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MEASURING AND EVALUATING VISITORS' BEHAVIORS INSIDE MUSEUMS: THE CO.ME. PROJECT

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Abstract

The use of ICT in the field of Cultural Heritage offers unprecedented opportunities to improve cultural sites management (e.g., archaeological areas or museum). Taking advantage of innovative methods of data acquisition through ambient intelligence and space sensing infrastructures, the Co.ME. project has developed a system to turn exhibitions into sensitive spaces, able to quantify and register visitors' behavior. A solution that provides to museum professionals all the necessary data to understand their public, making possible to structure a cultural offer based on visitors' needs. After a short theoretical introduction on the project framework, the paper presents the case study of the Civic Museums of Palazzo Buonaccorsi in Macerata (Italy), demonstrating the effectiveness of this approach in terms of both data collection and monitoring system; useful solutions to improve museum installations and communication, as well to optimally plan staff attendance.

Keywords

Museum systems, Space Sensing, Visitor behavior, Cultural Heritage management, Digital transformation

1. *Introduction*

Enhancing museum offer, both in terms of collection fruition and additional related services, is one of the primary aims set by the Triennial Plan for Museums' Digitization and Innovation (Direzione generale Musei - MIBACT, 2019).

The use of digital technologies for documenting and displaying Cultural Heritage is a mandatory step (Luo et al., 2018; Puma, 2016), but to effectively achieve this goal, the museum management must overcome its self-referentialism, strengthening the relationship with visitors to better understand their needs. This process could be supported by proper monitoring systems able to detect and measure visitors' behavior inside museums, transforming the user from a simple customer to a strategic resource to be involved in the design phase of museum exhibitions and installations, which can thus be tailored to address his needs.

This solution has multiple implications. First, it supports decision-making processes, providing tools that ensure an integrated overview of museum performances in terms of efficiency, effectiveness and affordability. Secondly, it facilitates the definition and assessment of public policies, providing a general framework of museums achievements thanks to the availability of integrated data readily accessible. Lastly, it allows to create a data-sharing system between professionals, a solution able to support the implementation of relevant services to promote museums and their cultural offer.

If data collection is fundamental, the definition of key performance indicators is equally so. These are set of indicators, typically built from heterogeneous data, useful to understand the processes to be kept under control. Whether they are related to the performance of the company business (e.g. tickets sold) or to the quality delivered or perceived (e.g. reputation), whether they are about organization and planning (e.g. expected flows of visitors) or visitor knowledge (e.g. profiling elements), the designed system has to enable the development of both in-depth and summary indicators useful to understand museum performances and to support their management.

It is therefore clear why in the field of cultural sites management, in particular those belonging to the complex scenario of museums, curators and other professionals are getting more and more interested in understanding what is happening at their structures: what exhibitions and exhibits do visitors attend to, what exhibits visitors spend most time at, what hours of the day are most busy

at certain areas in the museum and more (Lanir et al., 2017).

Monitoring museum visitors is a key element for audience development and audience engagement. Understanding the visitors' experience and, consequentely, evaluating the effectiveness of their relationship with the museum make it possible to obtain crucial information on the quality of the exhibit design and communication, on the reception and mediation services, and also on the educational and cognitive impacts generated (Bollo, 2004). And in fact, thanks to the analysis of their interactions with the exhibition and its contents, it is systematically possible to evaluate the effectiveness of an expositive path and its success. Moreover, the integration of data on what happens inside museums with the statistics from online stores, ticketing, interactions on social networks and other communication channels offers a complete information framework useful to design the museum display and the management of flows and visit times according to visitors' needs (Karaman et al., 2016).

In order to understand visitors' behavior, museums today rely either on self-reported questionnaires that visitors fill out at the end of their visit or on manual tracking and counting of individual visitors using unobtrusive observations. While questionnaires are useful for providing demographic and motivational information (such as frequency of museum visits and reason for arriving at the museum), tracking of visitors can provide objective information about the way visitors interact with the museum space and content, providing valuable information about exhibition placements and design.

However, these data are still too often collected through analogical approaches, based on questionnaires or discrete observant surveys. Usually, visitors' monitoring involves medium-large museums, and it is mostly based on the presence of operators who manually keep track of access. In this operation they have also to record way of fruition and time spent, annotating data with pen and paper, with outcomes not always satisfactory regarding the accuracy and the reliability of the collected information. Monitoring visitors' behavior is so entrusted on extremely time-consuming practices, affected by the subjective interpretation of the evaluator. Just a few international museums started to take advantage of technologies to support these operations enabling real-time visitors localization, thanks to Rfid, Wi-fi, UWB or Bluetooth (Yoshimura et al., 2012). Systems that present streghts such as cost-effectiveness and possibility of integrating the localization function to audio guidance or to provide other information, but also undeniable weaknesses referred to the accuracy of measurements, which can generate remarkable errors. The main problem furthermore lies in the impact they have on the visitor, as these solutions require every user to be aware of the ongoing monitoring, being an active part of the localization process, activating special functions on his portable device or transporting along the path a tool provided at the entrance, with inevitable consequences on the reliability of the data collected and the consistency of the registered users.

