can enable experiments and be explored through AI techniques. Spatial information modelling tools have a preeminent role in such digital archives. Enabling a connection between geospatial representations and attributes stored in a database, geographic information systems (GIS) have extensively been exploited in CH research[10]. In the last two decades, the spatial management of architectural information has been deeply connected to the building information modelling (BIM) technologies, which allow complex 3D parametric representations. BIM has been applied to existing buildings[11] and specific methods for historic structures and related databases have been developed (historic BIM, or HBIM)[12].

As appears from reviews and attempts to integrate the different approaches of GIS and BIM[13], a common issue is how to exchange information between models based on different standards and semantics. Research on how AI classifies and recognizes architecture from spatial features intertwines these topics and can make a contribution to the identification, structuring and operational use of architectural form.

Developing an "intelligent" digital guide

Using image classification techniques based on CNN models[14], we developed a mobile app that connects the real city to a set of documents such as images, texts, 3D

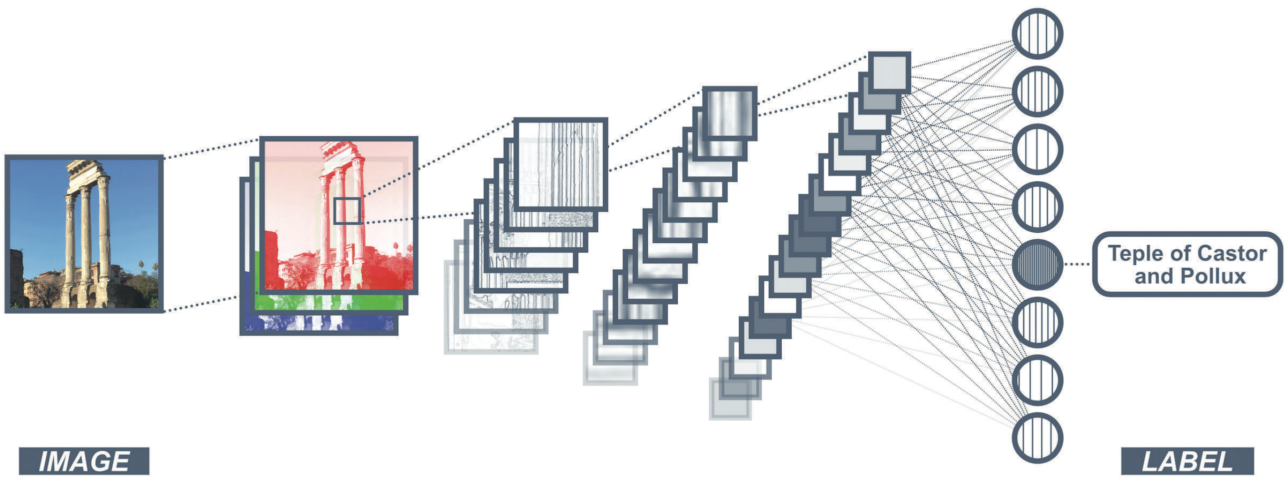

Fig. 3 - Scheme of a convolutional neural network applied to image recognition. Credits: Future Urban Legacy Lab, Politecnico di Torino.

models. It allows users to access a spatial database just by pointing the camera at a monument. We propose a shift from user geo-localization to the localization — both in the physical space and in the network of its related data — of what a user is looking at.
The app is composed of two main blocks of software: (1) an online, geographic-enabled database that makes it possible to upload different types of document and the related information and metadata; (2) the DL part, which is stored on the device and requires a very small amount of disk space. Up-to-date information can be downloaded from the web when the device is connected. When the recognition process is performed, the app gets an identification label from the AI algorithm and sends a query to the local database to fetch data.
The DL algorithm that processes images to get labels is made of interconnected functions called neurons (originally inspired by biological neuron behaviour). Each neuron receives values from other neurons and computes a weighted sum of the inputs to produce an output value. A first set (or layer) of neurons gets inputs from the pixel values of the input image and further layers extract

