



Situational assessment of hospital facilities for modernization purposes and resilience improvement

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ABSTRACT

Modernization of hospital facilities is one of the objectives of administrators and decision-makers of healthcare systems. Hospital facilities are both complex and critical infrastructures, because they are characterized by high level of interconnections, dynamism, technological innovation, and because they offer health and social essential services. Decision-makers have to implement modernization strategies of hospital facilities in order to guarantee a high standard of care and a resilient response during disasters and emergencies. The critical role played by hospital facilities is acknowledged by the international action programs, including the 2030 Agenda of United Nations for Sustainable Development, and it has been emphasized by the COVID-19 pandemic.

The paper illustrates the RADAR-Hospital Facilities methodology (RADAR-HF) developed for the situational assessment of the physical environment of hospital facilities. RADAR-HF provides the decision-makers with an overview of the main aspects for modernization (safety, functionality, sustainability, adaptability, comfort) and substantial information for planning interventions, considering hospital facilities as interconnected systems. The outcomes are represented by ad-hoc designed graphical indicators and overview-tools, that summarize the status-conditions of one or a set of existing hospital facilities, the upgrading needs, and the best occupancy of facilities. Decision-makers could use RADAR-HF to define integrated modernization strategies with resilience improvement, monitor the situation of the facilities, and understand the effectiveness of interventions. The paper ends showing the results obtained in a research project, in which RADAR-HF has been applied to assess the existing hospital facilities of the Friuli Venezia Giulia region (North-East of Italy).

1. Introduction

Hospital facilities constitute an important part of the healthcare system. They are critical infrastructures that provide essential services to the social functioning of a community [1]. Hospital facilities have to ensure the highest standards by delivering routine health service [2], and they must continue to operate during disasters [3].

Indeed, communities are at risk of disasters due to hazardous events including biological, environmental, geological or geophysical, hydro-meteorological, societal and technological hazards [4]. Therefore, the properly functioning of hospital facilities and the reduction of consequences due to disasters are vital for local, national, and global health security [5]. This reduces the cascading effects and helps build the resilience of communities, countries, and health systems [6]; this has been particularly evidenced by the COVID-19 pandemic.

For these reasons, several initiatives and resolutions concerning public health, disaster risk reduction and resilience of critical

infrastructure exist. Among these, there is the pathway to Universal Health Coverage (UHC) [7], the UN Agenda 2030 for the Sustainable Development (Agenda 2030) with its Sustainable Development Goals (SDGs) [8], the Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) [9], the Paris Agreement on Climate Change (Paris Agreement) [10], and other related initiatives and frameworks proposed at international level.

The 2012 UHC resolution urges to move towards providing all people with access to quality health-care services [7]. The Agenda 2030, formally adopted by world leaders in 2015, establishes that public health and resilience of hospital facilities play an important role in achieving the SDGs. In particular, SDG11.b has a direct link to the Sendai Framework, adopted by UN member states in 2015 [8]. Sendai Framework promotes the resilience of new and existing critical infrastructure to ensure that they remain safe, effective, and operational during and after disasters to provide life-saving and essential services [9]. Moreover, ensuring resilient and sustainable hospital facilities

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contributes to the achievement of the Paris Agreement [10].

In this context, the World Health Organization (WHO) states that ‘measures to ensure the safety, security and functionality of health infrastructure are needed at both national and community levels. Countries and communities need to prioritize the protection of new and existing hospitals and other health facilities from identified hazards and should ensure the physical integrity of buildings, equipment and critical hospital systems. In addition, they should provide for the security and well-being of health workers and patients, and should ensure that hospitals are able to continue to function and provide life-saving services in the immediate response to emergencies and in their aftermath. Hospitals can be made more resilient and functional through action aimed at improving the environmental sustainability of health infrastructure, including measures to increase the reliability of power and water supply systems and to reduce harmful waste’ [3]. For these reasons, WHO promotes activities not only concerning quality healthcare but also resilient hospital facilities [11,12].

A resilient hospital has the capacity to reduce the probability of failures, the consequences from those failures, and the time to recovery [13]. The concept of resilience can be applied to four different overlapping levels, hereinafter listed starting from the bottom: (1) physical, that expresses how physical systems behave when they are subject to particular stress; (2) organizational, which describes the ability, of a determinate system, to respond to emergencies and carry out critical functions; (3) social, focusing on the capacity to reduce the negative social consequences of loss of critical services; and (4) economic, describing the capacity to reduce both direct and indirect economic losses produced by the stress [13]. The performance of these levels depends on the different properties that resilience involves, and which are expressed in the four R’s framework proposed by Bruneau et al. [14]: robustness (the ability to withstand a given level of stress without loss of function), redundancy (the extent to which elements or systems are substitutable to perform similar functions), resourcefulness (the capacity to identify problems, establish priorities, and mobilize resources) and rapidity (the capacity to meet priorities and achieve goals in a timely manner). A finalized assessment of the physical environment constitutes the starting point for ensuring resilient hospital facilities.

At national and local levels, the decision-makers should take actions in support of commitments defined by the abovementioned international resolutions, programs, and initiatives. Furthermore, hospital is an ever-changing environment, with a strong dynamism and technological innovation, due to scientific knowledge evolution. Therefore hospital facilities are subject to rapid obsolescence, sometimes even shortly after their realization [15]. Existing hospital facilities are not always adequate to the current expectations of safety, sustainability, comfort, and reliability. Thus, decision-makers have to put in place strategies for modernizing and updating hospital facilities to newer standards [16, 17], as the European Health Service highlights [18].

While facing these complex challenges, decision-makers should answer the following questions:

- a) What is the actual situation of the hospital facilities in comparison with the desired situation?
- b) Which are the main aspects to consider for the hospital facilities assessment? How to consider them in an integrated way for modernization purposes and resilience improvement?
- c) Which types of gaps are present in the actual situation? How is it possible to fill them effectively?
- d) Assuming a change of occupancy, which is the best ‘vocation’ for every single facility?
- e) How is it possible to define an integrated and effective strategy of modernization of a single hospital facility or more hospital facilities (e.g., hospitals of a region)?

Decision-makers could take advantage of methodologies and/or tools that support them in planning modernization strategies and that

simultaneously allow achieving the targets defined by national and international policies.

For these purposes, the authors have developed the RADAR-HF methodology (Recon Analysis for Detecting the Actual situation and the improvement Requests, applied to Hospital Facilities). RADAR-Hospital Facilities (RADAR-HF) is a multi-aspects methodology for the situational assessment of the hospital physical environment. The main outcome is a situational dashboard useful for monitoring the status condition of the hospital facilities and enabling decision-makers in planning modernization strategies and resilience improvement.

First, the paper shares an overview of the available methodologies for the assessment of the physical environment of hospital facilities highlighting characteristics, purposes and indicating the different goals of the RADAR-HF methodology. Then, it presents the research approach with which the RADAR-HF methodology was developed, deepening in particular the general RADAR method for situational assessments, on which the methodology is based. After that, it is illustrated the specific customization of the RADAR method for hospital facilities. The customization process takes heed of the targets of the international literature and policies in the sector, as depicted in the introduction, and Italian regulatory documents and guidelines. This because the methodology was developed for the situational assessment of hospital facilities of the Friuli Venezia Giulia region (North East of Italy) [19]. The paper continues with the explanation of the assessment process and the methodology implementation. Then, the paper summarizes the obtained results from the first application as an example of use on multiple hospital facilities, in order to have an overview of the situation at regional level. Moreover, it presents the methodology application on a ‘pilot’ pavilion to outline the potential use of the methodology in a single facility. Finally, some general considerations and remarks on the methodology precede the conclusions.

2. Assessment methodologies of hospital facilities

In literature, there are several methodologies for the performance assessment of the health system addressed to decision-makers.

Most methodologies deal with the evaluation of the quality of care. They provide indicators for benchmarking on many aspects of health services [20]. An example for Italy is the method elaborated by the ‘Scuola Superiore Sant’Anna’ that has been adopted to benchmark how regions are close to the strategic goals fixed by national healthcare system [21,22].

There are methodologies concerning the evaluation and improvement of the hospitals during emergencies. Generally, they deal with emergency response focusing at the organizational level [23–25].

In the healthcare sector, accreditation systems are used to certify requirements and characteristics. At international level an important example is the Joint Commission International (JCI) accreditation [26]. The JCI works with healthcare organizations, governments and international advocates to promote rigorous standards of care and provide solutions for achieving peak performance. In JCI accreditation, the items related to physical environment are mainly related to the functional issues. This because the goal of JCI is to globally improve efficiency, quality and safety of healthcare.

Assessment methodologies of hospital facilities with specific focus on performance of physical environment are limited [27]. Among these, in the last decades, the methodologies with focus on safety assessment have started to spread, in particular as regards seismic safety. For a large number of buildings, the structural seismic vulnerability can be evaluated with qualitative [28] or quantitative methodologies [29]. The purpose is to produce intervention priority lists and to highlight specific criticalities to be deepened in the design phase. Greater and greater importance has been given to the safety of non-structural elements and systems [30]. Specific guides deal with this issue [31] and some methodologies take into account structural and non-structural seismic safety at the same time. For example, WHO Guidelines for seismic vulnerability

assessment of hospitals [32] proposes a rapid visual screening mainly targeted to civil engineers and technicians who bear the responsibility of ensuring stability of the hospital building structures and their contents during earthquakes.

This seismic safety approach, that takes into account non-structural elements and systems, is important for assessing the resilience of hospital facilities. Bruneau et al. in their work [14] quantify seismic resilience to provide a comprehensive understanding of damage, response, and recovery. This approach provides the administrators with an insight into how their decisions regarding the use of available resources before and after an earthquake affects the hospital functionality [33].

In addition to the earthquakes, other hazards can impact hospital facilities, therefore for planning purposes it may be appropriate to adopt multi-hazard safety methodologies to assess more safety aspects at the same time. In particular, some of these are checklists aimed at identifying potential problems and related solutions [34–38]. The Hospital Safety Index (HSI) [39], starting from a checklist, obtains a safety index which it associates a class of intervention need. These multi-hazard methodologies implement specific hazards depending on the territorial context for which they were designed or applied.

