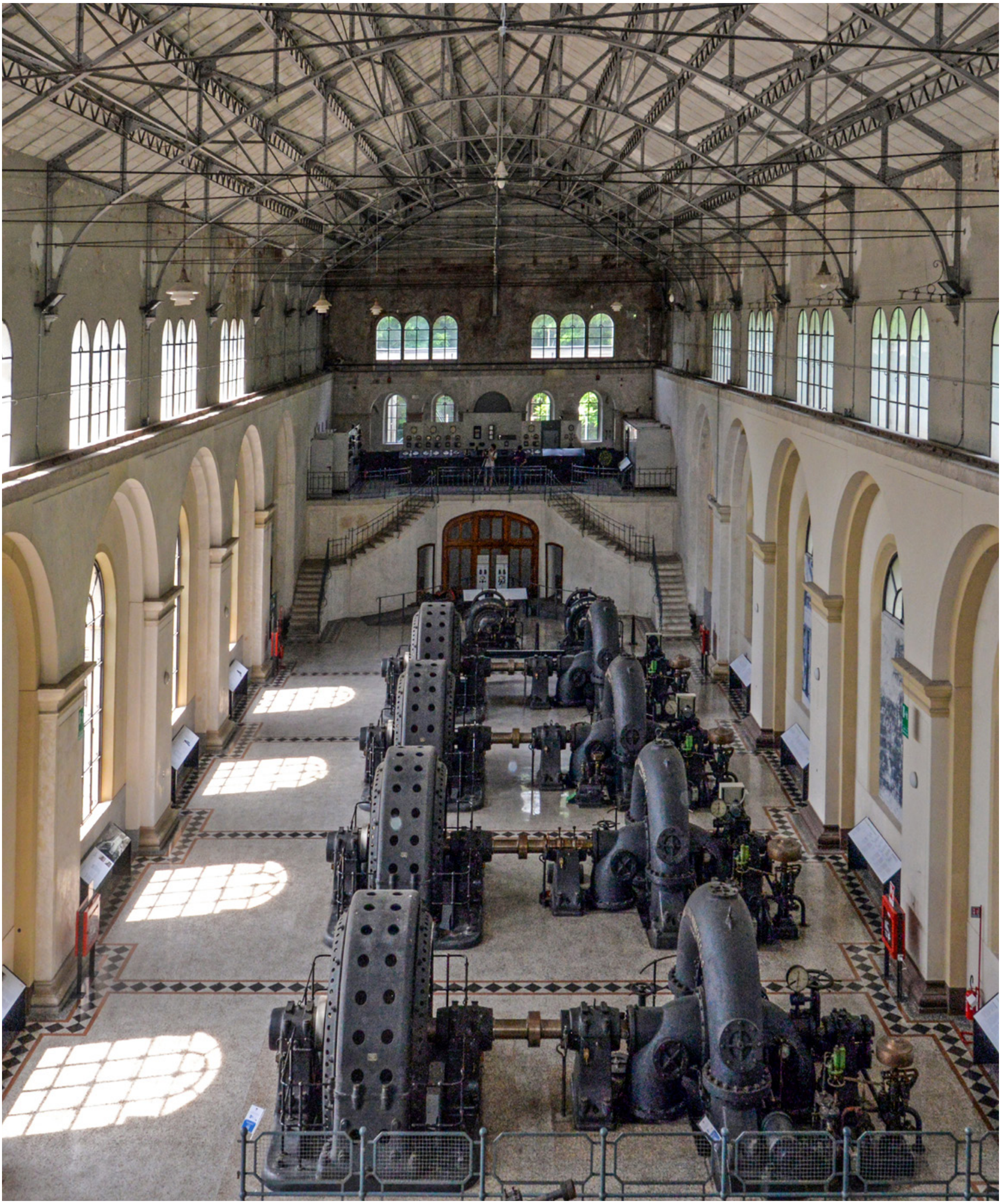

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SETTING AN EFFECTIVE USER REPORTING PROCEDURE TO ASSESS THE BUILDING PERFORMANCE

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Highlights

An overview of data acquisition from the users in architectural engineering is investigated.
Typical drawbacks and criticalities of the data acquisition from the users are expressed.
Eight steps to overcome the typical drawbacks and achieve effective *User Reporting* are proposed.
The presented *User Reporting* approach is applied to the building diagnostics in the Valencia region (Spain).
A set of 131 buildings are investigated and the intervention and maintenance priorities are defined.

Abstract

The importance of acquiring information from users to support the phases of the building process (design, construction, management and dismantling) is widely recognized by the scientific and technical community.
In addition, in the era of the "Digital Transition" in building construction, participatory-sensing systems leveraging smart devices offer unprecedented observational capacity at the scale of the individual.
On the other hand, data acquired by the users are typically characterized by multiple actors, many and often conflicting values and views, a wealth of possible outcomes and high uncertainty. Despite the widespread use of "user data acquisition" techniques, there are no procedures and guidelines to create effective user reported-based data acquisition in the building construction sector.
This paper proposes eight steps to set an effective *User Reporting* and overcome the classical drawbacks of data acquired by users for the inspection of technical and factual features. In particular, steps 1-2 a priori identify clusters of stakeholders and users to improve data homogeneity; steps 3-4 select technological tools, questionnaires and guidelines to independently acquire data from different clusters of users; steps 5-8 define the information flow, the validation approach and diagnostics.
In order to show the potentiality of the proposed approach, the *User Reporting* is applied to the building diagnostics of 131 RC buildings located in the Valencian coast (Spain).

Keywords

User Reporting, Building pathologies, Building performance, Visual survey, Maintenance Optimization.

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1. INTRODUCTION

The acquisition of information from users is an effective instrument widely employed in the building construction sector. Indeed, the direct involvement of the users generates continued insight and knowledge [1] that can have a positive influence in all the phases of the building process (*design*, *construction*, *management* and *dismantling*). Beyond the application field in a specific building phase, different typologies of information can be acquired from the users: i) their perception; ii) qualitative and quantitative information that can be detected through a visual survey; iii) specific measurements acquired exploiting the increasingly high-performance and technological smart devices (e.g. photo, video, audio, temperature, accelerometer registration).

In recent decades, the advent of the "Digital Transition" of the building sector brought benefits also in the field of the data acquired from users. Indeed, some authors included advanced techniques of "participatory sensing" to acquire data from the users. Participatory sensing is "the process whereby individuals and communities use ever-more-capable mobile phones and cloud services to collect and analyze systematic data for use in discovery" [2]. In particular, an effective possibility to bring together the user reports (qualitative and quantitative data) and the technicians' experience is offered by the use of participatory sensing data supported by smart devices and web-based platforms [3–6].