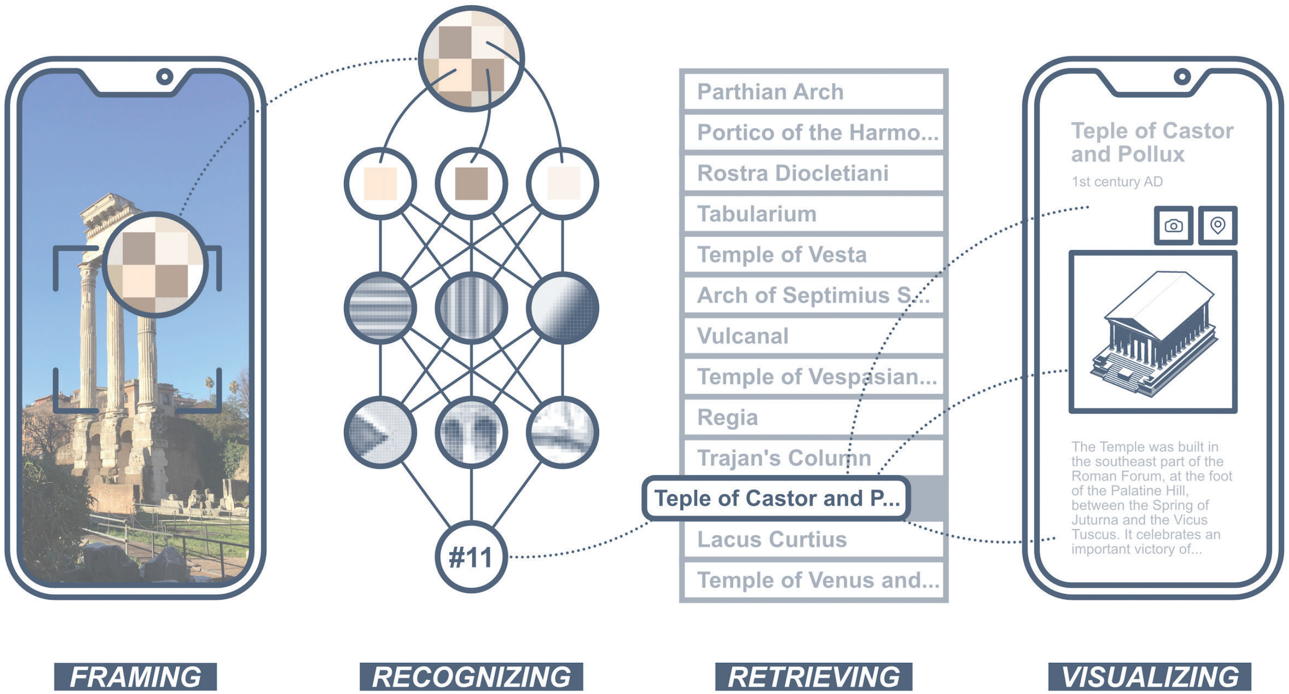

Fig.4 - Scheme of the developed app. The software uses deep learning to recognize monuments, then it retrieves and shows detail information. Credits: Future Urban Legacy Lab, Politecnico di Torino.

Fig.5 - The app features two main views. The first one lets the user frame monuments through the device camera. The second one shows data such as texts, images and navigable 3D models. Credits: Future Urban Legacy Lab, Politecnico di Torino.

increasingly abstract features, by comparing previous layers. These groups of neurons detect edges, then corners, contours and object parts, and finally recognize the object. Among the software tools, the open source libraries Keras and Tensor Flow were chosen to code the neural network. A second set of free and open source tools was employed to set up the web archive. The archive is stored on servers at the Università di Padova and it is accessible on the Cult website (Cult project 2018). The Swift programming language and the Core ML library were used within the Xcode environment to develop the prototype app for the iOS systems.
The app consists of two main user interface views and it was built aiming at ease and speed of use. A first view lets the user frame a monument using the camera. Automatic recognition algorithms compute predictions and, once accuracy exceeds a pre-determined threshold, the app shows the resulting monument title. When an object is recognized, the user can access monument details just by touching the camera frame on the screen. The second view shows data and documents such as texts, images and navigable 3D models.
The AI "learns" to recognize images through a training process, during which the machine optimizes a set of internal parameters, called weights, in order to make its prediction closer to the correct answers for a dataset of manually labelled images[15].
We built a training dataset covering 46 Roman monuments. Pictures were expressly taken for the project, aiming to give a complete overview of the architectural characteristics of the selected objects. Specific attention was given to the most common views for a visitor, including details, panoramic views and different lighting conditions. Some issues were related to the heterogeneous dimensions and conservation status of the monuments, these being sometimes quite incomplete, or part of more recent buildings.
Operations such as translation, rotation, scaling, noise injection and colour alterations were performed to multiply the training dataset and make the AI face a wider range of conditions. Such alterations are called *augmentation* techniques, and have proven particularly effective for DL object recognition[16]. The final dataset contained about 500 images per monument.
The training was conducted using a GPU cluster. Although the process was quite time expensive, a model can be re-trained, so new data can update a previously processed training status. The overall accuracy was calculated at 95% using a test subset of the input pictures. In fact, field tests revealed a much more heterogeneous behaviour of the recognition function across different monuments. Large objects such as the Domus Augustana or the Trajan's Market, which present many different parts resulted in objects being often mistaken for these larger ones. In