Another issue to focus on is energy and environmental sustainability. In fact, hospitals spend lots of energy because many services are active 24h a day, and medical activities require energy-intensive equipment and systems [40,41]. Moreover, they can be responsible for large emissions of greenhouse gases and production of large amounts of environmental waste and contamination [42]. In Europe, many existing hospital facilities have been built before the adoption of regulations on energy and environmental sustainability [43]. They often lack functioning infrastructure and are subject to inadequate energy supplies, water, sanitation and waste management services [42]. For this reason, there exist methodologies specifically designed for assessing, monitoring and improving energy and environmental sustainability [38,41,44–46]. Many evaluation systems are today available to assess buildings energy performance and environmental impact. Concerning sustainability, especially of healthcare structures, the most widely recognized and commonly used systems are the American LEED [47], the British BREEAM [48] and, within the Italian reality, the ITACA system [49,50]. These evaluating instruments use a set of predefined standards to calculate a score and they provide as outcome a certification of the performance level. WHO offers guides [38] and tools, like Smart Hospitals Toolkit [46], that integrate sustainability issues using the same approach used in the HSI. In the (energy and environmental) sustainability field, very specialized methodologies for analysing and improving building energy performance are widespread [40]. Furthermore, decision support systems and advanced algorithms are used to identify optimized solutions and specific interventions [41,45].

More and more attention has been paid to creating comfortable and functional hospital environments, where the patients can feel good and at ease maintaining the same efficiency of medical activities. In addition, flexibility has been particularly considered because hospital facilities must adapt to the continuous needs of change. A recent example are the changes to increase intensive care units due to the needs of the COVID-19 emergency [51]. In existing literature, there are evaluation methodologies, studies and guidelines to improve comfort [52–57], functionality [58,59] and adaptability [60,61] of the hospital facilities. The guidelines on these aspects offer references for new buildings or they can be used for the evaluation during design phase. On the other hand, many methodologies use a very effective and well-structured approach called Post Occupancy Evaluation (POE). POE compares actual building performance after completion and occupation. It compares building performances with explicit human needs, obtaining feedback not only from the aesthetic point of view, but also from social and behavioural fields. POE can be also seen as a strategy to make improved buildings more functional, comfortable and sustainable [27].

This brief overview of assessment methodologies of hospital physical environment highlights that they are mostly conceived for sectoral

performance evaluation and/or aimed at specific intervention design.

In literature, there are also multi-criteria analyses applied to hospital facilities to define capital renewal funding [62]. This methodology is aimed at technicians to properly prioritize the subsystems interventions on a single building. It is not suitable for extensive application on a large number of buildings.

All the previously cited methodologies, methods, and studies help to understand the situation of the hospital facilities physical environment, but none of them responds completely to all the needs of decision-makers (expressed with the key questions listed above). These methodologies can be used to plan sectoral parts of a modernization process.

Modernization policies should consider all the abovementioned aspects (multi-hazard safety, functionality, sustainability, adaptability, and comfort). The planning phase needs information at appropriate detail level for describing the situation of the hospital facilities in terms of critical issues and to hypothesize integrated modernization strategies.

Finding the best solution for an integrated intervention is the purpose of some of the most advanced methodologies. In some cases, it is not useful to provide the decision-maker only with the dominant solution or the best compromise, but it is better to provide information in a format that effectively assists them in the decision-making process. Especially in public hospitals, modernizing strategies do not depend only on technical choices, but also on local policies and financial aspects related to funding lines. Furthermore, the complexity and the dynamism of the hospital facilities require the ability to adapt to emerging needs. Therefore, it makes more sense to provide decision-makers with tools to monitor the situation (rather than the optimized solution and/or static/one-off census) and to identify choices for adaptation, both in short and long term. In the case of modernization of a set of hospital facilities, it is necessary to give priorities. Many methods evaluate the situation with index methods which are useful for comparing different hospital facilities. These methods provide information for planning modernization only in terms of priority with reference to specific aspects, but decision-makers need also situational information to hypothesize integrated improvement strategies.

The RADAR-HF methodology presented in this work has been conceived and developed for giving a contribution in the field of the assessment methodologies of hospital facilities coherently to the hereinabove mentioned purposes. In particular, the methodology aims at performing a pragmatic and cost-effective situational assessment of physical environment useful for defining comprehensive strategies of modernization and resilience improvement of hospital facilities belonging to a regional healthcare system.

3. Method

In the process of developing the RADAR-HF methodology, the authors used principles of the charrette design process. A charrette is a collaborative design process that aims to deliver a project with the support of all stakeholders [63]. A charrette design process could be divided in three phases. The first phase is the charrette preparation, which consists of gathering a multidisciplinary team and give to them information to familiarize themselves with the project context [64]. The second phase is the charrette itself, a design process with three feedback loops - generating concepts, generating alternatives, and refining the final design - between the design team and the different stakeholders [63]. At the end of the second phase, the final project design is presented for an open discussion about its implementation. The third phase is the plan implementation in which the design team try to shape a design that addresses as many stakeholder concerns as possible [65].

The charrette design process was held with 27 experts and 9 stakeholders and potential users. The experts come from different backgrounds, both scientific and professional: civil engineering, architecture, construction engineering, facilities engineering, management engineering, earthquake/seismic safety, fire safety, energy sustainability, healthcare management. The stakeholders were chosen between

technicians working in hospitals of different types and sizes of the Friuli Venezia Giulia regional health system.

From the organizational point of view, the authors have organized multidisciplinary and thematic working groups and meetings (management, technical, logistic, health area). Experts and stakeholders were involved in the working groups with different purposes according to the development phase of the methodology. All key points of the methodology (strategic goals, reference standards, algorithms and outcomes) were discussed in periodic charette-style meetings.

In order to prepare the charrette meetings, the authors conducted a preliminary analysis on the issues concerning the modernization of hospital facilities. The primary sources of data were government reports, internal publications, and scholarly articles. Secondary collecting data were employed including site visits and in-depth interviews with the administrators and staff members of regional health system, as well as the decision-makers authorities.

A multidisciplinary workgroup (with the regional decision-makers) discussed on the strategic goals of the methodology and the relevant aspects to evaluate, which were the most functional to manage the modernization planning process. The charrette-style meetings revealed the importance of having an overview in more aspects rather than a series of sectoral information in the planning phase. The meetings pointed out the value of designing a methodology with a holistic approach. Thematic tables were organized with the experts of the specific sectors to identify standards and reference documents. From these documents, the substantial elements of the evaluation algorithms have been identified. The algorithms were calibrated thanks to other focused charrette sessions in which expert's reasoning and knowledge were pre-codified through elicitation. Other meetings were addressed to refine the outcomes such as graphical indicators and overview-tools.

The pre-codification of expert's reasoning through elicitation permitted to make explicit the reasoning process that the experts use for formulating the judgments. This process allowed the identification of the information that mostly concurs to qualify and quantify the indicators useful in decision-making. In order to assure a sufficient degree of pragmatism in the developing assessment procedure, the elicitation and the pre-codification were performed by adopting the Pareto principle (also known as the 80/20 rule). This principle states that the minority (about 20%) of causes, inputs, or efforts usually contributes to the majority (about 80%) of results, outputs, or rewards [66].

For developing the situational assessment methodology of the hospital facilities taking into account the outcomes of the charrette meetings, the authors used the RADAR method, a customizable multi-purpose situational assessment method, implemented by SPRINT-Lab researchers of the University of Udine and applied in different fields [67–70]. The method is illustrated in detail in the following section 3.1.

3.1. RADAR positioning method

To identify the actions for rationally dealing with the improvement of a situation of a specific entity, a preliminary assessment is required. This assessment should be finalized: a) to characterize the actual situation with respect to all the aspects considered as meaningful and characterizing, b) to identify the gaps between the current and a desired final situation and c) to suggest the interventions necessary to reach the desired target situation. To address these needs, the SPRINT-lab researchers have developed a multi-parameter assessment method, named RADAR (Recon Analysis for Detecting the Actual situation and the improvement Requests).

RADAR method conceptualizes the problem considering an n-dimensional space of situations, where every dimension is related to one main aspect. In this space, each situation can be localized by the n-coordinates; each coordinate represents the position along a dimension. Each dimension has two extremes related to the best and the worst possible situations. The actual position (initial position) can be compared with a desired situation (target position) and the

improvement can be conceived as a shift towards a better position.

Each dimension has a specific metric that can be continuous, discrete, or blended (Fig. 1). The first (continuous) is used for specific entities quantitatively measurable on a continuous scale (Fig. 1-a). The second (discrete) consists of a set of reference scenarios defined by a qualitative description or identifying the presence or absence of discriminants (Fig. 1-b), i.e., list of features, properties or characteristics. The discriminants separate scenarios considered substantially different. The last (blended metric) is a combination of the first two, using discriminants for dividing different ranges of positions and a continuous scale between them (Fig. 1-c).

Generally, the n-dimensions are more than three, therefore, for representing the overall situation, all the considered dimensions are depicted as a RADAR around a common central point. In that RADAR each axis starts from a common point identifying the (0,0,0,...,0) position (representing the ideal best position O) and develops radially dividing the circle into n sectors. The external circumference represents the worst position and the intermediate circumferences identify specific borders in the metric, related to specific discriminants of different ranges of positions. As result, the positions characterizing the whole situation of the entity are visualized on a sort of RADAR monitor.

In this way, the RADAR method provides both a multi-aspect assessment and useful information for improving the situation of the entity pointing out the conditions to be changed. The RADAR method permits to outline also improvement strategies because it allows not only to know the actual situation of the entity but also the gaps to fill and the conditions to change for reaching a specific new position (target position). The method permits also the prioritization of the strategies, suggesting to intervene first on the characteristics and features that determine the passage into a better position.

The positions that characterize the situation of each main aspect of an entity are defined using specific algorithms that are explained in the next section.

3.1.1. RADAR positioning algorithms

The algorithms for defining the position of the situation on the single i-th dimension use the following assumptions and definitions:

- P_i is the position that represents the actual situation of the entity in the i-th dimension.