The mobile and smart devices allow amplifying and speeding up the acquisition process to carry out analysis on a very large scale. On the other hand, if these tools are applied without a precise procedure and attention to the data flow, quality and inconsistencies could also be amplified and compromise the analysis [7]. The principal drawbacks and criticalities of the data acquisition from the users are listed as follows: i) multiple actors with different levels of knowledge, ii) many and often conflicting values and views iii) information reported by non-experts. In this context, a structured procedure to limit and overcome the typical drawbacks of the user's report would be very useful in both the scientific and technical world.

In the proposed work, the term *User Reporting* specifies the acquisition of the different information typologies from the user in a structured way. The acquired information can include on-site visual inspection, questionnaires and other information obtained by using smart devices "participatory sensing". In particular, this paper proposes eight steps to set an effective *User Reporting* data acquisition procedure in order to overcome or limit the principal drawbacks of this process for the specific acquisition of technical and factual features. The narrowing of the field of investigation to the technical aspects allows more specific and quantitative control of the results, avoiding possible misinterpretations of the reports. In order to show the potential of the proposed approach, the presented *User Reporting* procedure is applied to the building diagnostics of 131 RC buildings located in the Valencian coast (Spain) by exploiting a participatory-sensing system and suitable KPIs (Condition Ratings).

The paper is organized as follows: Section 2 presents the state of the art. Section 3 shows the overview of the approach and explains how this approach can overcome existing drawbacks. Section 4 explains the eight steps to set an effective *User Reporting*. Section 5 shows the application of the approach in the context of building construction performances and management. Section 6 draws conclusions.

2. LITERATURE REVIEW

The literature review firstly faces the general theoretical frameworks of data reported by the users; secondly, it discusses how the building process can benefit from such an acquisition process; thirdly, it discusses the actual drawbacks of the related literature for the application of the *User Reporting* in the construction field.

2.1. THEORETICAL FRAMEWORK

User Reporting is the process whereby users of buildings or inhabitants can report objective or subjective information based on on-site visual inspection, specific questionnaires and the support of technological tools [3]. In the last decades, data reported by the user have aroused the interest of the academic and technical world for the enormous potential of the available data. Indeed, the widespread use of mobile devices offered unprecedented observational capacity and allowed the theorization of participatory sensing to improve user reporting [8]. In 2021, the number of people that own a smart and feature phone is 4.88 Billion, making up 62.11% of the world's population [9]. This great reporting potential was initially exploited in urban planning, public health, cultural identity, creative expression, and natural resource management. But in a few years, the user reporting supported by mobile devices became fundamental in many fields of research, including building construction [10, 11]. A complete overview of the theoretical framework and applications of the "Human-Powered reporting" is developed by Guo et al. [12]. In particular, the review of Guo et al. proves the importance of establishing effective procedures for the application of user reporting in each specific application field.

2.2. USER REPORTING IN THE BUILDING PROCESS

The data reported by the users can have a positive influence in all four phases of the building process (*design*, *construction*, *management* and *dismantling*), as discussed in the following.

In the *design* phase, the user perception is fundamental in the early stages of design, when users' needs and expectations are being expressed [13]. In the related literature, the direct acquisition of information from users is considered an essential procedure to develop an inclusive design or a participatory design [1, 14].

In the phases of building *construction* and *dismantling*, the users can report smog, noise or dust deriving from a construction or demolition site in their neighbourhood [15]. This tool can be very effective for improving sustainability, reducing interference and criticism of the construction site, and improving the construction organization process.

Regarding building *management*, the information acquirable by the users can be useful for different purposes. Some authors developed sustainability reporting tools to assist in the management of "green" building/infrastructure [15–17], including the investigation of the user's subjective views and needs [18, 19]. Other researches investigate the social influence, behavioural uncertainty [20] and large-scale data acquisition for the purpose of the multi-risk assessment [21–23], also exploiting the user reports for the monitoring and protection of the artistic and architectural heritage [24].

2.3. MAIN DRAWBACKS OF THE USER REPORTING IN THE BUILDING PROCESS

Even if acquiring information from the users is widely employed in the technical and research world, several drawbacks need to be solved. The main problems related to the user reporting in the building process are reported as follows [12]:

i) Data acquired by the users are typically composed of multiple actors with different levels of knowledge, hence considering all the information together leads to errors in the homogeneity of the data.
ii) Many and often conflicting values and views (deriving from the different skills and backgrounds of the diverse users) could affect the data.
iii) A wealth of possible outcomes and high uncertainty in the acquired data could occur specifically for the information reported by non-expert users.

3. OVERVIEW OF THE METHODOLOGY

The eight steps to set an effective *User Reporting* are defined as follows: 1) identification of the stakeholders, 2) definition of the users, 3) selection of technological tools, 4) creation of questionnaires and user guidelines, 5) definition of the flowchart, 6) data acquisition 7) data processing and validation, 8) data analysis.

In particular, every step contributes to overcoming a specified drawback defined in the literature review. The three defined drawbacks can be faced as described in the following by applying the proposed eight steps:

i) In the *User Reporting* procedure, stakeholders and users are identified a priori and grouped on the basis of the different levels of knowledge and numerosity (cluster of users). In this way, it is possible to identify the quality and quantity of reportable information, classifying them independently in order to overcome the issue of the data homogeneity (steps 1 and 2 of the *User Reporting*).

ii) The technological tools are specifically selected on the basis of different users (e.g. expert users, non-expert users). In addition, different questionnaires can be calibrated on the basis of the different skills and backgrounds of the cluster of users. This part of the procedure allows acquiring data from different clusters of users separately by reducing the problem of conflicting values and views which cannot be simultaneously analyzed (steps 3 and 4 of the *User Reporting*).

iii) The definition of a flowchart allows designing the overview of the acquisition process, defining the rules of stakeholders and users and the information flow. In particular, during the data acquisition, data processing and data analysis, effective *User Reporting* should allow selecting and checking the quality of the information in every step. The validation can be carried out in a qualitative way (having the information of non-expert users corrected by technicians) or quantitatively by inserting specific key performance indicators (KPIs) [23] (steps 5, 6, 7 and 8 of the *User Reporting*).

4. USER-REPORTING IN BUILDING CONSTRUCTION

This section describes the eight steps to set an effective User-Reporting in the management phase of the building process. Note that, preliminarily, it is fundamental to define the purpose of user reporting, the necessary information to be acquired, and any KPI or multi-criteria decision method to be included in the approach.