Therefore, it is necessary to go beyond these solutions, moving to a data-driven approach of data collection and analysis, the optimal solution to provide an objective and reliable source of information. An approach that is still barely explored in the CH field, although from a technological point of view the ICT are already able to support it, providing efficient solutions to collect multiple information, including those related to the user experience within an exhibition (Gupta et al., 2014; Martini et al., 2020; McLaughlin et al., 2016). Furthermore, the new frontiers of space sensing, which finds its widest declination in the IoT, allow to make the space sentient, aware of the human presence and able to react and adapt to it (Alletto et al., 2015; Chianese & Piccialli, 2014; Del Fiore et al., 2016; Osaba et al., 2018; Petrelli et al., 2016). Intelligent CH spaces can include these technological solutions that detect user's interactions and positions, collecting huge dataset that provide a complete knowledge on museum visitors behaviour. A great opportunity for understanding users' preferences with accurate and detailed information that relies on data acquired by hundreds and thousands of visitors.

Another aspect to consider is that the need to monitor visitors' behaviour inside the museums has become even more stringent because of the distance measures required in the containment of the Sars-Cov2 pandemic. Today it is even more important to know information about museum visits, starting from the exact number of accesses and paths followed, to ensure an adequate use of the rooms, restricting the entries and avoiding gatherings.

Acting in this framework, the present contribution describes a solution to make museums sensitive, showing how they can exploit visitors' feedbacks, obtained through a network infrastructure, to orient the management process in continuous improvements of the cultural offer to be structured according to visitors' needs. In particular, the paper presents the results obtained within the framework of Co.ME., a project born from a process of cross over between the cultural sector and high-tech companies that is structured to take advantage of their different knowledges.

2. The Co.ME. project

The digital solutions and wireless sensor networks represent a potential for growth and innovation for the italian museum sector, which is lagging the main world cultural centres. The causes of this are related to a chronic delay of our "official" cultural world to take advantage of technologies and digital solutions compared to many innovative international exhibition centers, often equipped with technological infrastructures that allow to record the online and onsite accesses and the interactions that their profiles get through the social networks. Another cause can be identified in the failure of the technological companies to adapt digital infrastructures and solutions to the needs and characteristics of museum institutions, which must take into account several factors in adopting digital strategies: primarily the resources involved, human and financial, but also the contribution that technologies can ensure in terms of achieving the objectives and their social and cultural mission.

If knowing the number of museum visitors and of online accesses and social interactions is strategic for the communication and promotion policies of cultural centers, understanding the behaviour and experience of visitors in a museum or an art gallery is vital to make the space itself interactive and adaptable to the visitor and to provide guidelines for the design of installations and interventions on the layout, the schedule of events, so overall, to propose a more satisfactory user experience (Pierdicca et al., 2019).

In this context the "Co.ME. - Change your museum" project aims at defining a solution based on a network of sensors able to monitor the behavior and emotions of users inside a museum and supported by a web-platformbased able to collect the recorded data and smart process them in order to orient the choices of museum curators, directors of cultural centers and other operators to make exhibitions more comfortable and interactive and their experience more attractive.

The project aims in particular at the development of a new monitoring system for museum audiences which, exploiting the possibilities offered by the most modern technologies for tracking and analysis of behaviours, can provide museums with effective solutions to improve the visiting user experience, aiming to optimize the interaction between people, spaces, installations, works of art and all the elements of internal communication.

The project is based on an interdisciplinary approach that arises from the encounter between museological and museographic knowledges and technological skills, especially in the field of retail intelligence. The proposed monitoring is in fact a modular and scalable system based on the characteristics and needs of each museum institution, that may have different needs in terms of understanding of the behavior of its visitors and of audience development strategies to implement.

Therefore, the overall purpose of the project is to offer museums objective, scientific and effective tools, already adopted in other fields and customized to guarantee museums an innovative procedure of knowledge of their public, in order to change and innovate their design formats, logic of mediation and communication, finally arriving to identify and intercept in more appropriate way their target audience.

2.1 Project methodology

The Co.ME. project aims to guide the museums in the choices regarding their exhibitions as times and routes of visit, the materials and the informative contents, in order to reach an optimized interaction, more effective and satisfying, between the demand and the cultural offer. The logic on which it is structured is that of the cycle of Deming or PLAN, DO, CHECK, ACT: plan, to establish the objectives necessary to achieve measurable results; do, to implement or review processes; control, to monitor and measure processes through the evaluation of clear and shared performance indices among the various stakeholders; act, to introduce solutions that improve performances (Fig. 1).

According to this logic, interdisciplinarity plays an essential role, because only through an in-depth audit phase conducted by experts in museography and audience development it is possible to develop

together with the museum professionals a plan of specific needs of a museum and therefore the information necessary to implement actions aimed at improving the performance of the installations. After this phase, thanks to the modulability of technological solutions and to specific technical and IT skills, it is possible to identify the most suitable combinations to ensure effective and efficient monitoring. This will be followed by the analysis of the data collected, guaranteed in the simplest and most immediate way thanks to the provision of graphic dashboards constantly updated, and finally, the identification by museums of the most appropriate intervention strategies.