- P_i^{best} and P_i^{worst} are the positions that represent, respectively, the best situation and the worst situation of the entity in the i-th dimension.

If the adopted metric is discrete or blended, it is necessary to define the discriminants. $(D_k)_i$ is a reference position associated with a discriminant, characterized by a pre-defined set of features, properties, and characteristics. If the adopted metric is blended, two subsequent reference positions define a range in the positioning axes where the extreme are named $(D_{inf})_i$ and $(D_{sup})_i$. v_j are the variables, quantitative or qualitative, associated with specific features and properties characterizing the situation.

Depending on the adopted metric in a specific dimension (continuous, discrete, or blended), the position of the situation is differently calculated. In particular, if the adopted metric is blended the P position is computed in two steps: a first 'rough' positioning and a second 'fine-tuning'. The first 'rough' positioning defines the range in which P_i is positioned. The 'fine-tuning' refines the positioning in the range between its two extremes (Fig. 2).

The extremes of the range of 'rough' position are determined by logical functions, as follows:

$$(D_{inf})_i = \max(D_k)_i \mid f_{logical(D_k)_i}(v_j) \text{ is true,} \quad (1)$$

$$(D_{sup})_i = \min(D_k)_i \mid f_{logical(D_k)_i}(v_j) \text{ is false,} \quad (2)$$

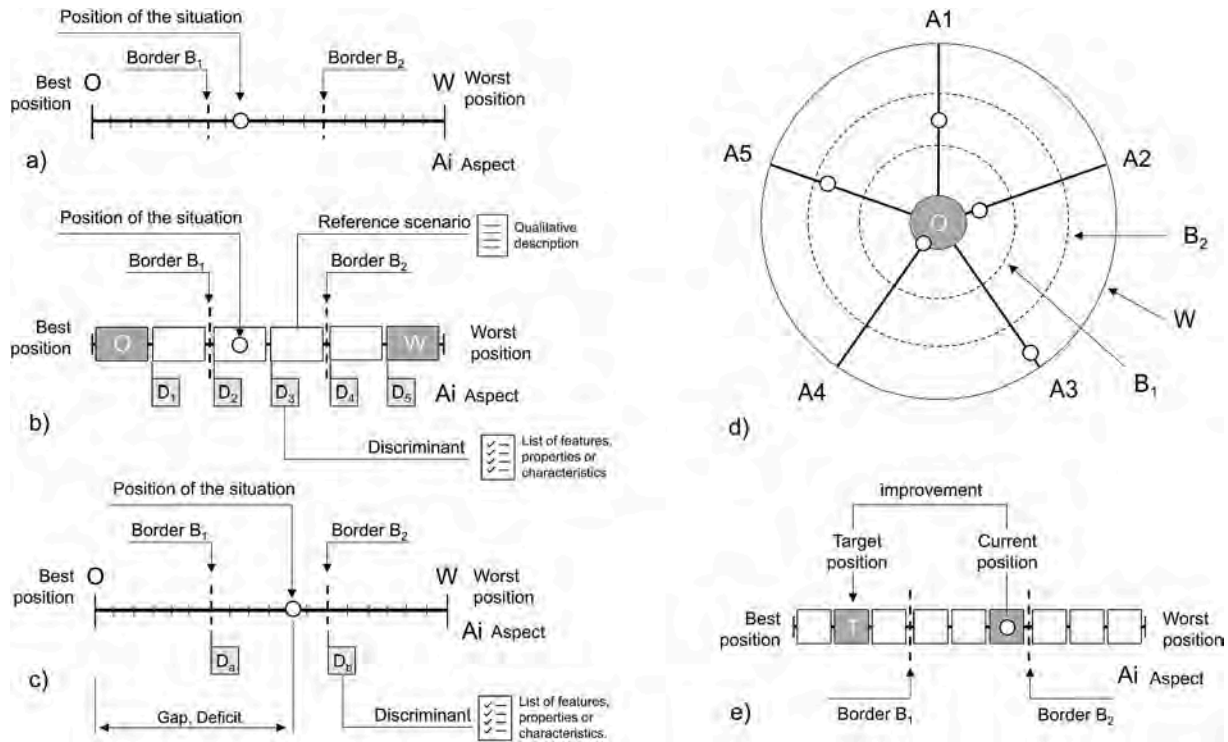


Fig. 1. Position of the situation using different metrics: a) continuous, b) discrete with discriminants and reference scenarios, and c) blended with discriminants. RADAR representation as an overview of the positions on all aspects (d), improvement conceived as a change of position toward a (better) target position (e).

where:

$(-D_k)_i$ are the reference positions pre-defined for the i -th dimension, $(D_k)_i \in [P_i^{best}, P_i^{worst}]$, and the minimum value coincides with P_i^{best} , while the maximum value coincides with P_i^{worst} ;

$f_{logical}$ is a logical function that permits verifying if the assessed situation has the features, properties, and characteristics associated with a reference position.

The position P_i , is calculated considering ‘rough’ positioning and the ‘fine-tuning’, using the following ‘Characterized Positioning function’ (f_{CP_i}):

$$P_i = f_{CP_i}(v_j) = (D_{inf})_i + \frac{\sum_j v_j^{worst} (w_j)_i}{\sum_j (w_j)_i} [(D_{sup})_i - (D_{inf})_i] \quad (3)$$

where:

$-P_i$ is the value that represents the entity’s position in the i -th dimension, $P_i \in [P_i^{best}, P_i^{worst}]$ where conventionally $P_i^{best} = 0$;

$-v_j$ are the variables on which the P_i position depends, each $v_j \in [v_j^{best}, v_j^{worst}]$ where the value v_j^{best} is the minimum value, conventionally $v_j^{best} = 0$, while the value v_j^{worst} is the maximum value that can have a specific variable v_j ;

$-(w_j)_i$ is the weight associated with the j -th variable v_j in the i -th dimension;

$-(D_{inf})_i$ and $(D_{sup})_i$ are the reference situations that define the extremes of the range in which P_i is positioned in the i -th dimension.

If the metric adopted is discrete, the P_i position is calculated with only the ‘rough’ positioning part of f_{CP_i} function: $P_i = (D_{inf})_i$. If the metric adopted is continuous the P_i position is calculated with only the ‘fine-tuning’ part of f_{CP_i} function, considering $(D_{inf})_i = P_i^{best}$ and

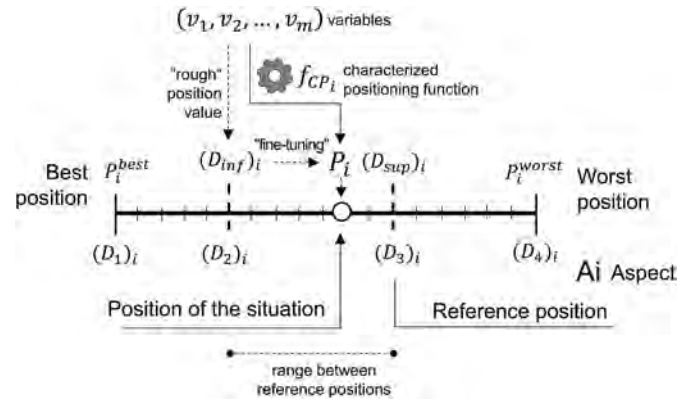


Fig. 2. RADAR positioning algorithms (blended metric).

$$(D_{sup})_i = P_i^{worst}.$$

The f_{CP_i} function can be applied recursively, i.e., the v_j input variables can be the output of another f_{CP_i} function; thereby is possible to evaluate complex entities and also give outcomes (positions) at different levels of detail.

3.1.2. Customization of RADAR method for specific assessments

The RADAR method can be customized for a specific assessment through the following steps based on the fundamental key questions: Why? What? Who? How? and in particular:

1. Definition of the objectives of the assessment;
2. Definition of the aspects to evaluate (defining parameters and elements of evaluation);
3. Identification of the entities of evaluation (defining the components of the reality);
4. Definition of the algorithms of evaluation (discriminants and rules);

5. Representation of the outcomes in a functional way for their use in the decision-making process.

3.1.3. The RADAR situational assessment process

Three main phases divide the RADAR assessment process:

1. Characterization
2. Evaluation
3. Representation of the outcomes

The characterization phase regards the collection of all the substantial information, that constitutes the input of the evaluation phase. Considering all the information acquired in the characterization phase, the evaluation phase permits to express qualitative or quantitative judgments for the different aspects. The evaluation phase outcomes are the base of knowledge for decision-making process. The representation of the outcomes aims at facilitating decision-makers in having an overview of the assessed situation through a summarized and simply readable form.

All the points listed above (section 3.1.2 and 3.1.3), necessary to customized the RADAR method, were discussed in the charrette-style meetings. This allowed the development of the RADAR-HF methodology for the situational assessment of hospital facilities for the Italian context, illustrated in the next sections.

4. RADAR-HF: situational assessment for hospital facilities

To address the issue of situational assessment of hospital facilities, the authors have developed the RADAR-Hospital Facilities methodology (RADAR-HF methodology) taking into account the fundamental questions and steps defined in section 3.1.2. Following the list presented in section 3.1.2, the next sections discuss the customization of RADAR method and other fundamental concepts used for developing the RADAR-HF methodology.

4.1. Objectives of the assessment

The RADAR-HF methodology has been conceived for situational assessment of hospital facilities considering the following objectives:

- to provide decision-makers with an overview of the actual situation of the hospital facilities;
- to provide decision-makers with indicators for planning modernization strategies with an integrated approach and monitoring the effectiveness of interventions;
- to create a cost-effective and easily-updating methodology based on substantial (few and focalized) information;
- to provide decision-makers with indicators about the best occupancy of facilities through a characterization of the physical environment and the functional zoning of spaces;
- to perform the assessments, coherently with the more advanced standards and requirements, that guarantee a high quality of the hospital activities in ordinary situations and during hazardous events;
- to link the assessments to the SDGs, considering a hierarchy of main indicators which assign greater importance to safety and functionality;
- to focus the assessment on the physical environment of hospital facilities and considering them as a complex system of buildings, connections, support infrastructures and interrelated activities.