4.1. DEFINITION OF STAKEHOLDERS

The stakeholders are individuals or groups of people who have an interest or some kind of interest in the faced problem. The identification of stakeholders typically starts with brainstorming. It is important to identify all the people who could be involved in the *User Reporting*, who could support the data acquisition, validation, analysis of the building performance, or have an interest in the result of the analysis. The list of potential stakeholders could include municipal technical office, administrators, companies, different typologies of building users, building staff, development/engineering/manufacturing, services, consultants, etc.

Once the stakeholders are identified, it is necessary to classify them into different clusters. A *Power/Interest Grid* [25] is a powerful support to map out the stakeholders and can be effectively used to classify them according to their "power" over the *User Reporting* (left part of Fig. 1). The position of a stakeholder on the grid shows the actions that it is necessary to take with them:

High power, highly interested people (Manage Closely): it is important to fully engage these people and make the greatest efforts to satisfy them.

High power, less interested people (Keep Satisfied): it could be useful to put enough work in with these people to keep them satisfied.

Low power, highly interested people (Keep Informed): these people should be adequately informed, and their opinion needs to be considered to ensure that no major issues are arising.

Low power, less interested people (Monitor): these people can be monitored, but it is not recommended to provide them excessive communication.

4.2. DEFINITION OF USERS

Once the stakeholders are specified, it is important to define the clusters of users. The users are individuals or groups of people who are identified among the stakeholders for their characteristics of being able to provide useful information (good quantity and quality) during the user reporting. A correct clustering of the users (based on different levels of knowledge, quality and quantity of reportable data) is crucial to carry out the successive steps of the User Reporting effectively.

Following the footsteps of the stakeholder analysis [25] this paper proposes the *Numerosity/Expertise grid* to create and classify clusters of users according to their levels of knowledge and numerosity (right part of Fig. 1).

1. High numerosity, high expertise: This is the most important category of users, essential for large-scale data acquisition. Indeed, such a category is able to provide a large amount of reliable data.

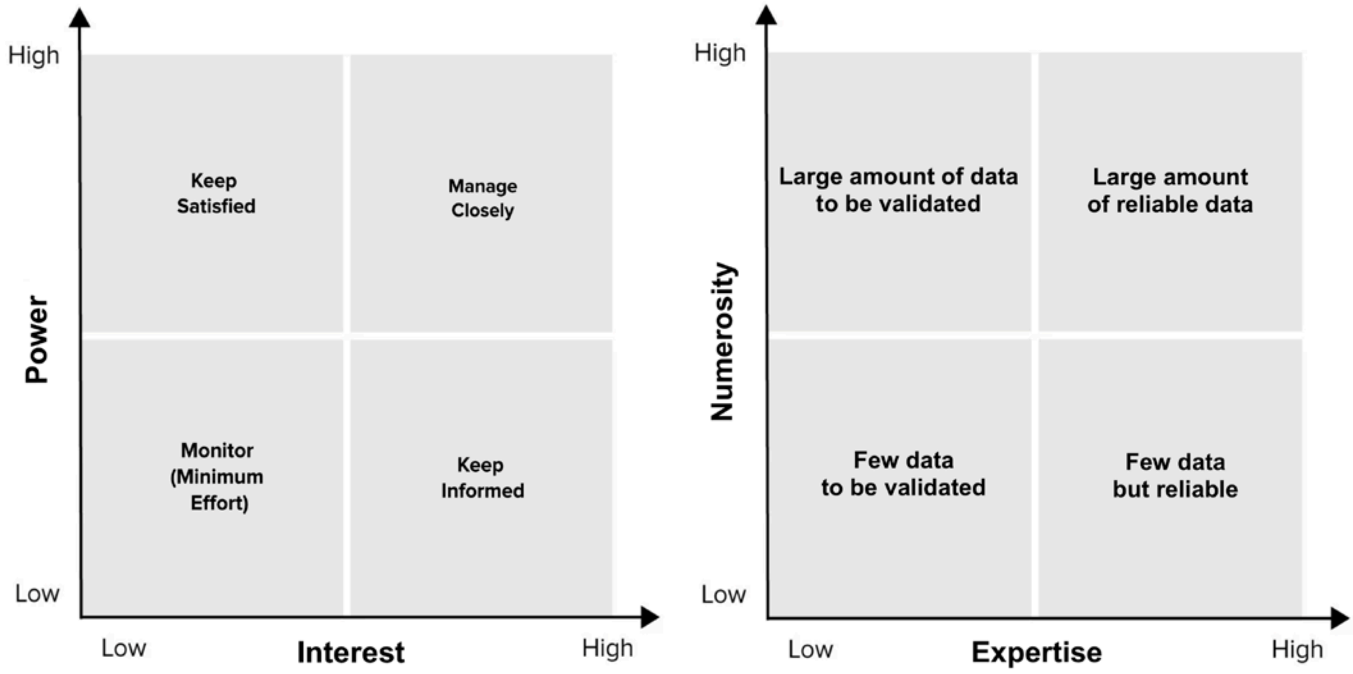

Fig. 1. *(left) Power/interest grid to support the stakeholders classification, (right) Numerosity/Expertise grid to support the users clustering.*

2. High numerosity, low expertise: This category of user does not have the expertise to provide totally reliable data. On the other hand, these users become important for acquiring a large amount of data in the absence of users classified in the first category, "High numerosity, high expertise".
3. Low numerosity, high expertise: Even in this case, this category of user becomes important in the absence of the first category. Indeed, this class is able to provide reliable data even if the number of users does not allow a large-scale acquisition.
4. Low numerosity, low expertise: This category classifies all the users who are unable to provide neither reliable data nor large quantities of them. To this aim, this category must be involved in data acquisition only in cases of lack of other types of stakeholders.

In a user reporting procedure, when highly interested people match with an important category of users, the user information and rewards become important to ensure that users continue reporting constantly and effectively the building criticalities. A notification that the report has been taken charge or that an on-site intervention has been carried out gratifies the user for the reporting and encourages him to make new ones.

4.3. SELECTION OF TECHNOLOGICAL TOOLS TO SUPPORT THE ACQUISITION

The technological tool can provide important support in the data acquisition process. Among the numerous technologies that can support the data acquisition, the choice can be guided by the users clustering obtained with the *Numerosity/Expertise grid*.

In particular, the technology can improve the "*Numerosity*" (*quantity* of users who can report data) or improve the "*Expertise*" (*quality* of acquired information) of the user during the data acquisition.

To improve the "*Numerosity*", *smart devices* can be used together with specific application software to reach a large number of users and increase the quantity of the collected data (participatory sensing).