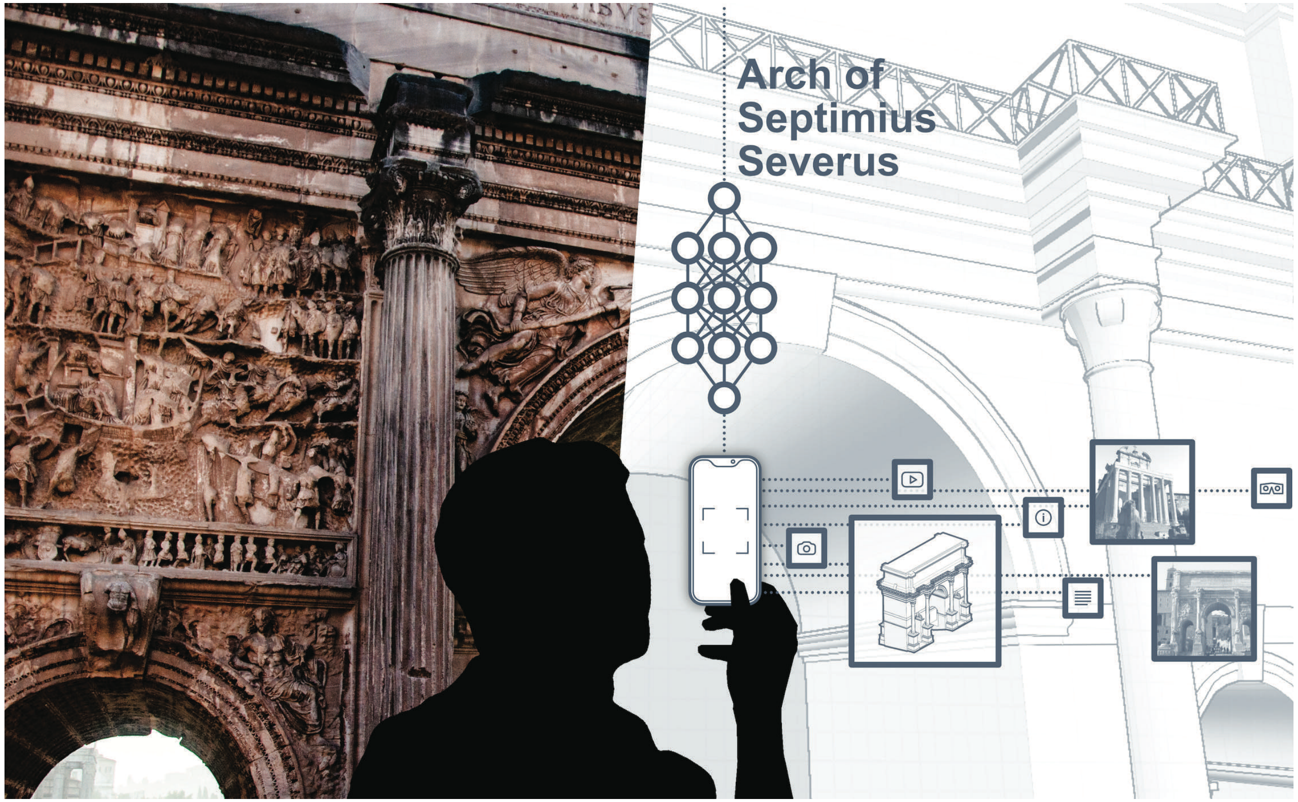

Fig.6 - The app allows users to access a spatial database just by pointing the camera at monument. A shift is proposed from user geo-localization to the localization of what a user is looking at both in the physical space and in the network of its related data.
Credits: Future Urban Legacy Lab, Politecnico di Torino. Original image: Sarah Nichols (CC BY-SA 4.0).

the final model, these monuments were divided in sub-elements, each one with its own label.
The resulting AI "brain" is a lightweight model of just 13 MB. We expect this kind of model to learn to recognize a much larger number of objects, without significantly changing size, which is constrained by the neural network size.