Fig. 1: Scheme of the cycle of Deming. This logic was adopted according to the need of a solution able to provide a continuous improvement

The described process lends itself to different declinations, according to the specificities that characterize the different players that operate in the museum scene, different by type of collections and buildings, but also by dimension and financial capacity. The data and information to be collected must therefore be available according to the "desired" of the stakeholders to whom the analysis and monitoring system is aimed.

In order to pursue audience development and audience engagement strategies, the institutions and museum managers first need to assume a new awareness of their audience and the behaviour of visitors within museums. In particular, the Co.ME. project allows museums to collect quantitative and qualitative data related to public profile and spatial (tracking) and temporal (timing) interaction between visitors and the museum structure, such as:

- visit itineraries;
- number of entrances and segmentation of visitors (age, gender, entry mode);
- visitors' flows (by hour, day, month);
- individual and overall stops in the different points of the exhibit (art works, panels, multimedial installations) and related times.

These data may allow museums and managers to identify indicators relating to the attractiveness of their equipment, the degree of attention of users in front of their proposals and the ways in which visitors interact with them (Fig. 2).

These indicators immediately allow a more effective distribution of flows, with benefits both for the users of the museum spaces and for the management of them, an even more obvious need because of the measures of distancing and staggering the inputs following the Sars-Cov2 pandemic. The identification of the hot and cold points of the path and the time spent in front of individual works and/or exhibition contexts is also fundamental for the needs of partial realignment, allowing museums to take action with timely improvements or to integrate the route with other set-up solutions (e.g. multimedia instruments or installations).

The possibility of obtaining information about visitors' preferences and orientations may also make it possible to make better choices in internal communication, to propose cultural services adapted to the characteristics of the public and to prepare cultural marketing actions oriented and more effective.

As highlighted by studies and national statistics (*MIBACT - Ufficio Statistica*, 2019), the museum sector as well as representing a cultural and social growth dimension fundamental to the community is an active industry with a huge potential, also in economic terms, which is obviously directly proportional to user satisfaction and, consequently, by the number of visitors that museums can attract. So, the optimized management of museums reached thanks to the Co.ME. project based on the knowledge of their public has positive results both as regards the social and cultural impact of museums on the community and the sustainability of the institutions themselves.

The project has included a phase of testing and optimization, to define the packages of

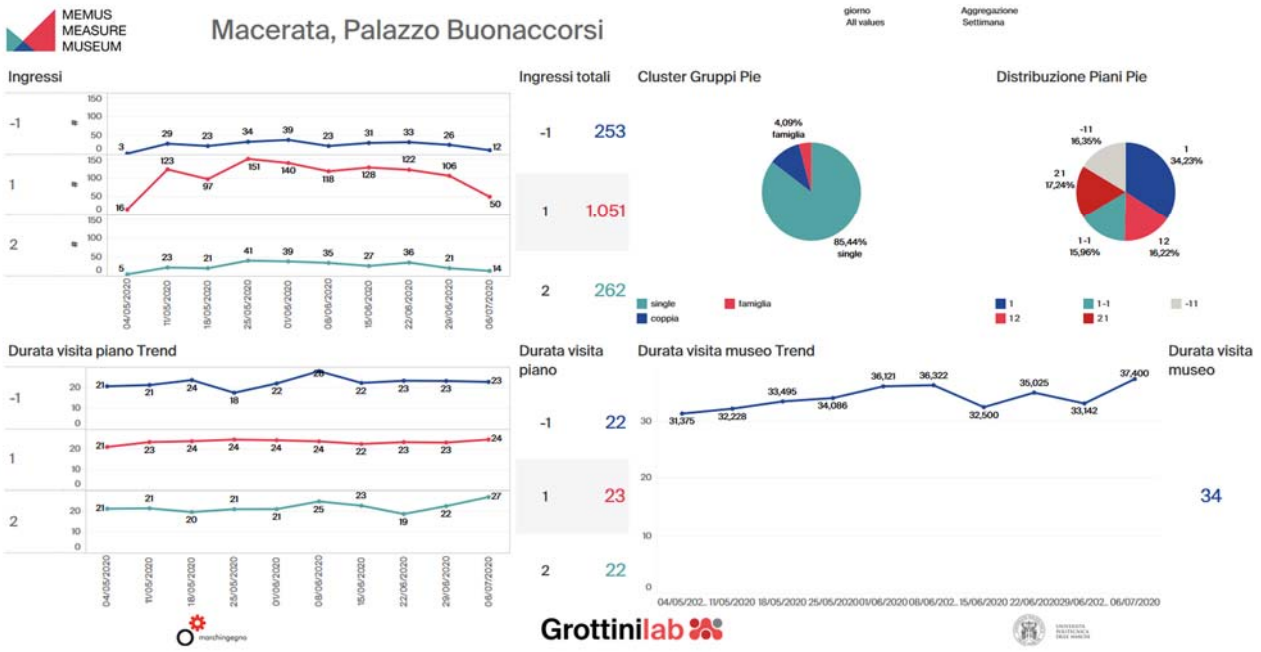

Fig. 2: Dashboard homepage. Thanks to the dashboard interface the museum professionals are able to browse several data filtering them by different criteria

technologies and services to be offered on the market for museums.