To improve the "*Expertise*" and consequently the quality of the acquired data, the *smart devices* can provide useful information, specific questionnaires and a guided data acquisition process. To provide some examples, the *User Reporting* can be correlated with photo, video, audio, accelerometer registration, temperature, geolocation and other quantitative information by using *smart devices* [26, 27].

4.4. CREATION OF QUESTIONNAIRES AND USER GUIDELINE

The creation of the questionnaires is strictly dependent on the *User-Reporting* purpose. Indeed, the questionnaires are developed to acquire the information required to use any KPI or multi-criteria decision methods.

The questionnaire needs to follow two guidelines:

i) It is fundamental that a specific questionnaire is developed for every cluster of users in order to calibrate the questions on the basis of the skills and background of the users.

ii) If specific KPIs are used to analyze the investigated buildings, the information needs to satisfy the data required for the KPI calculation.

4.5. DEFINITION OF THE FLOWCHART OF THE USER REPORTING

After the questionnaires are expressed, the flowchart describing the whole *User-Reporting* procedure can be defined. A correct flowchart offers the possibility to clarify all the steps of the procedure to better specify the connection among the technological tools, the users and the stakeholders by using the Unified Modeling Language (UML) framework [28]. In particular, the UML activity diagram is a kind of flowchart that includes Start node, Action states, Control Flows, Decision nodes, Forks, Joints and End listed in Figure 2.

4.6. DATA ACQUISITION

Once the flowchart is stated, the operative data acquisition can start. In this phase, it is important to include in the acquisition process-specific registry data in order to correctly storage the information of the users and the investigated buildings:

i) The users need to provide personal data and information about the expertise level for the effective classification of the information.

ii) For every investigated building, specific registry data should be acquired to describe the geographical, geometric, morphological and constructive features of the building, including design prescriptions, reference building codes, and possible constructive details.

This data, together with the questionnaires and the additional information obtained with the technological tools, complete the "User-Reporting" supported data acquisition process.

4.7. DATA PROCESSING AND VALIDATION

In the data processing, all the information is stored in a database by considering the clusters of users and the registry data of the building to associate every report to a specific component of the construction.

In this step, a validation procedure is required in the eventual reporting of "*low expertise*" clusters of users. The validation can be performed by the *high expertise* cluster of users (e.g., technicians, building staff, services, consultants) that check the information acquired by the *low expertise* clusters.

4.8. DATA ANALYSIS

In the data analysis step, the KPIs or multi-criteria decision methods are used to quantitatively evaluate the acquired data and aggregate all the results in a final output (statistical graph or overall building performance indicators).

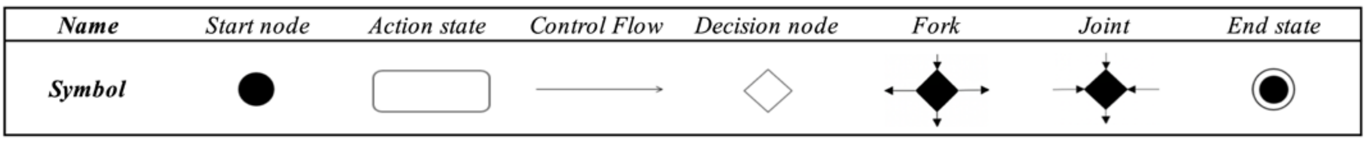

Fig. 2. *Start node, Action states, Control Flows, Decision nodes, Forks, Joints and End state to define flowchart of the User Reporting.*

5. USER-REPORTING TO SUPPORT BUILDING MAINTENANCE AND DIAGNOSTICS IN THE VALENCIAN REGION

The proposed eight steps to set an effective *User Reporting* are applied to the building performance analysis and maintenance of reinforced concrete (RC) buildings located in the coastline of the Valencian region (Spain). The building typology used in these areas is the apartment block, although there are also many terraced houses. The structure of the buildings is usually made with RC frames and generally precast joist slabs [29, 30].

The purpose of the *User Reporting* is to support the diagnostics of these buildings and provide a continuous acquisition of data. These data can support the diagnosis of damage and pathologies that in this zone is principally related to the aggressive marine environment [30]. This case study is particularly effective to show how the proposed procedure can narrow down the problems of the user's subjective contribution, bringing it back to an objective and deterministic datum. Indeed, the acquired information is elaborated thanks to specific KPIs, defined and calibrated in Sangiorgio et al. [3, 31] through an optimized multi-criteria decision method [21]. Such KPIs are useful to quantify the state of conservation and the pathologies of the buildings exploiting the following four criteria:

i) *Damaged component*, i.e., the importance of the damaged component (for instance Beam, Column, Floor slab);
ii) *Damage extension*, i.e., the damage extension in relation with the component dimension expressed in percentage (damage extended for the 10%, 20%, 30% of the element);
iii) *Damage severity*, i.e., the gravity of the damage (for instance, thin cracks, medium cracks, wide cracks);
iv) *Component Position*, i.e., the position of the component based on the floor in which it is located (for instance, first, second, and third floor).

By using these criteria, the KPIs can be evaluated in the range (0–10) where 10 corresponds to the state of critical condition. In addition, the KPIs set is defined to identify the conservation state of every single building component, the conservation state of a class of components (e.g. Beam, Column, Floor slab) and the whole condition of the building by aggregating all the single damages detected in the same building [3, 31, 32].

5.1. THE STAKEHOLDERS INVOLVED IN THE VALENCIAN USER REPORTING

In the first step, the stakeholders are defined and classified according to the *Power/interest grid* as follows.

High power, highly interested people are identified in *Building technicians* and *Expert Users* of the Buildings (e.g. professionals and inhabitants with basic competence in the construction field).

High power, less interested people are recognized in *Local Public Authorities*.

Low power, highly interested people are identified as *Non-expert Users* of the buildings.

Low power, less interested people are represented by local residents but not users of the investigated buildings (neighbours).

Among these identified stakeholders, the most important clusters are the *Building technicians, Expert Users* and *Non-expert Users* since they can be actively involved in the *User Reporting*.

5.2. DEFINITION OF USERS INVOLVED IN THE VALENCIAN USER REPORTING

Starting from the stakeholders, potential Users are defined and classified according to the

Numerosity/Expertise grid as follows.

High numerosity, high expertise users are not present in this case study.

High numerosity, low expertise users can be represented by the *Non-Expert Users* of the building that are able to provide a large set of data to be validated.

Low numerosity, high expertise users are identified in two potential classes: *Building technicians* and *Expert Users*. The number of these users is not high, but they can provide reliable information.