4.2. Aspects to evaluate

The aspects to evaluate have been identified to provide decision-makers with an overview of the situation of hospital facilities. The overview is finalized to modernization and to outline how to increase

the physical environment contribution to the resilience of the entire hospital system.

The RADAR-HF methodology considers the following main aspects: safety, functionality, sustainability, adaptability, and comfort. Some aspects are described by sub-aspects, in order to address the issue in a more specific way. Safety is divided into static and seismic safety, fire safety, and flooding safety. Functionality is divided into ordinary functionality, emergency functionality, and maintainability. The emergency functionality describes the capacity of the physical environment of a hospital facility to be operational in case of (during and after a) hazardous event specifically earthquakes, fires, and floods. Sustainability is divided into energy sustainability and environmental sustainability. Adaptability and comfort do not have sub-aspects. The situational assessment evaluates each main aspect referring to specific established goals. Table 1 summarizes all the aspects, the sub-aspects, the established goals of each aspect or sub-aspect and the characterizing parameters used in RADAR-HF methodology.

The aspects are consistent with international studies, research works, the most advanced proposals of hospital organizational model [16,71] and the documents of the European Observatory on Health Systems and Policies [18]. Moreover, these documents were used as reference during the design of outcomes such as the upgrading needs impact indicators, and to identify the data to evaluate building vocation.

The last columns of Table 1 quotes documents used in the customization process. Basic requirements are based on regulatory documents and advanced requirements on guidelines and best practices. For instance, the Piano-Veronesi Model [16] is the reference for defining metrics, discriminants, and algorithms of the evaluation of the functionality aspect. This is because the first application of RADAR-HF has been done in Italy, where this model is one of the most used for the design of new hospital facilities.

4.3. Entities of evaluation

The entities of evaluation are hospital facilities, i.e., the physical environment of the hospital (Fig. 3-a). The physical environment is conceived as a system of buildings, connections and support infrastructures (Fig. 3-c). They are composed of sub-systems like structural and architectural components, systems and technical installation, basic equipment, and furniture (Fig. 3-b). The methodology does not analyse medical equipment and devices. Moreover, the hospital facilities are considered as interconnected system because of the relationships among the hosted activities (Fig. 3-d).

4.3.1. Categorization of physical environment based on life expectancy

RADAR-HF categorizes physical environment in sub-systems according to life expectancy. Sub-systems are primary, secondary and tertiary, with 50–100 years, 15–50 years and 5–15 years of life expectancy respectively [18]. Moreover, it categorizes the components in structural, architectural, systems and technical installations (Fig. 3-b, Table 2). Table 2 describes the physical environment sub-systems (PES). This categorization allows decision-makers to be aware of the life expectancy of the physical environment of hospital facilities and to base the modernization planning on strategies that consider the whole life-cycle cost model [18].

4.3.2. Hospital facilities as a highly interconnected system

The hospital facilities are a complex interconnected system not only for their technological characteristics but also for the relationships between the hosted activities. Medical activities are interconnected with other activities and services both from a functional and spatial point of view. Moreover in most hospitals, systems and technical installations are placed in separated and dedicated structures and infrastructures. Therefore, a hospital facility is a 'highly interconnected system' that does not allow separate analysis of the individual components regardless of their interrelationships [87]. The functionality of a hospital's building

Table 1
Aspects, sub-aspects, goals, and characterizing parameters used in RADAR-HF methodology.

Aspects	Sub-aspects	Goals	Characterizing parameters	Regulatory documents and guidelines	
				Basic requirements	Advanced requirements
Safety	Ss - Seismic and static safety	Life safeguard in case of an earthquake and in ordinary conditions	Ss1 - Collapses (Structural safety) Ss2 - External fall of elements (non-structural elements) Ss3 - Internal fall of elements (non-structural elements) Ss4 - Movement of elements (non-structural elements) Ss5 - Releases of hazardous substances Ss6 - Egress and reachability of safe place	[72,73]	[74]
	Sf - Fire safety	Life safeguard in case of fire	Sf1 - Fire scenario Sf2 - Explosions Sf3 - Compartmentalization Sf4 - Contamination Sf5 - Egress, safe place and reachability of safe place Sf6 - Safety of rescue teams (relief facilities)	[75,76]	[77,78]
	Sw - Flood safety	Life safeguard in case of flooding and water seepage	Sw1 - Flooding and water seepage Sw2 - Electrical hazard (during a flood) Sw3 - Contamination Sw4 - Egress, safe place and reachability of safe place Sw5 - Safety of rescue teams (relief facilities)	[79]	[35]
Functionality	Fo - Ordinary functionality	Optimal functioning during ordinary time	Fo1 - Location and spatial relationship Fo2 - Space, accessibility, technological requirements (compatibility with hosted activities) Fo3 - Reliability of systems and equipment	[80–82]	[16,58]
	Fe - Emergency functionality	Fully operational in case of hazardous events (earthquake, fire, flooding and seepage)	Fe1 - Earthquake Fe2 - Fire Fe3 - Flooding and seepage	–	[26,83]
	Ma - Maintainability	Maintenance of functionality conditions	Ma1 - Durability Ma2 - Inspectionability Ma3 - Cleanability	–	[84]
Sustainability	Ee - Energy sustainability	Efficient energy consumption	Ee1 - Heat loss Ee2 - Efficiency of energy generators Ee3 - Efficiency of systems terminal unit Ee4 - Primary energy	[85]	[47]
	Es - Environmental sustainability	Reduction of the environmental impact	Es1 - Emissions and renewable energy Es2 - Pollution and waste Es3 - Water use Es4 - Materials	[86]	[49,50]
Adaptability	Ad - Adaptability	Possibility of modifications	Ad1 - Elasticity (the possibility of changing volume) Ad2 - Generality (the possibility of changing functions) Ad3 - Flexibility (the possibility of changing layout)		[60]
Comfort	Co - Comfort	Comfortable environment	Co1 - Style, space perception and privacy Co2 - Extra services Co3 - Wayfinding and hospital accessibility		[53]

should be analysed and evaluated considering all connected elements, including structures that contain systems and technical installations required for functioning. To this aim, RADAR-HF methodology introduces the concept of ‘functional cluster’. The functional cluster is the set of all medical activities, services, support activities related to a specific activity. The RADAR-HF methodology requires defining the functional clusters for each activity. Fig. 3-d illustrates an example of ‘functional cluster’. The intensive care activity is connected to surgical units and wards; it needs activities carried out in laboratories, diagnostic imaging rooms, and support services, such as sterilization activities. Such activities could be carried out in the same building of the intensive care unit or other buildings.

The aspect ‘Fo - Ordinary Functionality’ (Table 1) evaluates the adequacy of the physical environment hosting the activities, the adequacy of the connections, and the spatial configuration of the hospital activities. In the ‘Fo - Ordinary Functionality’ aspect, the functional cluster is

used to understand what are the relationships between activities.

The functional cluster concept is also important for evaluating The ‘Fe - Emergency Functionality’ aspect (Table 1). For instance in acute care hospitals, essential activities (e.g., first aid, surgery, emergency medicine) must guarantee their services even during or after a hazardous event. Other hospital activities as day-hospital medicine could be suspended in case of a hazardous event, because they are not essential services. The RADAR-HF methodology requires identifying the essential activities and define their ‘emergency functional cluster’. The emergency functional cluster reports the only activities, services and support activities that must continue to operate in case of a hazardous event.

4.3.3. Functional zoning

Hospital facilities host various types of activities: medical, support to medical activities, offices, logistics, services, etc. Each activity needs a physical environment with specific characteristics. The areas that

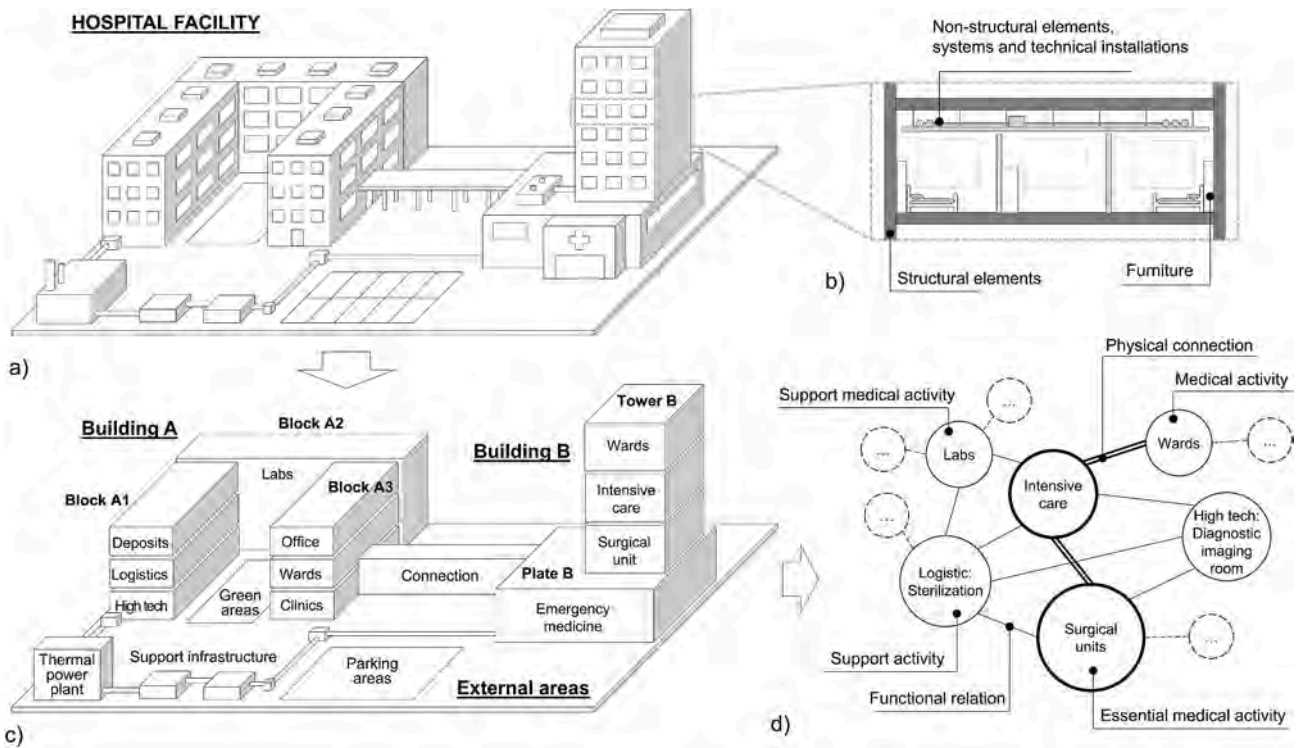


Fig. 3. a) Example of hospital facility b) Example of sub-systems of physical environment c) Example of functional zoning d) Example of interconnected activities hosted in a hospital facility (cluster example).