A first experiment concerned the Museo Tattile Statale Omero in Ancona, during a period characterized by the measures of social distancing adopted in response to the Sars-Cov2 pandemic. Two exhibition rooms were infrastructured to be able to monitor in real time the number and concentration of visitors, automatically providing the ticket office with the necessary information to allow or not additional visitors to access the museum.

A second pilot was the National Archaeological Museum of the Marche Region (Quattrini et al., 2020). Here the test involved the monitoring of the performances of two important points of the exhibition: a showcase with extraordinary finds belonging to the Galli Senoni civilization and a digital library with 3D models of the main objects kept in the museum. For both, the indicators of attraction and attention generated were recorded and analyzed, also monitoring the variations over time and analyzing the differences according to the different types of public in the museum (summer and school tourism).

3. Case study: Palazzo Buonaccorsi

The most complete and complex experimentation for technological solutions and quality of the monitored data, was carried out at the Civic Museums of Palazzo Buonaccorsi in Macerata.

In the audit phase, an investigation was carried out with the scientific director of the Museums, aimed at identifying the characteristics and criticalities of the exhibition, the route layout and the visitors' knowledge needs. In this phase also a technical diagnosis was carried out to identify the facilities and structural needs, for a correct localization of the interventions with due regard for a historical building of great artistic value.

At the end of this phase, it was possible to identify the objectives of visitors' knowledge and structure a proposal for personalized monitoring on the needs of the museum and the characteristics of its spaces.

The test was thus aimed at monitoring the flow of visitors within the building, to provide those responsible for the establishment of information useful to reconstruct the path of users between the three collections hosted: the ground floor with the collection of historical carriages, the main floor with frescoed rooms and ancient works of art and the second floor with contemporary works of art.

3.1 Data collection

One of the current trends is to configure location-aware services, i.e., applications driven by

location information, in particular, by users' movements in the environment.

Recently, RGB-D cameras have demonstrated their suitability for solving this task. In fact, this kind of solution provides affordable, additional rough depth information coupled with visual images, offering enough resolution and accuracy for indoor applications. The advent of low-cost RGB-D devices, such as Microsoft's Kinect and Asus's Xtion Pro Live sensors, has revolutionised computer vision and vision-related research. The combination of high-resolution depth and visual information has generated new challenges and opportunities for activity-recognition and people-tracking for many applications based on human-environment interactions.

Based on the identified needs, a network of cameras with infrared sensors and re-ID (namely person re-identification) plug-ins has been identified as the most suitable technological solution. These sensors are able to identify the user and to anonymously register his presence in compliance with privacy policy. The general workflow performed by our architecture is depicted in (Fig. 3).

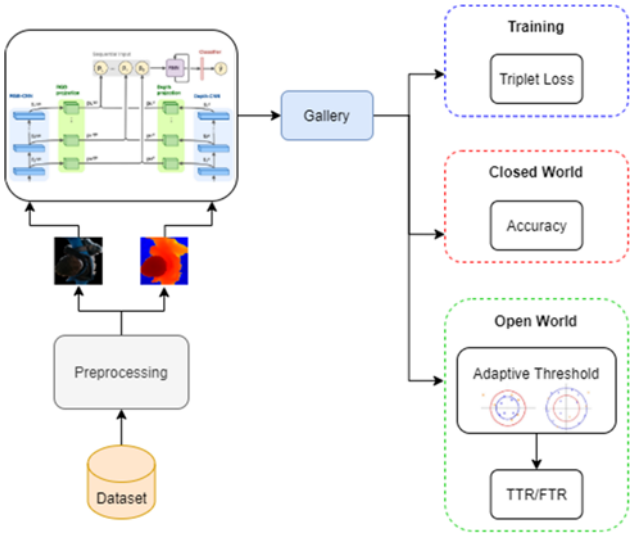

Fig. 3: General workflow of the re-id and people counting infrastructure

A dataset containing museum's visitors has been specifically collected, with 6 RGB-D cameras placed in 4 different floors: one camera at the entrance of floor 0, one camera for the entrance and exit of floor -1, one camera for the entrance and one for the exit of floor 1, one camera for the entrance and one for the exit of floor 2. The cameras record an RGB-D data flow with 640x480 pixel resolution. The proposed dataset consists of 55 days of video recordings from 10 July 2020 to 13 November 2020. People detected are 6200 (Fig. 4). Three days of registrations have been used as training set. An example of the hardware setup is depicted in (Fig. 5).

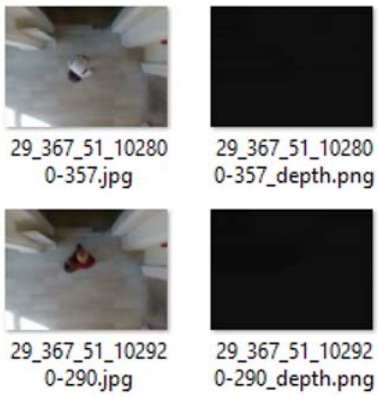

Fig. 4: Frames from the dataset collected and labelled to train the AI-based system

Fig. 5: Re-ID Cameras intalled at the entrance and exit of the thematic itineraty on contemporary art.