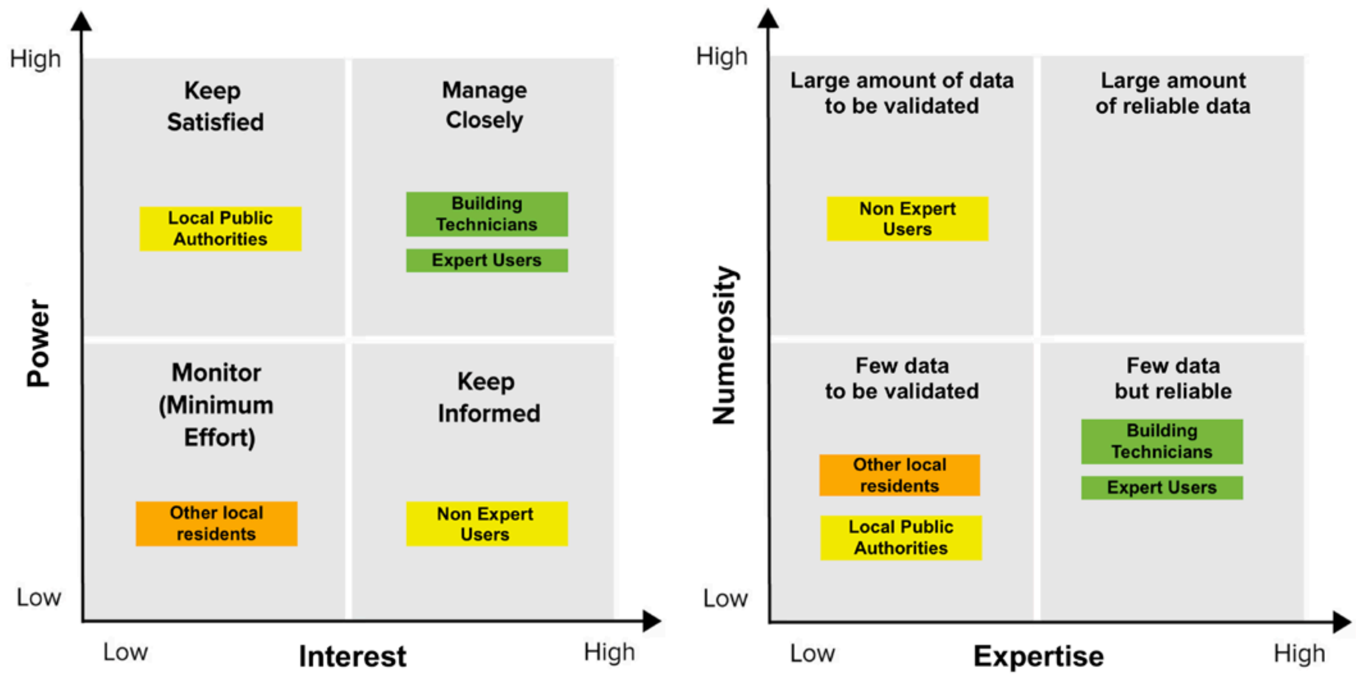

Fig. 3. *(left) Power/interest grid used to classify stakeholders, (right) Numerosity/Expertise used to cluster users.*

Low numerosity, low expertise users can be represented by other local residents that cannot be able to provide useful information because they do not live or work in the considered building (neighbours).

Fig. 3 shows the *Power/interest grid* on the left and the *Numerosity/Expertise grid* on the right for the case of the Valencian building diagnostics. Note that among the identified stakeholders, *Non-Expert Users, Expert Users* and *Building technicians* are considered supportive of the *User Reporting*.

5.3. SMART DEVICES AND WEB-BASED PLATFORM TO SUPPORT THE DATA ACQUISITION

Among the available technological tools for the proposed *User Reporting*, an application (APP) for mobile devices and a suitable Web-Based Platform, named *Quality Detection Platform* (QDP), can be used to support the Valencian building diagnostics. In particular, the APP is developed for the operative system of "Android", and the main characteristics and functions are: login system, registration system with email verification, server and host in Italy, security protocol https, photo shoot from front and rear cameras or images selection from phone's library, geolocation, possibility to answer specific questionnaires, sending the report (both Wi-Fi and broadband cellular network) and notification system. By exploiting the *Numerosity/Expertise grid,* the operators of the APP are identified in the *Expert Users* and *Non-Expert Users* of the building. In this way, the technological tool is able to extend the *quantity* of reported information (involving a larger number of users) and improve the *quality* of the information by developing specific questionnaires, guidelines and allowing photographic survey acquisition.

On the other hand, the users of the QDP are *Building technicians*. This platform is useful to validate the data through a visual check from the *Building technicians* and automatically calculate the KPI for the diagnostics and prioritization of interventions.

5.4. CREATION OF QUESTIONNAIRES AND USER GUIDELINE

The APP can be employed by the building users to report their visual inspection, i.e., photos and other useful information about the building's damages. The APP is based on two main operations: photographic shoots and compilation of a guided questionnaire. The photographic shoot enables the users to send images about the