What's next

The app is an access point to a yet under-exploited network of digital information. Instead of being found in a catalogue or a map, a large amount of multimedia content can be linked to the physical elements of cultural sites, answering questions on how to make newly available information easily and sustainably reachable.

Future developments can of course expand the information connected to the app. The Central Archaeological Area in Rome is the first test field of the developed "AI guide", but this is just one among the possible applications of this technology. CNNs are general models and can be trained to recognize a wide range of objects. We are planning to extend the project to other sites, covering different scales and time spans.

Furthermore, we are working on how to bridge our AI experiments to other technologies: AR can improve the interaction with 3D digital models and superimpose digital information layers on live images of the real environment; 5G cellular mobile communications can make large amounts of data immediately available, redefining location-based services and content access; IoT devices can enable remote access control and enhance on-site experience, providing cost-effective monitoring solutions which do not need the physical presence of supervising personnel.

While AI is just beginning to interact with the built environment, heritage technologies have long been producing and exploring digital models and spatial archives. The interaction between DL algorithms and information modelling, with its underlying semantics, should lead the way to both exploit heritage collections and optimize new object recognition techniques. In fact, one of the main challenges remains to build DL tools which are specific for architectural heritage. Models could be trained to recognize building types, construction techniques, structural components, materials, decorative styles and relations between the parts.

As many have pointed out, the availability of vast and public datasets has been a boost for the development of DL models. Nevertheless the "*drosophila*" of architectural machine leaning[17] has still to be found.

Notes

[1] *FULL* is an interdepartmental research center at the Politecnico di Torino. The project is part of *FULL's HeriTech* research stream. The team working on the project is composed by Matteo Robiglio (full professor in Architectural and Urban Design), Francesca Frassoldati (associate professor in Architectural and Urban Design), Claudio Casetti (associate professor in Communication Engineering), Louis N. Andrianaivo (research fellow) and the author. The author is working on the project as a PhD candidate in *Architecture. History and Project* at the department of Architecture and Design of the Politecnico di Torino. Louis N. Andrianaivo first worked at the ML model as a PhD student at the Department of Mathematics of the Università di Roma Tre. The ReLOAD_Research Lab of ArchitectURban Design of the Università di Padova has made available and maintained the Cult web service (Cult project, 2018). The project is carried out in partnership with Roberto D'Autilia.

[2] Source: Eurostat, General government total expenditure on 'recreation, culture and religion', 2015. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20170807-1 (accessed on 26 March 2019)

[3] Cf. Hosny et al. 2018.

[4] Cit. Goodfellow et al. 2016, p. 1.

[5] Cf. Hosny et al. 2018; Webb 2018; Amato et al. 2016.

[6] Cf. tathopoulou, Remondino 2019.

[7] Cf. Cordts et al. 2016.

[8] Cf. Gada et al. 2018; Amato et al. 2016.

[9] Cf. Cecchini et al. 2018; Haus 2016.

[10] Cf. Soler et al. 2017; Cerutti et al. 2015; Apollonio et al. 2012.

[11] Cf. Volk et al. 2014.

[12] Cf. Murphy et al. 2009.

[13] Cf. Liu et al. 2017; Saygi and Remondino 2013.

[14] A variant of MobileNet V1 models is used; Howard et al. 2017.

[15] Cf. LeCun et al. 2015.

[16] Cf. Goodfellow et al. 2016.

[17] Geoffrey Hinton has defined the MNIST dataset, collecting handwritten digits and related labels, *"the drosophila of machine learning"*, to stress its importance in ML research. Ibid., p. 22

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Cultural Heritage is as rich as complex and its documentation is an increasing challenge. The digital solutions are numerous and their potential is a topic of constant investigation by the scientific community, that is requested to deliver digital strategies to make heritage permanently open and shared. The volume collects the contributions to the second conference of the 'Digital & Documentation' series, extending the debate to a multidisciplinary network of experts. It presents a frame of strategies for the documentation of Cultural Heritage in a wider perspective, stimulating reflections on: the relationships between physical and digital assets; the consistence of digital data and its management; digital representation as a mean to the transfer of cultural heritage. It comprehends theoretical studies and best practices on tangible and intangible heritage, taking into account applications for the research and the communications of Cultural Heritage as 3D representations, digital anastylosis, Augmented and Virtual Reality, Artificial Intelligence, semantics and databases. Aiming to give a comprehensive view on digital and documentation, the volume involves multiple perspectives from cultural institutions and universities, from experts in representation, geomatics, history, architecture, archaeology and ICTs for a multidisciplinary outcome.

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