Table 2
Physical environment sub-system (PES).

Name	Life expectancy	Fundamental characteristics	Typology subdivision	PES Code	Example physical environment components
Primary	50–100 years	Durability	Structural	I s	Structural elements (structural frame, exterior and interior bearing walls, slabs, etc.)
			Architectural	I a	Building envelope (exterior nonbearing walls, glass facades, ventilated facades etc), heavy infill walls, etc.
Secondary	15–50 years	Inspectionability, accessibility, repairability	Architectural	II a	External coatings, light internal partitions, finish floors, false ceilings, doors and windows, ornaments, etc.
			Systems and technical installations	II i	HVAC duct, pipe, reserve water tank, waste pipe, energy generators, terminal unit, elevators, elevators machinery, electricity cable, electricity distribution panel, fire pump, etc.
Tertiary	5–15 years	Replaceability of the single component	–	III	Basic equipment, furniture, etc.

contain activities with the same physical environment requirements (having similar functions and hosting the same type of people) can be grouped. To obtain functional zoning of the physical environment (Fig. 3-c), the RADAR-HF methodology introduces the RADAR-HF categories. This categorization is consistent with the classifications of the main technical documents or regulations relating to hospital facilities, and other classifications.

The functional zoning proposed by the RADAR-HF categories is used both as input and output. As input it summarizes the needs in terms of physical environment of an existing activity. As output it identifies the potential predisposition of an area to contain a different activity.

Table 3 sums up the RADAR-HF categories, how they group the homogeneous areas of the Piano-Veronesi Model [16] and how they can be grouped with reference to European official research works [18,71] (EU categories in this paper).

4.4. Algorithms of evaluation

In the RADAR-HF methodology, the elaboration of substantial

information is based on RADAR positioning algorithms. The positioning criteria and the discriminants have been adapted for the situational assessment of hospital facilities according to RADAR-HF objectives and pre-codifying the expert’s reasoning.

Fig. 4-b summarizes the RADAR-HF evaluation processes: acquisition of substantial information, elaboration and outcomes. Fig. 4-b highlights the recursive application of positioning algorithms to generate outcomes. In particular, RADAR-HF applies the characterized positioning function f_{CP} recursively up to three times. This allows to create outcomes at different levels:

- the first level provides a detailed characterization and indicators for interventions;
- the second level synthesizes the characterization results;
- the third level calculates status scores for prioritization.

Fig. 4-a shows the framework of RADAR-HF evaluation processes and Table 4 describes inputs, metrics, functions, and outputs of the RADAR positioning algorithms.

Table 3
RADAR-HF categories.

RADAR-HF categories		Piano-Veronesi homogeneous functional areas	Groups EU categories	
Code	Description	Examples	Code	Description [18]
Cat.1	Surgical units	Surgery rooms, surgical endoscopy room, interventional radiology rooms, delivery room, etc.	H	Hot-floor A hot-floor with all the capital-intensive functions unique to the hospital, including the operating rooms, diagnostic imaging and intensive care facilities.
Cat. 2	Emergency medicine	Emergency room, children’s emergency room, ambulance entrance, etc.		
Cat. 3	Intensive care units	Intensive care, neonatal intensive care, paediatric intensive care, etc.		
Cat. 5	Laboratories	Clinical laboratory services, biological laboratory, pathology laboratory, blood bank, pharmacy labs, etc.		
Cat. 6	High technology	Diagnostic imaging rooms, radiotherapy rooms, nuclear medicine rooms, and molecular imaging rooms, etc.		
Cat. 9	Mortuary services	Mortuary services, morgue		
Cat. 4	Wards	Immunosuppressed patients ward, infectious diseases ward, maternity ward, etc.	R	Residential Low care nursing departments where, in addition to care, the residential function plays a primary role. This asset is similar to a hotel.
Cat. 7	Clinics	Clinics, outpatient clinic, preventive care clinic, doctor’s office, etc.	A	Administration and clinics All office facilities, administration, staff departments and outpatient units.
Cat. 8	Administration	Reception, administrative offices, reservation centre, public relations office, etc.		
Cat. 10	Logistics	Sterilization and disinfection unit, laundry service areas, kitchen and canteen, hazardous (chemical, radioactive, infectious) waste storage areas, not-hazardous waste storage areas, etc.	F	Factory A fourth segment, factory, concerns production line functions that are not part of the primary process, such as laboratories and kitchens.
Cat. 11	Deposits	Storehouse, medical archives, changing rooms, etc.		
Cat. 12	Technical areas	Technical infrastructure, underground tunnels for systems, mechanical equipment room, etc.	–	Not medical area
Cat. 13	Common areas	Atriums, double-height public spaces, entrance areas, waiting room, etc.		
Cat. 14	Paths	Streets, pedestrian tunnels and galleries, corridors, sterile corridors, stairs, elevators, bed elevators, etc.		
Cat. 15	Services	Hospital cafeterias, restaurant, church/chapel, car park, gardens, ATM/Bank, police/security unit, meeting room, conference room, etc.		
Cat. 16	Not used areas	–		

4.4.1. Example of RADAR-HF positioning algorithms

This section describes as example two RADAR-HF positioning algorithms used for the assessment of the sub-aspect ‘Ee - Energy sustainability’ (Table 1). The example aims to present both the customization of the RADAR positioning algorithms and their use in the evaluation process. The criteria and discriminants of RADAR positioning algorithms are customized concerning the established goal ‘Efficient energy consumption’ (Table 1) and the characterizing parameters are:

- Ee1 - Heat loss.
- Ee2 - Efficiency of energy generators.
- Ee3 - Efficiency of systems terminal unit.
- Ee4 - Primary energy.

Every characterizing parameter is described by the conditions of specific ‘base elements’. The base elements are features, properties or characteristics of the physical environment. The base elements of ‘Ee1 - Heat loss’ are:

- Thermal insulation of building envelope.
- Thermal insulation of HVAC systems.

Each base element is associated with a list of pre-codified possible conditions called ‘elementary situations’. Table 5 lists the elementary situations of the base elements above mentioned.

For analyzing the reality, RADAR-HF methodology requires recognizing one or more elementary situations through the identification of the specific conditions of each base element. The $f_{CPk-th\ parameter}$ characterized positioning function uses the recognized base element conditions as input for the characterizing parameters assessment (Fig. 4-a, Table 4).

All the characterizing parameter has a specific $f_{CPk-th\ parameter}$ charac-

terized positioning function. In particular, Fig. 5 describes the $f_{CPk-th\ parameter}$ of ‘Ee1 - Heat loss’ as example of customization. ‘Ee1 - Heat loss’ is evaluated using the conditions of ‘Thermal insulation of building envelope’ and ‘Thermal insulation of HVAC systems’. The detected base element condition are checked in green in Fig. 5.

In RADAR-HF all the $f_{CPk-th\ parameter}$ function uses a discrete metric with discriminants and reference scenarios. Certain base element conditions active the discriminants. In order to identify the reference scenario, the procedure selects the worst discriminant (the farthest from the best position) even if it is activated by only one base element condition. The outputs are judgment classes (A+, A, B, C, D), corresponding to reference scenarios. The reference scenario of ‘Ee1 - Heat loss’ represent different energy insulation levels (e.g., Complete insulation, Partial insulation, Dissipation).

In the example of Fig. 5 the base element conditions active the discriminants Dp_2 and Dp_3 (green colored). The worst discriminant (Dp_3) identifies the reference scenario ‘Dissipation’, therefore the judgment class of characterizing parameter ‘Ee1 - Heat loss’ is C.

Similarly, RADAR-HF evaluates the other characterizing parameters.

The judgment classes of characterizing parameters are the input of $f_{CPi-th\ aspect}$ for the aspect or sub-aspect evaluation (Fig. 4-a, Table 4). Fig. 6 presents as example the characterized positioning function of ‘Ee - Energy sustainability’ sub-aspect.

For the evaluation of the aspects and sub-aspects, RADAR-HF uses the metric blended with discriminants. In this case, the position is computed in two steps: a first ‘rough’ positioning based on logical rules to identify the range of positioning and a ‘fine-tuning’ within the identified range.