The purpose was to collect quantitative data related specifically to the number of accesses (total entrances to the building and entrances for each floor), the order of entrances (distribution of

the entrances on the three floors and access sequences to the collections), and the time spent (total and for each floor).

Four different deep learning approaches were tested by pre-training the network on TVPR2, a publicly available dataset containing 235 recorded videos in a top-view configuration (Paolanti et al., 2020). Finally, the best approach was chosen in order to perform users' re-ID for collecting meaningful information from the visitors.

A preprocessing phase is required for the data analysis and it is applied to each frame. In particular, a crop of each person is done with a 200x200 pixel bounding box, using the depth channel and a threshold on the person's minimum height. In this way, noise produced by the frame background is removed highlighting details of people. Inside the bounding box is applied a black mask to remove the background. This step is implemented using the previous mask to determine the outline with the largest area and then removing everything outside of that area. Moreover, the Depth information is converted to the JET color map. This conversion, after a normalisation of the values between 0 and 1, usually transforms values close to zero into colours with a tendency towards blue, while values close to 1 are transformed into colours with a tendency towards red. Since the RGB-D camera gives the distance between itself and the detected person, to obtain this colour map an inversion of the values is performed. After this preprocessing phase, the obtained frames are used as input for the neural network.

3.2 Deep Learning Model

The Deep Learning Model is based on a state-of-art network for object recognition, namely RcFusion network (Loghmani et al., 2019). This choice arises from the work of Caglayan et al. in which the RcFusion outperforms other state-of art networks (Caglayan et al., 2020).

In this work, RcFusion has been improved and adapted to solve the task of top-view person re-identification. The proposed network, showed in is a multi-modal deep neural network for RGB-D person re-identification. It comprises three components:

- **Multi-level feature extraction**. Two ResNet18 extract respectively RGB and Depth features at different levels of abstraction.
- **Feature projection and concatenation**. Since each feature has different dimension, the multi-level features are projected in a common feature space using Projection Blocks. Each Projection Block is composed by two convolutional layers and a global max pooling. Thus, each output is a 1-D vector and all the Projection Blocks outputs are concatenated.
- **Recurrent multi-modal fusion**. A Recurrent Neural Network (RNN), in particular a Gated Recurrent Unit (GRU) is used to aggregate the RGB and Depth features coming from the Projection Blocks. The GRU's memory embeds a summary of the most relevant information from the different levels of abstraction creating a multi-modal feature. Compared to the original approach, it has been used a GRU instead of LSTM, because it requires less parameters, allowing an improvement in training time and memory consumption.

Finally, the multi-modal feature, that represent RGB-D features at many levels of abstraction, is feeded on a SoftMax classifier to predict the person label. The schema of DL model is reported in (Fig. 6).

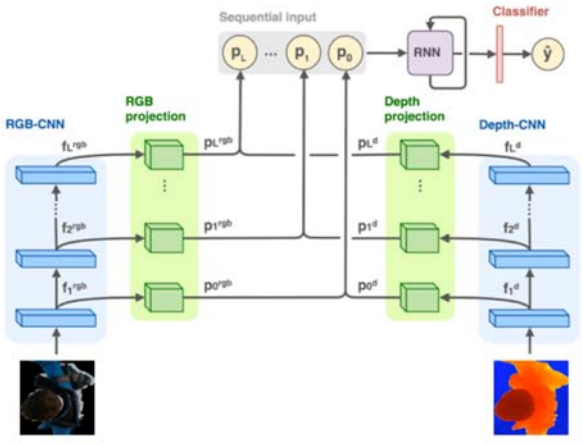

Fig. 6: Workflow of deep learning model.

Before training, data augmentation techniques are applied to increase the dataset and improving the performance. In particular, each image is augmented six times with vertical flip, horizontal flip, 90-180-270-degree rotations. The network has been trained using a particular function loss called triplet loss. The triplet loss function implemented is the batch hard function presented

in Hermans et al., which allowed performing end-to-end learning between the input and the desired embedding space (Hermans et al., 2017). This particular function can achieve state-of-the-art performance both with a pre-trained CNN and a model trained from scratch.

The key idea is the following: *P* person *IDs* and *K* frames of each individual are randomly sampled, so that batches of *P*K* frames are created for the training. The entire loss function is evaluated by defining triplet as in Gao et al., the hardest positive and the hardest negative samples are selected within the batch, for each sample *a* of the batch itself (Gao & Nevatia, 2018).

Finally, in the testing phase an image gallery approach is used instead of the Softmax classifier, to assign the predicted class to each test image. This method is more useful than the softmax function because allows to train the network once, and then use it also with people never. A new gallery with new people to re-identify is collected and people outside the gallery are defined 'intruders'. The classification ranking is computed by using the Euclidean distances as distance metric: for each input image is calculated the Euclidean distance between the test image and each image in the gallery set. Finally, network performance is evaluated in a closed world scenario by using the Accuracy metrics, computed on the Test set of the relative Dataset. The framework, however, has bee tested in an open world scenario, where there is a large set of people including target people (people in the gallery set to be re- identified) and non-target people (intruders) that are not to be re-identified. The main challenge of this scenario is understanding when an image represents intruders and exclude it from re-identification. When an image describes target people, the network should be able to understand it and do the re-identification correctly. The method proposed in this work can also be adapted to solve person re-identification in an open world environment, by applying an adaptive thresholding to measure the distance between the close and open world datasets.