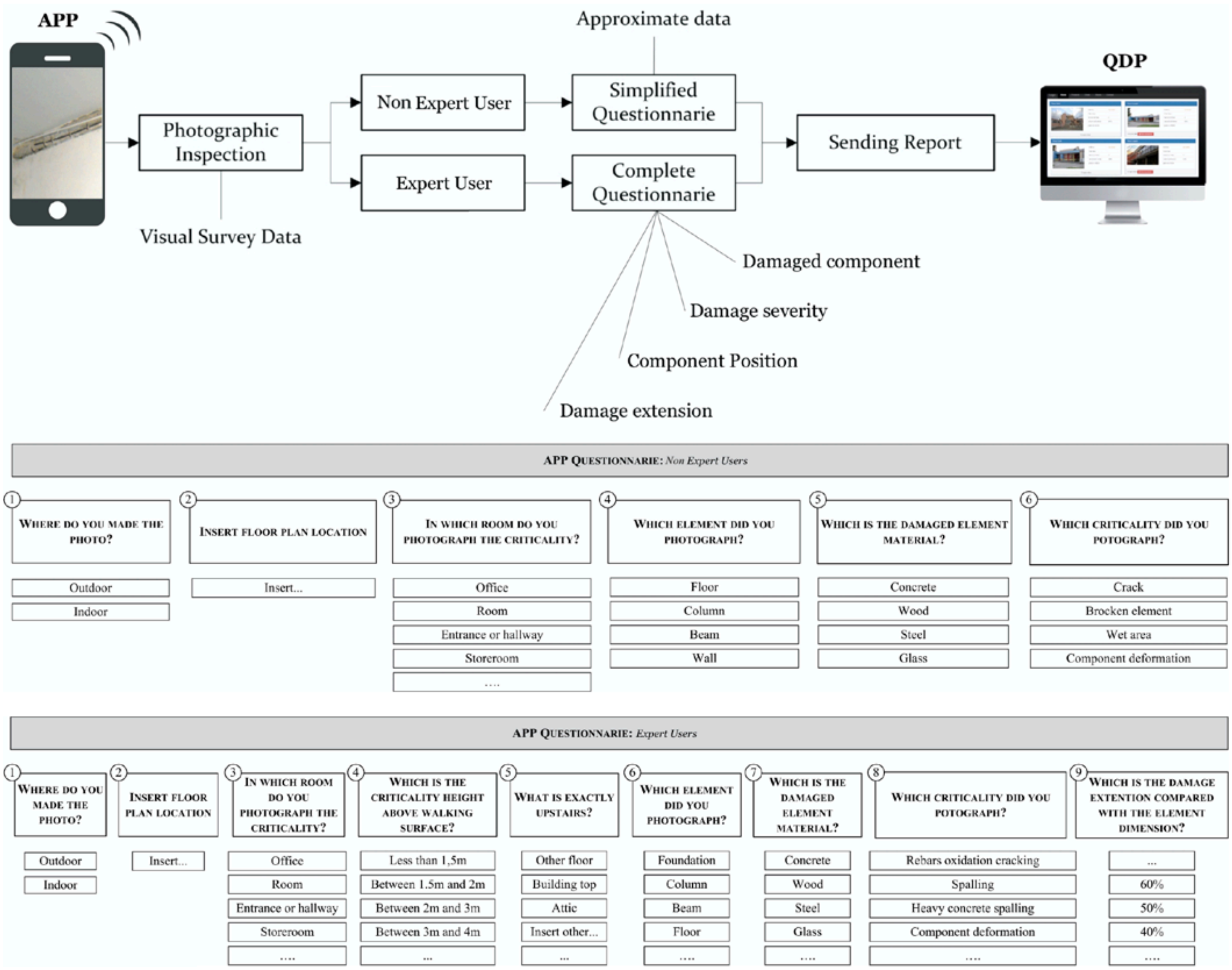

Fig. 4. *APP, Quality Detection Platform and questionnaires.*

criticalities equipped with labels indicating the localization and the date of the picture. Moreover, in order to complete the description, two alternative questionnaires are proposed to guide the user and correctly identify additional data involved by the reported damage. The first one is a structured questionnaire simple and calibrated for non-professional people (*Non-Expert Users*), and the second one is a semi-structured questionnaire designed for people with specific competencies in the building field (*Expert Users*). The semi-structured questionnaire is provided to the expert user to allow including other important information regarding the pathologies. To provide an example, in expert question number 5 (Fig. 4), the user can express his idea of what is present upstairs that can be connected to the reported criticality. On the other hand, this possibility is not granted to non-expert users to avoid a large number of unstructured and non-expert information, difficult to classify automatically in the QDP.

Note that the main purpose of the questionnaires is to acquire the necessary information to use the KPIs (i.e., Damaged component, Damage extension, Damage severity and Component Position). A scheme of the APP, questionnaires and QDP, together with an example of the two questionnaires (*Non-Expert Users* and *Expert Users*), are shown in Figure 4.

5.5. DEFINITION OF THE FLOWCHART OF THE USER REPORTING FOR VALENCIAN BUILDINGS

At this point, the stakeholders, users, technologies and questionnaires are defined. Consequently, a UML activ-