In the ‘Ee - Energy sustainability’, the logical rules of ‘rough’ positioning depend on the judgment classes of some characterizing parameters and the type of area evaluated (key areas). In particular, the key

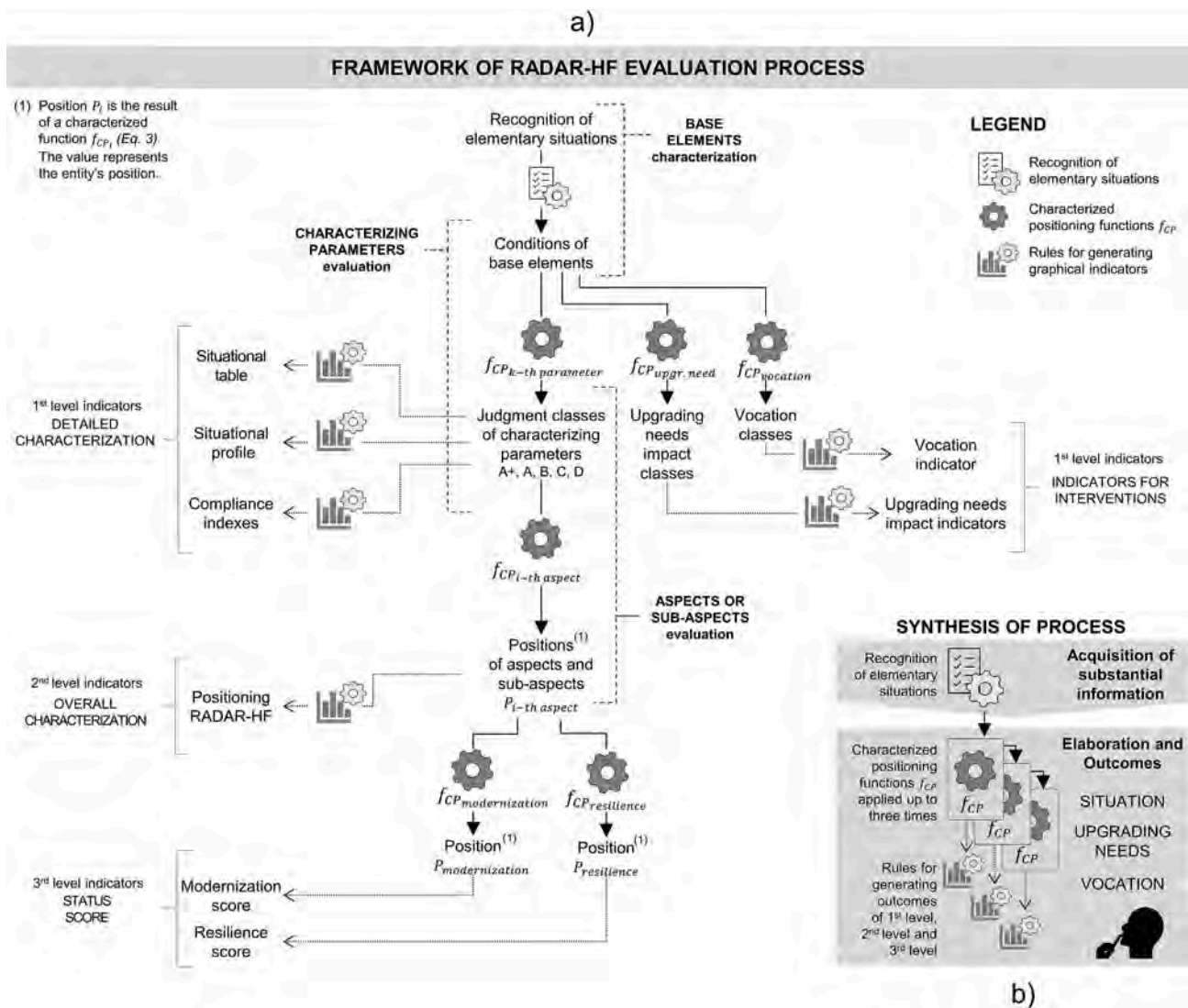


Fig. 4. a) Framework of RADAR-HF evaluation process and b) synthesis of process.

Table 4
RADAR-HF evaluation processes.

Situational indicator		Evaluation			
Outcomes	Level	Input	Metric	Function	Output
Situational table, Situational profile, Compliance indexes	1st	Conditions of base elements	Discrete with reference scenarios	$f_{CPk-th\ parameter}$	Judgment classes A+, A, B, C, D
Positioning RADAR-HF	2nd	Judgment classes of characterizing parameters	Blended with discriminants	$f_{CPi-th\ aspect}$	Position $P_{i-th\ aspect}$
Resilience score 0 (worst) – 100 (best)	3rd	Positions of aspects and sub-aspects	Blended with discriminants	$f_{CPresilience}$	Position $P_{resilience}$
Modernization score 0 (worst) – 100 (best)	3rd	Positions of aspects and sub-aspects	Blended with discriminants	$f_{CPmodernization}$	Position $P_{modernization}$
Upgrading need impact indicators (summary and detail indicators)	1st	Conditions of base elements	Discrete with reference scenarios	$f_{CPupgr.\ need}$	Upgrading needs impact classes: Intensity classes (integral, heavy, light, none) Invasiveness classes (complete, partial, none) Duration classes (short, medium, long term)
Vocation indicator	1st	Conditions of base elements	Discrete with reference scenarios	$f_{CPvocation}$	Vocation classes (suitable, compatible, incompatible)

Table 5
Base elements and elementary situations of Ee1 – Heat loss characterizing parameter.

Characterizing parameter	Base element	Elementary situation
Ee1 - Heat loss	Thermal insulation of building envelope	<ul style="list-style-type: none"> - Building envelope with no thermal insulation - Thermal bridges - Windows and/or transparent shell with air infiltration - Parts of building envelope with no thermal insulation - Complete thermal insulation of building envelope with standard or low performance - High performance complete thermal insulation of building envelope
	Thermal insulation of HVAC systems	<ul style="list-style-type: none"> - Pipes and/or ducts of HVAC system installed outside with no thermal insulation - Pipes and/or ducts of HVAC system with no thermal insulation - Complete thermal insulation of HVAC system with standard or low performance - High performance complete thermal insulation of HVAC system

areas are areas hosting activities with high energy consumption. Then the logical rules were built, not only to evaluate the achievement (or not) of the sub-aspect goal but also to highlight the presence of criticalities in areas with high energy consumption.

In the example of Fig. 6, the verified conditions activate the discriminant Da_2 and consequently the positioning range is identified (light green band).

The weights for ‘fine-tuning’ within the range are the extensions of the areas evaluated (as a percentage to total) and specific weights for each characterizing parameter.

The outputs of $f_{CP_{i-th Aspect}}$ are the $P_{i-th aspect}$ positions (in Fig. 6 $P_{Energy sustainability}$). The obtained $P_{i-th aspect}$ positions of all aspects and sub-aspects are graphically represented in the ‘Positioning RADAR-HF’ indicator. Moreover, the $P_{i-th aspect}$ are the input of $f_{CP_{resilience}}$ and $f_{CP_{modernization}}$ for assessing modernization and resilience scores respectively (Fig. 4-a,

Table 4).

4.5. Outcomes

RADAR-HF methodology adopts an ad-hoc designed set of graphical indicators to provide a summarized visualization of the outcomes. The modernization planning process involves different subjects. The outcomes and the graphical indicators have been designed for different end-user, such as technicians (technical staff) and decision-makers (who do not always have a technical background).

In fact, the detailed characterization indicators (first level of outcomes) facilitate technicians (technical staff) in managing and monitoring the hospital facilities. The situational indicators for overall characterization and the status scores (second and third level of outcomes) facilitate decision-makers having an overview of the situation with reference to all the main aspects. In addition, the situational indicators for interventions are important for identifying the upgrading actions even considering the best occupancy of the assessed facilities.

Each situational indicator provides the end-users with different information, reading keys and details. Next paragraph presents the indicators and how to read them following the flow of Fig. 4-a, then starting from first level of outcomes to the third level.

Fig. 7 represents a portion of the ‘Situational table’ and ‘Situational profile’. These indicators provide a detailed characterization of the hospital facilities evaluated (first level of indicator). They summarize the situational characterization, which is the core of RADAR-HF methodology, and they are the base for generating the other indicators (e.g., indicators for interventions, status score).

4.5.1. Situational table

The ‘Situational table’ is the most detailed graphical indicator of RADAR-HF methodology. ‘Situational table’ reports the judgment of each characterizing parameter for each analysed area. The judgment is expressed by using symbols that graphically represent the severity of the situation. Viewing the whole table allows immediately to find the diffusions of criticalities and where they are localized.

The ‘Situational table’ is addressed to technicians in order to identify critical issues in a targeted way and to hypothesize potential interventions area by area.

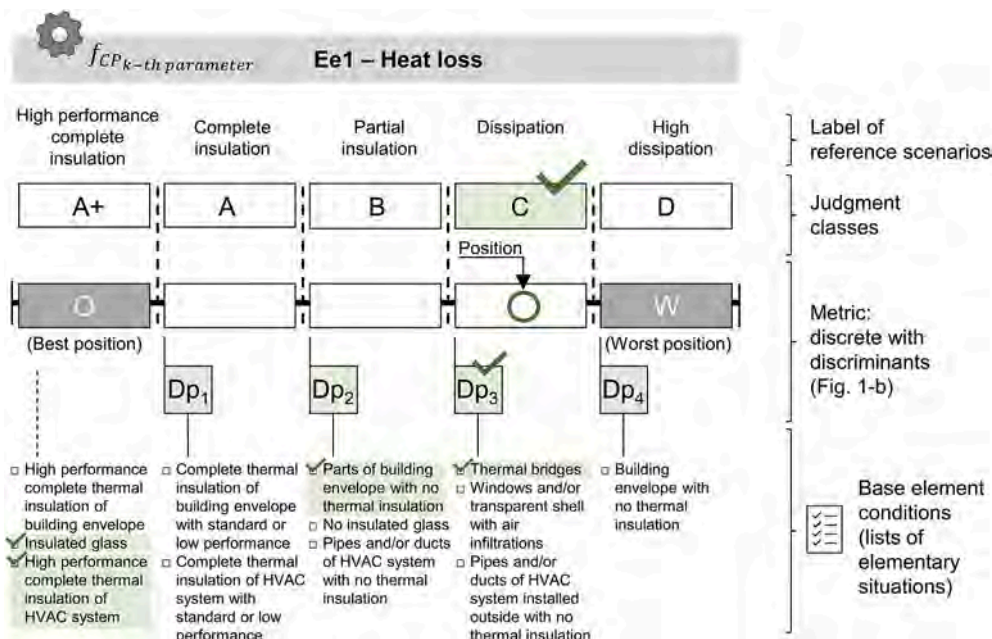


Fig. 5. Example of characterized positioning function for parameter ‘Ee1 – Heat loss’: metric, discriminants, reference scenarios and outputs.