Thanks to this method, it has been possible to evaluate the system and analyse the results, as described below.

3.3 Data analysis: quantitative and qualitative results

The test took place from July 14 – September 13, 2020, for a total of 61 days. In this period the room at the entrance of the building recorded 6,175 total entries, of which 1,169 in July, 3,926 in August and 1,080 in September. To achieve the objectives set during the audit phase, it was necessary to first gather the partial data recorded by the individual collections: 1,152 people visited the ground floor with the carriage museum, 4,256 the main floor with the ancient art collection and 2,817 the second floor with the one related to modern art.

Clearly many of the registered people visited more collections of the building and thanks to the tested Re-id system it was possible to reconstruct the path followed by individual users and group the flows into macro-aggregates expressed in percentage.

Thanks to this analysis it emerged that: 6,7% of the visit involved only the ground floor, 42,0 % only the main floor and 22,0 % only the second floor. To these are added a 5,75% of users who visited the ground floor and the main one, a 2,3% the ground floor and the second one, a 17,3% the main floor and the second and only a 4,0% who made a complete visit of all the three floors of the building (Fig. 7).

The analysis of the data also showed that who visit all the collections, in the majority of cases the sequence of the visited plans has always been 1-2-0: ancient art, modern art and collection of carriages, although access to the floors is free and left to the discretion of each visitor.

The evidences shown by the quantitative reading of the accesses are also confirmed by the analysis of the average residence times recorded. The main floor confirms, in fact, its centrality within the visit path, recording an average time of stay equal to 27 minutes, out of a total of 35 minutes of the average visit inside the building. The second floor and the ground floor registered lower time of stay, 15 and 14 minutes respectively (

Tab. 1). From this comparison the main floor represents the principal reason of access of visitors to the palace, proving to be the only element attracting the public of museums in several cases. Even where the visit provides a path that in addition to the plan 1 also involves other plans, it is evident that most of the monitored users spend a large part of their time visiting the collection of ancient art, overshadow the visit to the other two floors.

The qualitative analysis of the recorded data allowed to interpret these more in depth,

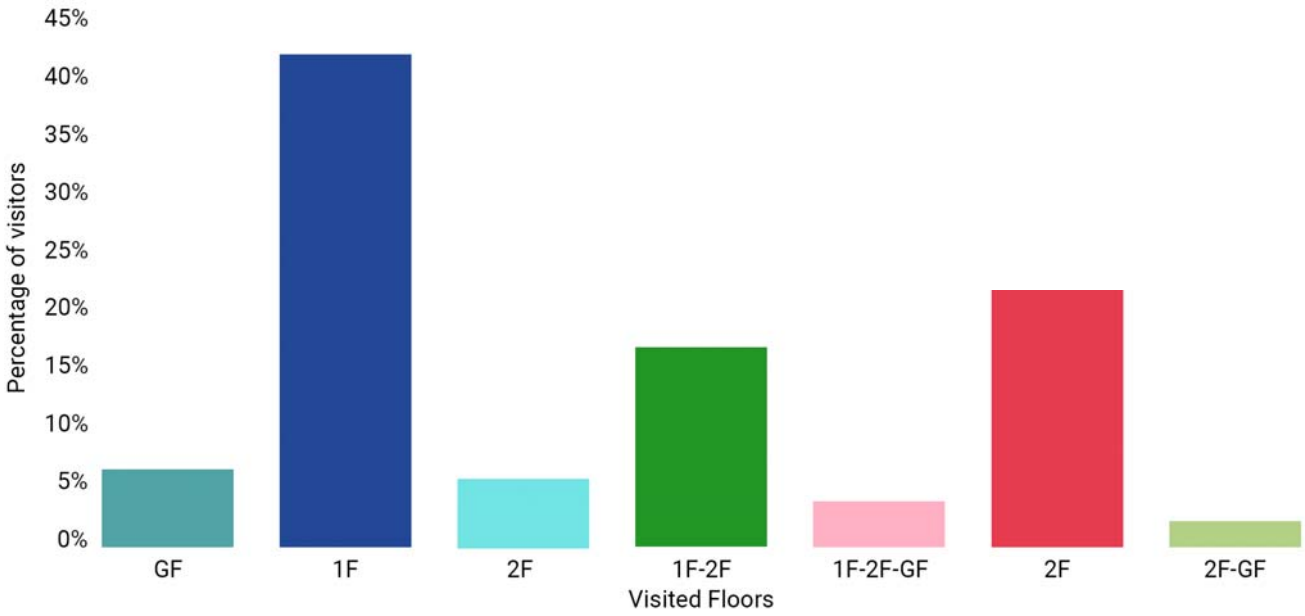

Fig. 7: Bar chart of the percentage related to the visit combination of different floors.

comparing the general data with some specific periods characterized by events hosted at the museum and in the city.