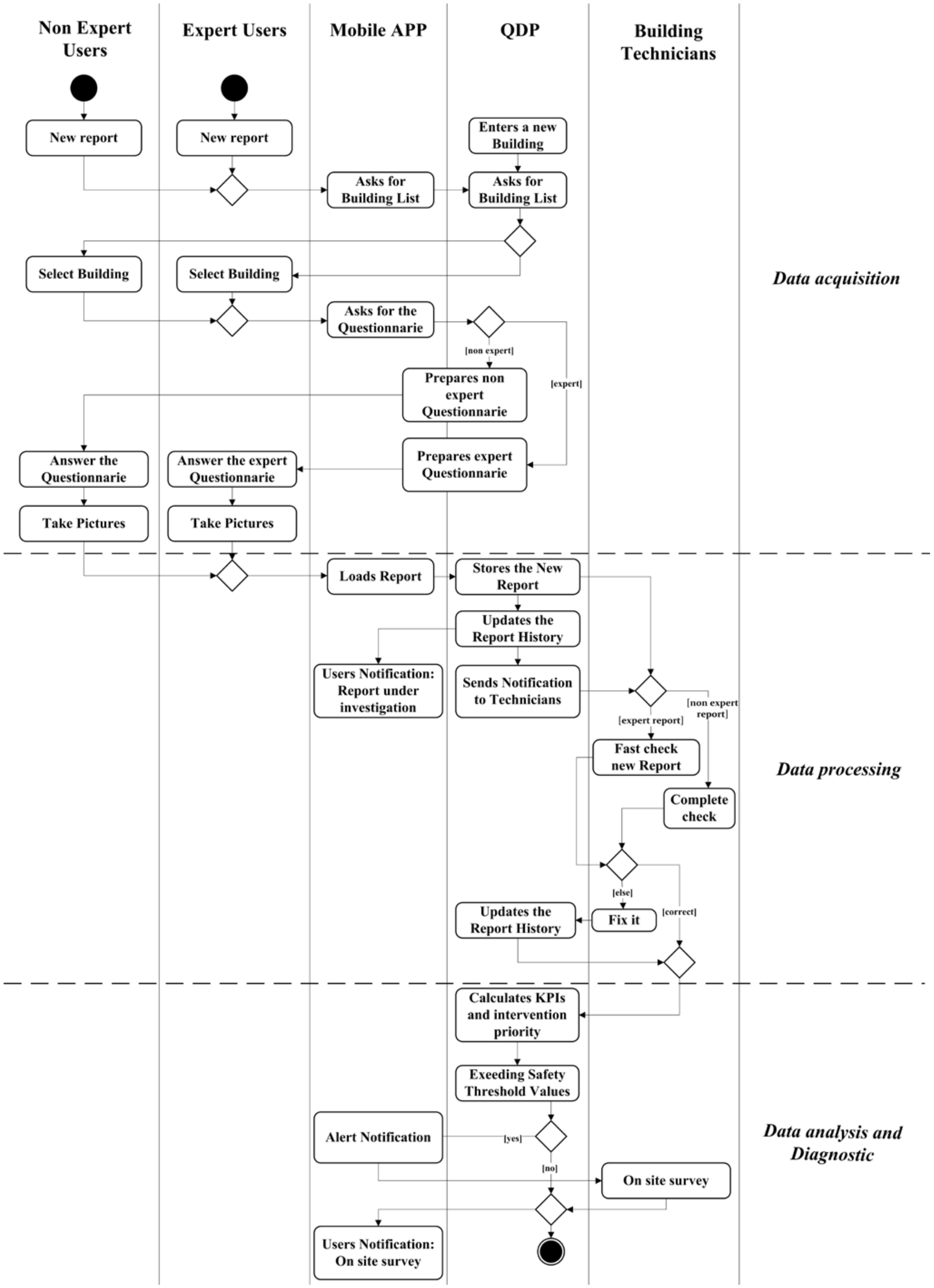

Fig. 5. *UML activity diagram of the Valencian User Reporting procedure.*

ity diagram of the procedure can be sketched to clarify the whole process of the *User Reporting* for the proposed application (Fig. 5). The UML activity diagram reports in the columns the cluster of users and technologies that perform the actions listed in the corresponding columns.

In the data acquisition, the APP selects the expert or non-expert questionnaires on the basis of the typology of users (expert or non-expert). In addition, in the data processing, the building technicians check all the user reports. It is worth noting that the visual check of the technicians is of basic importance in the proposed procedure for validating both expert and non-expert reports. In particular, reports sent from expert users need only a fast visual check. On the other hand, the reports of non-expert users require the technician to carefully check data and complete the information that can not be provided by the simplified questionnaire (e.g. damage extension).

Finally, in the data analysis, the KPIs are evaluated, and the intervention priority is defined. In addition, if some KPIs overcome specific threshold values, the building technicians are asked to perform a prompt on-site survey.

Note that when a report is correctly stored or when the report has led to an intervention on-site, a notification is sent to users to inform them and to show that the report has led to an intervention.

The operative steps of Data acquisition, Data processing and Data analysis (steps 6, 7, 8 respectively) are discussed in the following subsections.

5.6. DATA ACQUISITION OF THE VALENCIAN BUILDINGS

The operative data acquisition starts by filling suitable Registry Tabs to include registry data of each investigated building [33], including nine sets of data: general data, characteristic data, dimensional data, original project availability, intervention or modification, structural intervention, vulnerability assessment, technical reference code, and other information. Successively, the *User Reporting* can start, and the users can send reports and damages inspections with the support of the APP.

5.7. DATA PROCESSING AND VALIDATION

The user reported data are processed in the QDP, and technicians can check and validate the reports by reading, editing or deleting the information. For the expert reports, the Technicians display the photographic inspections and verify that the user correctly reported the information about *Damaged component*, *Damage extension*, *Damage severity* and *Component Position*. On the other hand, for non-expert users, the reported information is indicative (e.g. *Damage severity*: Spalling), and the technicians need to identify the specific information (e.g. *Damage severity*: Heavy concrete spalling) among a predefined list [31], exploiting the user's photographic inspections.

Once the checking is complete, information can be stored in a suitable database by preparing the parameters useful to evaluate the KPIs. The complete description of the *KPI* calibration and calculation is reported in [31]. In the following, a concise description of the procedure to evaluate *KPIs* is presented. Let us consider a generic component "*e*" and its detected damages $d=1,\ldots,\Delta$. Now, v_i and w_{ij} are the weights associated with the criteria i and w_{ij} the reportable parameters, respectively. Table 1 shows an extract of such weights.

At this point, the single damage D_d is obtained by the following equation:

$$Dd = \Sigma_i V_i \times W_{ij} \quad (1)$$

Moreover, by acquiring a large set of damages *Dd* on the building, it is possible to evaluate the state of conserva-

Criteria	v_i	Reportable parameters	w_{ij}
Damaged component	v_1=0.10	Ground floor	$w_{1,10}$=6.1
		Balcony or projection	$w_{1,11}$=5.5
		Curtain wall	$w_{1,12}$=2.4
Damage extension	v_2=0.43	100%	$w_{2,1}$=10
		90%	$w_{2,2}$=8.3
		80%	$w_{2,3}$=6.2
Damage severity	v_3=0.44	Cracks and rebar oxidation	$w_{3,1}$=2.1
		Spalling	$w_{3,2}$=3.9
		Heavy concrete spalling	$w_{3,3}$=8.8
Position	v_4=0.03	First or second floor	$w_{4,1}$=10
		Third or fourth floor	$w_{4,2}$=6.2
		Other floor	$w_{4,3}$=1.1

Tab. 2. *Example of weights [31].*

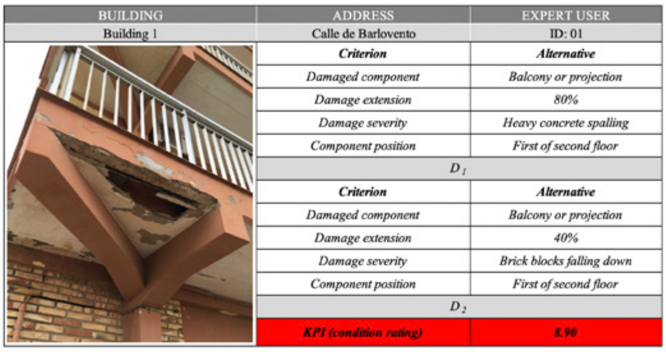

Fig. 6. *Example of Report and KPI evaluation according to Sangiorgio et al. 2019 [3, 31].*

tion of specific component *e*, class of components and of the whole construction through three KPIs:

i) The *Condition Rating* (*Cr*) that aggregates the damages of every specific element e by using a kind of weighted sum of *Dd*;

ii) The *Component Condition Rating* (*CCr*) that aggregates the damages of every specific class of component by using a weighted sum of *Dd*;

Slight damage	Medium damage	Serious damage
Green	Yellow	Red
KPI < 3	3 < KPI < 5	KPI > 5

Tab. 2. *The threshold values: numerical range, qualitative expression a corresponding colour.*

iii) The *Building Condition Rating* (*BCr*) that aggregates all the damages of a single building by using a weighted sum of *Dd* to achieve a global condition overview.