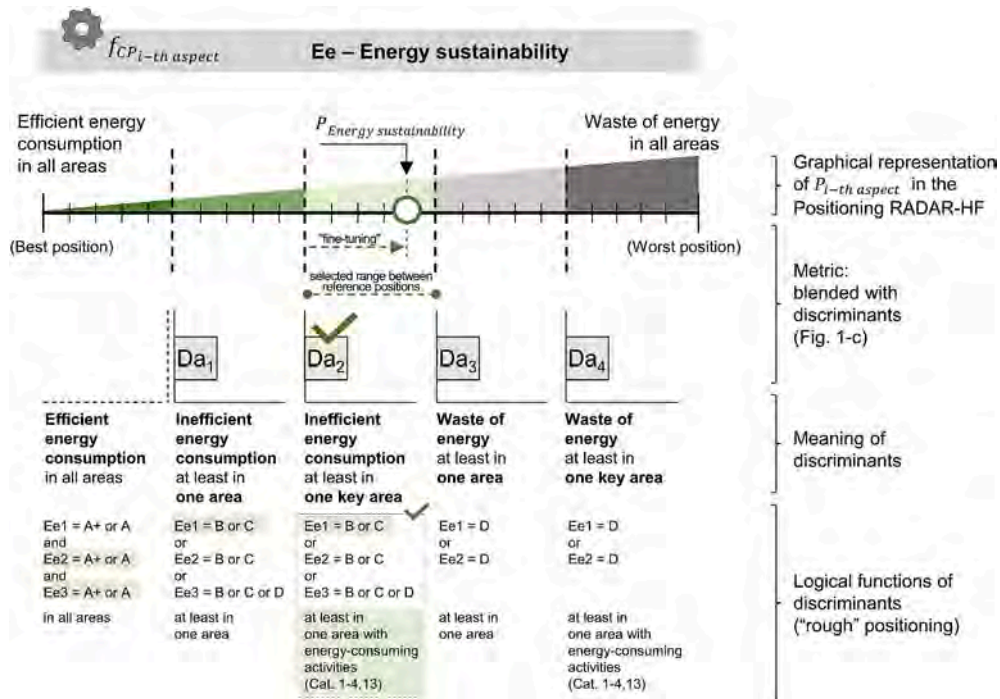


Fig. 6. Example of characterized positioning function for sub-aspect 'Ee - Energy sustainability': metric, discriminants and outputs.

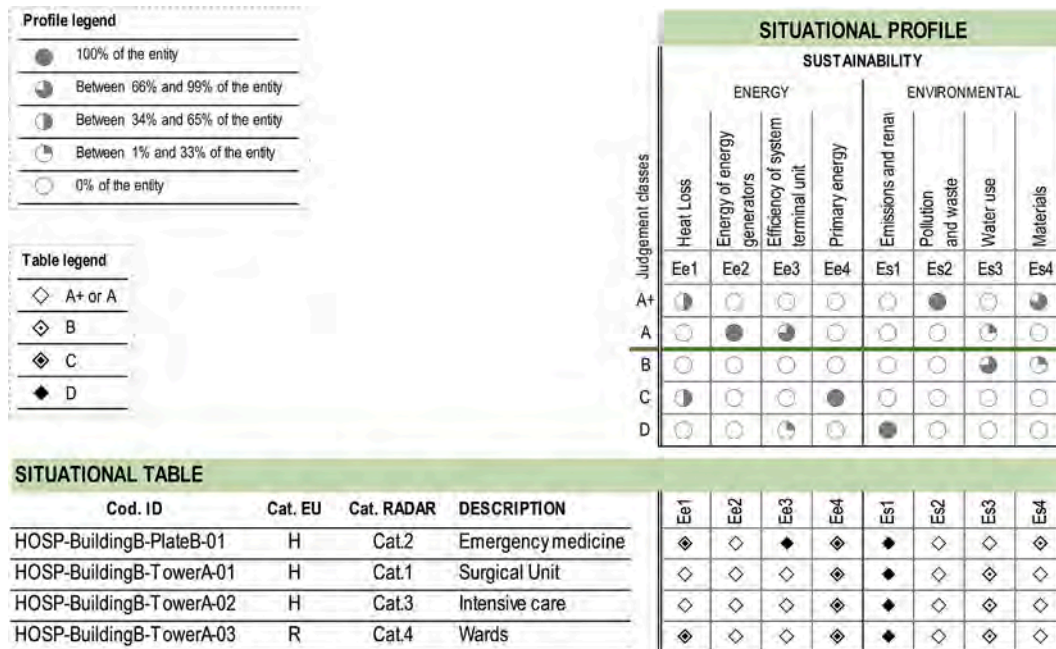


Fig. 7. Example of outcomes and graphical indicators: portions of a 'Situational profile' and 'Situational table' indicators.

4.5.2. Situational profile

The 'Situational profile' summarizes the assessments obtained (judgment classes) for all the characterizing parameters. The lowest judgment class (D) represents the worst reference scenario, while the highest (A+) outlines the best scenario. Judgment classes have a different meaning in each parameter.

The graphic representation is a small pie symbol that depicts the diffusion of judgment class in the building areas. A fully sampled pie symbol indicates that judgment class is extended to the whole building, while a symbol with partial pie indicates that only certain areas of the building have that judgment class.

Thanks to the 'Situational profile', the decision-makers could understand the situation in each characterizing parameter, if the problems are widespread or localized and what are the potential improvements by intervening in localized criticalities. The green line separates the judgment classes between the ones that satisfy reference standards or not. Intervention strategies should aim to get all the evaluations above the green line.

Fig. 8 depicts the other outcomes of RADAR-HF methodology in a single frame, in particular:

- 'Compliance indexes', 'Vocation' and 'Current use' indicators, 'Upgrading need impact' (outcomes for specific reading keys - first level of indicators Fig. 4);
- 'Positioning RADAR-HF' (outcome for overall characterization - second level of indicator Fig. 4);
- 'Modernization score' and 'Resilience score' (status score - third level indicators in Fig. 4).

4.5.3. Compliance indexes

The 'Compliance indexes' allow a thematic reading of judgments obtained in all the characterizing parameters. Characterizing parameters are divided into two groups: parameters based on basic requirements of regulatory documents and parameters based on advanced requirements of local and national guidelines. The 'Basic Requirement Index' (iRB) measures the satisfaction level of basic standards and the 'Advanced Requirement Index' (iRA) measures the satisfaction level advanced standards.

The indexes range from 0 to 1. The maximum value means that in all characterizing parameters, respectively based on basic and advanced requirements, the judgment class is A+ or A.

4.5.4. Vocation and current use indicators

'Vocation' highlights the best occupancy of the areas of the hospital facility. 'Vocation' expresses two levels of predisposition to host a specific activity: 'compatible area' (absence of incompatible conditions),

and 'suitable area' (absence of incompatible conditions and presence of predisposing conditions). Ideally, it is possible to modify every area, but the 'vocation' characterizes a situation in which heavy interventions for the modification of the current physical environment conditions are not required. 'Vocation' is assessed separately for different occupancy with respect to the following groups of RADAR-HF categories (EU categories): Hot floor (H), Residential (R), Administration and Clinic (A), Factory (F).

The 'Vocation' graphical indicator is a histogram that expresses the percentage of the building area predisposed to host activities with reference to the groups H, R, A, F of the RADAR-HF categories. The percentage of suitable area is represented in the 'Vocation' histogram as part of the compatible one.

The 'Current use' pie chart describes the percentage of the building that hosts activity of the groups H, R, A, F at the time of the evaluation.

The decision-makers could use these two indicators to identify the best occupancy of the areas of the hospital facility. Moreover 'Vocation' and 'Current use' indicators provide data for a resilience assessment.

4.5.5. Upgrading needs impact

The 'Upgrading needs impact' indicators describe the impact of improvement actions required to remove any critical issues. Two parameters characterize upgrading needs impact: 'intensity' expresses the technical impact of the intervention; 'invasiveness' measures the impact of the intervention on the activities, in terms of interruptions or

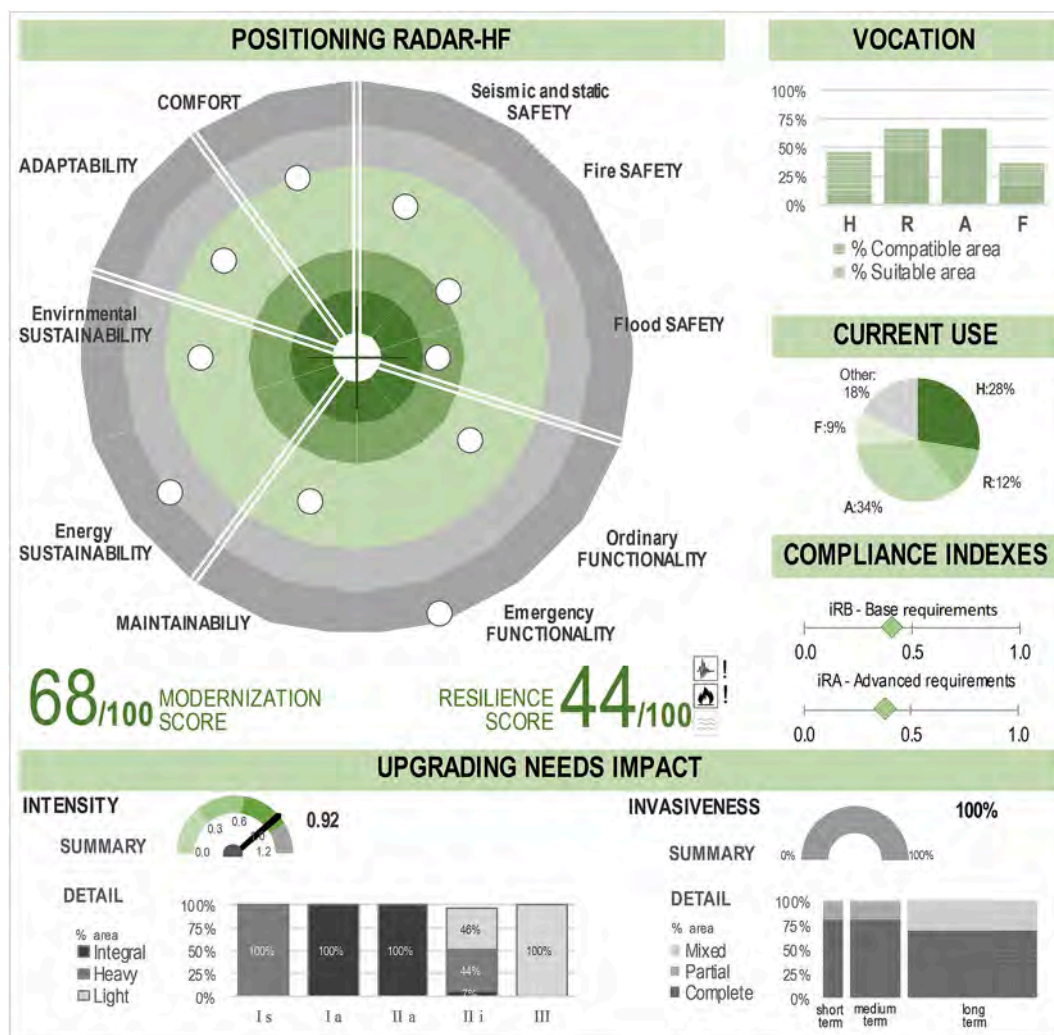


Fig. 8. Example of outcomes and graphical indicators: Positioning RADAR-HF, Modernization score, RADAR-HF resilience score, Vocation indicator, Current use, Compliance indexes, Upgrading needs (summary and detail indicators).

interferences (e.g., need to move the activities out or to reduce them) and duration of intervention.