In particular, from 18 July to 9 August the city hosted the events of the Macerata Opera Festival, welcoming a large number of visitors that every year arrives in the city for this international initiative. In this period the main variations concern the number of accesses to the main floor. The percentage of users visiting only it rises to 45,1% and the percentages of those visiting only the ground floor or the first floor and the ground floor together also register a slight increase. At the same time, the performance of modern art worsens, with a 0.8% drop in the percentage of visits to the second floor alone and a more significant drop in the percentages of visitors to the main floor and the second floor together, with a drop of 1,8 %.

The same trend emerges even more strongly in conjunction with six of the eight shows in the formats "Palco Reverse" and "Contaminations", with the participation of contemporary artists and the protagonists of contemporary showsAn opposite trend is recorded in the period of September in which Macerata hosted the "Artemigrante Festival", dedicated to street art and contemporary circus. From the 3rd to 6th of September, in fact, the performances of the second floor and its collection of contemporary art, improve significantly.

Tab. 1 Table concerning recorded data related to the time spent by visitors within the building and individual collections.

Visitor Id.	Date	Entrance time	Entrance time 1F	Visiting time 1F	Entrance time 2F	Visiting time 2F	Entrance time GF	Visiting time GF	Total timing
1049	16/07	16:01:18	-	-	16:02:14	8'	-	-	9'
1668	31/07	17:40:46	17:49:42	22'	18:20:43	10'	-	-	50'
499	21/08	12:46:37	12:54:41	45'	13:42:58	28'	14:15:25	14'	103'
926	26/08	13:12:56	13:21:05	25'	-	-	-	-	34'
606	05/09	12:19:23	12:27:56	46'	13:15:39	28'	13:51:55	10'	102'
1195	12/09	12:16:25	12:24:53	33'	-	-	13:03:36	14'	61'

Visits to only the second floor rise to 30.3%, with a peak of 42.1% on the opening day, while those travelling through first floor fall to 33.3%. Even with less intensity, visitors to ground floor and to second floor and ground floor together also increase. It should be noted that these variations in

flows between floors do not determine as many changes in the visit times of the three collections, with the relative indicators of attention, linked to the minutes of stay, that attest to stable and regular performance in their average levels, with some deviations even relevant only on days of negative or positive peak of access to the floor.

4. Conclusion

Some critical issues were encountered in this experimentation, linked first to the anomalous access modes dictated by the containment measures due to the Sars-Cov2 pandemic. During the testing phase, in fact, some security requirements were adopted, spreading out the accesses to each floor and single rooms and preventing the use of multimedia touch devices, resulting in lower attractiveness and attention to the routes involved.

The test also found problems related to the structure of the museum, a historic building not equipped with wi-fi. The camera on the ground floor, located in a room partially underground and not well lit, reported data not completely reliable, in particular during the first days of the test and therefore those days that have encountered problems of counting have been excluded from the final presentation of the data conveyed to the managers of the museum.

Finally, a margin of error in the monitoring of flows must necessarily be considered as the system also monitors the passages of the internal staff and guardianship.

However, the experimentation carried out at Palazzo Buonaccorsi has demonstrated the validity of the monitoring system and has allowed to transform the collected data into useful information for museum referents in order to improve the installations and the communication, and also to optimally plan the attendance of the staff.

For an even more conscious reading of the data, the next step may be the comparison of the information obtained through this monitoring with other analysis sources, such as: ticketing data and user profiling, observant survey of visitor behaviour in certain scenarios or sample questionnaires given to visitors.

Thanks to a systematic collection of these data, it would be possible to develop a more comprehensive map of the behavior of the public within the museum spaces, providing museum service managers with valuable information on the user experience inside the museum as a whole, articulating the study of performance and the reconstruction of flows based on parameters such as age, origin, motivation of the visit and feedback issued.

The same analyses could also be extrapolated for more cultural containers in the city and also for places that host events and shows, such as those of the Macerata Opera Festival.

In this way it may be possible to understand performance and variations in the behaviour of the public also in the light of certain local recall events, obtaining information useful to build a plan of cultural marketing and tourism aware and consistent that connects the museums to other local cultural attractors.

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REFERENCES

Alletto, S., Cucchiara, R., Del Fiore, G., Mainetti, L., Mighali, V., Patrono, L., & Serra, G. (2015). An indoor location-aware system for an IoT-based smart museum. *IEEE Internet of Things Journal*, *3*(2), 244–253.

Bollo, A. (2004). Il museo e la conoscenza del pubblico: gli studi sui visitatori. *Bologna: Istituto per i Beni Artistici, Culturali e Naturali*, *20*, 2017.

Caglayan, A., Imamoğlu, N., Can, A., & Nakamura, R. (2020). When CNNs Meet Random RNNs: Towards Multi-Level Analysis for RGB-D Object and Scene Recognition. *ArXiv Preprint ArXiv:2004.12349*.

Chianese, A., & Piccialli, F. (2014). Designing a smart museum: When cultural heritage joins IoT. *2014 Eighth International Conference on next Generation Mobile Apps, Services and Technologies*, 300–306.