To provide an application example, Fig. 6 shows the report of two damages surveyed by an expert user on the balcony of the first floor of the "Building 1": D1) a *Heavy concrete spalling* extended on the *80% of the balcony, D2) broken brick blocks falling down* extended on the *40%* of the *balcony*. Consequently, the combination of these damages D_1 and D_2 allows achieving the KPI (*Cr*) of the considered *Balcony or projection*.

Fig. 7. *Schematic image representing User Reporting and the prioritization of interventions.*

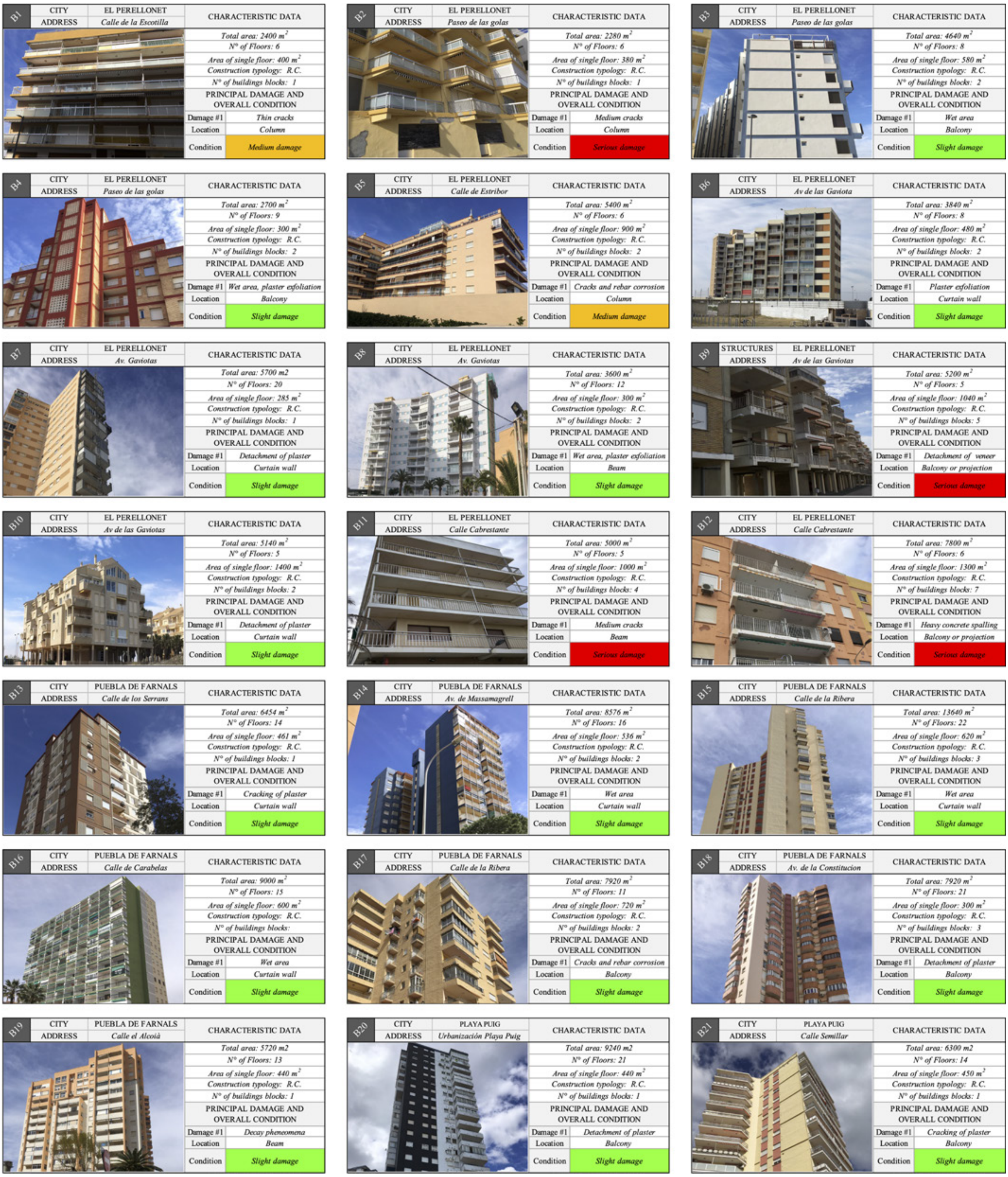

Fig. 8. *Summary tabs of 21 of the 131 investigated buildings, including information extracted from the Registry Tabs, principal damage reported and overall condition of the structures.*

5.8. DATA ANALYSIS AND INTERVENTION PRIORITIES

Once the check is complete, the *KPIs* can be calculated for every single component, class of components and for classifying all the considered buildings. In addition, specific limit values are identified in Sangiorgio et al. [34] for every *KPI* by associating the numerical range to a qualitative expression and a colour representing the condition severity (green, yellow and red). An example of the threshold values to classify the global condition of the building used in this case study are reported in Table 2. The verification of the overcoming of specific threshold values is automatically performed by the QDP during the data analysis.

In the example of Figure 6, the obtained KPI is equal to 8.9 and is classified as serious or critical damage (red colour). This value of KPI suggests a prompt on-site survey and intervention. Once the user reporting is fully operational and numerous reports are processed in the QDP, all the received reports can be analyzed to identify the intervention priority. Figure 7 schematizes the aggregation of the reports to obtain the intervention priorities.

In conclusion, to provide an example of the *User Reporting* result, the summary tabs of 21 of the 131 investigated buildings are shown in Fig. 8. The summary tabs include: the principal building characteristics data (extracted from the Registry Tabs), the major damage of the building reported by the users and the qualitative expression of the overall condition of the structures (obtained on the basis of the KPI: *Building Condition Rating*).

6. CONCLUSIONS

This work proposes eight steps procedure to set an effective *User Reporting* process in building construction to define the maintenance and intervention priorities at a large scale. The proposed *User Reporting* procedure allows the acquisition of technical and factual features including: i) qualitative and quantitative data through on-site measurement carried out directly by the users; ii) other specific measurements reportable by using modern technological tools and smart devices (e.g. photo, video, audio, temperature, accelerometer registration). In conclusion, the resulting eight-step procedure could be used by researchers, engineers and public authorities in order to perform user-reporting supported performance analysis with different purposes (sustainability, risk, environmental impact, social impact). Future research will modify the eight steps of the *User Reporting* to interpret not only technical features but also to investigate users' subjective views on more complex aspects. In this context, the non-expert users assume greater impotence and need to be clearly understood. A complementary approach will be proposed to investigate aspects such as the quality and use of the inhabited space, the risk perception connected to residential building criticalities and other qualitative aspects that can be very useful in all the phases of the building process.

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