Del Fiore, G., Mainetti, L., Mighali, V., Patrono, L., Alletto, S., Cucchiara, R., & Serra, G. (2016). A location-aware architecture for an IoT-based smart museum. *International Journal of Electronic Government Research (IJEGR)*, *12*(2), 39–55.

Direzione generale Musei - MIBACT. (2019). *Piano Triennale per la Digitalizzazione e l'Innovazione dei Musei*. Retrieved from http://musei.beniculturali.it/wp-content/uploads/2019/08/Piano-Triennale-per-la-Digitalizzazione-e-l'Innovazione-dei-Musei.pdf

Gao, J., & Nevatia, R. (2018). Revisiting temporal modeling for video-based person reid. *ArXiv Preprint ArXiv:1805.02104*.

Gupta, S., Girshick, R., Arbeláez, P., & Malik, J. (2014). Learning rich features from RGB-D images for object detection and segmentation. *European Conference on Computer Vision*, 345–360.

Hermans, A., Beyer, L., & Leibe, B. (2017). In defense of the triplet loss for person re-identification. *ArXiv Preprint ArXiv:1703.07737*.

Karaman, S., Bagdanov, A. D., Landucci, L., D'Amico, G., Ferracani, A., Pezzatini, D., & Del Bimbo, A. (2016). Personalized multimedia content delivery on an interactive table by passive observation of museum visitors. *Multimedia Tools and Applications*, *75*(7), 3787–3811.

Lanir, J., Kuflik, T., Sheidin, J., Yavin, N., Leiderman, K., & Segal, M. (2017). Visualizing museum visitors' behavior: Where do they go and what do they do there? *Personal and Ubiquitous Computing*, *21*(2), 313–326. https://doi.org/10.1007/s00779-016-0994-9

Loghmani, M. R., Planamente, M., Caputo, B., & Vincze, M. (2019). Recurrent convolutional fusion for RGB-D object recognition. *IEEE Robotics and Automation Letters*, *4*(3), 2878–2885.

Luo, S.-S., Shedd, B. A., & Nanetti, A. (2018). Enhancing the Experience of the Western Xia Imperial Tombs Heritage Site (PRC, Ningxia) through Animated Installations. *SCIRES-IT-SCIentific RESearch and Information Technology*, *8*(1), 1–32. http://dx.doi.org/10.2423/i22394303v8n1p1

Martini, M., Paolanti, M., & Frontoni, E. (2020). Open-World Person Re-Identification With RGBD Camera in Top-View Configuration for Retail Applications. *IEEE Access*, *8*, 67756–67765.

McLaughlin, N., Del Rincon, J. M., & Miller, P. (2016). Recurrent convolutional network for video-based person re-identification. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 1325–1334.

MIBACT - Ufficio Statistica. (2019). Retrieved from http://www.statistica.beniculturali.it/Visitatori_e_introiti_musei_18.htm

Osaba, E., Pierdicca, R., Malinverni, E. S., Khromova, A., Álvarez, F. J., & Bahillo, A. (2018). A Smartphone-

Based System for Outdoor Data Gathering Using a Wireless Beacon Network and GPS Data: From Cyber Spaces to Senseable Spaces. In *ISPRS International Journal of Geo-Information* (Vol. 7, Issue 5). https://doi.org/10.3390/ijgi7050190

Paolanti, M., Pietrini, R., Mancini, A., Frontoni, E., & Zingaretti, P. (2020). Deep understanding of shopper behaviours and interactions using RGB-D vision. *Machine Vision and Applications*, *31*, 66. https://doi.org/10.1007/s00138-020-01118-w

Petrelli, D., Marshall, M., Not, E., Zancanaro, M., Venturini, A., Cavada, D., Kubitza, T., Schmidt, A., Risseeuw, M., & Van Dijk, D. (2016). mesch: Internet of things and cultural heritage. *SCIRES-IT-SCIentific RESearch and Information Technology*, *6*(1), 15–22. http://dx.doi.org/10.2423/i22394303v6n1p15

Pierdicca, R., Marques-Pita, M., Paolanti, M., & Malinverni, E. (2019). IoT and Engagement in the Ubiquitous Museum. *Sensors*, *19*, 1387. https://doi.org/10.3390/s19061387

Puma, P. (2016). The Digital Cultural Heritage-DigitCH Programme: experiences of documentation and survey for the smart fruition of archaeological heritage. *SCIRES-IT-SCIentific RESearch and Information Technology*, *6*(2), 151–164. http://dx.doi.org/10.2423/i22394303v6n2p151

Quattrini, R., Pierdicca, R., Paolanti, M., Clini, P., Nespeca, R., & Frontoni, E. (2020). Digital interaction with 3D archaeological artefacts: evaluating user's behaviours at different representation scales. *Digital Applications in Archaeology and Cultural Heritage*, *18*, e00148. https://doi.org/10.1016/j.daach.2020.e00148

Yoshimura, Y., Girardin, F., Carrascal, J., Ratti, C., & Blat, J. (2012). *New Tools for Studying Visitor Behaviours in Museums: A Case Study at the Louvre*. https://doi.org/10.1007/978-3-7091-1142-0_34