There are two types of graphic indicators for 'Upgrading needs impact': detail and summary indicators, for technicians and administrators/decision-makers, respectively. A bar chart describes the 'intensity' in the detailed indicators. Every bar depicts a PES and the length of the bar indicates the extension, as a percentage of the total area of the building analysed. The colour of the bar indicates the 'intensity': the darker the grey, the higher the level of intensity (integral, heavy, light). In the detailed indicators, a block chart represents 'invasiveness' that expresses the quote of the building involved in the improvement activities/works and relative duration (short, medium, long term).

In summary indicators, speedometer charts depict the 'intensity' and 'invasiveness' referring to the entire building, without representing the distinction between the physical environments.

4.5.6. Positioning RADAR-HF

The 'Positioning RADAR-HF' is an overall graphical representation of the position obtained for each aspect or sub-aspect. Providing an overview of the situation, it allows to understand the distance from the best situation at a glance and highlights the presence of problems in key areas, i.e., areas with essential activities.

The five colored bands of the radar (from dark green to dark grey) represent the five ranges of positions. In each aspect, they have a different meaning that depends on the established goal and discriminants, as in the case presented in Fig. 6 for the 'Ee - Energy sustainability'. The white dots represent the position for a specific aspect, that could be more or less close to the centre of the radar (ideal situation/best position). Every sector of the radar has its metric; then dots positioned at the same distance from the centre of the radar in the different sectors have a different meaning. Therefore, a gap from the ideal position in the comfort sector, such as the positioning of the dot in a grey band, has a different meaning in terms of severity than the positioning in the grey band in a safety radar sector.

The 'Positioning RADAR-HF' generally represents the outcomes of a building (e.g., a pavilion). Nevertheless, the evaluation of functionality, especially functionality in case of emergency, depends also on the evaluation of interconnected activities (clusters), which can be located in other buildings.

4.5.7. Modernization score

The 'Modernization score' expresses the level of modernization considering the evaluation of all aspects.

The 'Modernization score' ranges from 0 to 100. The maximum score represents the satisfaction of the goals in all aspects. Between the two extreme values, there are intermediate scoring ranges divided by discriminant positions. The discriminant positions are chosen in order to compute the aspects according to a propaedeutic logic (like a Maslow pyramid [88]). Positive assessment of one aspect does not increase the score if the preparatory aspects are not evaluated positively. In particular, the discriminants are designed to make the modernization score insensitive to improvements in sustainability, adaptability, and comfort as long as significant safety and functionality deficiencies persist.

For example, the decision-makers can compare levels of modernization of different buildings through the 'Modernization score' and, at the same time, they can understand the situation of evaluated buildings due to positioning ranges scores meanings. Moreover, the 'Modernization score' allows planning intervention strategies that solve first the criticalities of safety and functionality aspects.

4.5.8. Resilience score

The 'Resilience score' expresses the contribution of the physical environment to a resilient response in case of hazardous events. 'Resilience score' highlights potential failures and damages, as well as the predisposition of the physical environment to quickly recover and re-establish a normal functionality after an event. 'Resilience score'

focuses on the functionality of areas containing medical activities, in particular the essential ones.

Therefore, 'Resilience score' considers only the physical level of the resilience because RADAR-HF methodology evaluates only the physical environment. The algorithm uses the assessments obtained in the aspects, characterizing parameters and base elements that impact three of the properties of the 4Rs framework i.e., robustness, rapidity, redundancy (those most related to the physical environment).

'Resilience score' ranges from 0 to 100. The maximum score means that there would be no loss of physical environment functionality and out-of-service. Between the two extreme values, there are intermediate scoring ranges divided by discriminant positions. A fundamental discriminant position is the score of 60: values below 60 mean that essential activities are not guaranteed in case of a hazardous event caused by physical environment behaviour. This situation is not acceptable in critical infrastructure. 'Resilience score' is calculated for every type of hazardous event considered in the methodology. The graphical indicator shows the worst score of the three ones. With a score lower than 60 the graphical indicator points out in which types of hazardous events there could be essential activity interruptions (in the example, the hazardous events are earthquake and fire). 'Resilience score' provides the decision-makers with information to plan intervention strategies that increase the resilience of the hospital system.

5. The RADAR-HF assessment process

The assessment process of the RADAR-HF methodology follows three main phases, like the generic RADAR method:

1. Acquisition of substantial information and assignment to entities (characterization);
2. Elaboration of the acquired information (evaluation);
3. Outcomes and graphical indicators (representations of the outcomes).

RADAR-HF SW-tool is an operational tool, designed to carry out all the phases and guide users in the application of RADAR-HF methodology. The RADAR-HF SW-tool has forms to enter substantial information and it automatically processes the entered information. The implemented algorithms are based on the concept of positioning and the criteria previously described. Moreover, the RADAR-HF SW-tool generates the outcomes and graphical indicators (described in the previous sections). Different overview-tools organize outcomes and graphical indicators: the 'Hospital facility dashboard (HF-dashboard)', the 'Overall situational panel', and the 'Characterization dossier'. By using these overview-tools, the end-users of RADAR-HF could read the situational assessment results, monitor the situation of the hospital facilities and plan improvement strategies. The following sections describe the three phases of the assessment process.

5.1. Acquisition of substantial information and its assignment to entities

The complexity and extension of hospital facilities require a subdivision into parts and sub-parts to facilitate both the assignment of data and the reading of results. Some data as the type of primary energy supply are usually the same for all the hospital facility buildings. Other data as the structural typology are common throughout a building or a part of it. Instead, HVAC systems or furniture depend on the single activity. RADAR-HF methodology adopts criteria based on typological and functional characteristics to identify parts and sub-parts. The minimum unit for data assignment usually consists of areas inside buildings where the same activity is performed (typically the hospital departments).

In RADAR-HF the data/information can be assigned to (Fig. 9):

- a hospital facility;
- a single building;

- a part of a building (block);
- a single area (e.g., a department or a specific external area).

The information falls into three main categories: general data, situational data, and spatial and functional relationships. General data describe the hospital facility and its parts. Some examples of general data are hospital name and localization, buildings/pavilions name, RADAR-HF category, and basic geometric data (e.g., floors number, areas extension). Situational data are the core of information acquisition. RADAR-HF methodology requires recognizing the elementary situations, that are pre-classified micro-scenarios. Being a micro scenario, each elementary situation collects a simple data set; in this way, the methodology needs fewer input data and it is more suitable for monitoring and planning purposes. Spatial and functional relationships are information finalized to define the activities clusters for the functionality aspects assessment.

The RADAR-HF methodology guides the collection of information through a structured checklist and forms implemented in the RADAR-HF SW-tool. For fast and not-sequential compiling, the checklists can be filtered by aspect (e.g., seismic safety, sustainability issues) or by PES (e.g., structural elements, systems).

The information can be obtained from various sources: documents, observation, interviews and in-depth investigation. Some aspects, such as adaptability and comfort, could be assessed from observational data. Other aspects, such as safety, may require technical or expert investigations. To compare the results of different aspects with different data sources, each data (elementary situation) is assigned to a reliability level (limited, adequate, or accurate level of knowledge). This permits understanding the confidence level of the outcomes, depending on the reliability level of the input information and to keep in memory the source type.

5.2. Elaboration of the acquired information

The positioning algorithms elaborate the acquired substantial information. The algorithms are based on the methods and criteria described in sections 3.1 and 4 and they are implemented in the RADAR-HF SW-tool. The algorithms and the RADAR SW-tool have been built in a parametric way and prepared to accept different criteria according to specific needs and objectives. Therefore it will be possible to modify the parameters by adapting them to any existing local reality.

5.3. Outcomes and graphical indicators

The graphical indicators are organized into overview-tools: the 'HF-dashboard' for the decision-makers and the 'Overall situational panel' for technical staff. These tools are linked in order to help an effective and finalized dialogue between the subjects of the planning process. The 'HF-dashboard' (Fig. 10-a) allows an overall view of the hospital facility situation and it summarizes the outcomes of the main parts of the hospital facility (i.e., each medical pavilion, external areas, service infrastructures). 'Overall situational panel' (Fig. 10-b) gives a more detailed overview of each building or infrastructure situation by providing data of each area. The RADAR-HF SW-tool automatically creates the dashboard and the panel with all outcomes and graphic indicators. Table 6 lists the graphical indicators in the tools for end-user.

Moreover, a building dossier collects all the substantial information of the evaluated facility (Fig. 11). In addition to gathering general data and evaluations results, the 'Characterization dossier' depicts substantial information through thematic characterization maps. In particular, there is the architectural and structural map, the system and technical installation map and the functional map. The maps are useful as support for understanding the outcomes of RADAR-HF and for other purposes, such as the transfer of knowledge in case of turn-over of technical staff. RADAR-HF methodology provides a set of legends, layouts, icons, symbols, colour codes to facilitate the creation and standardization of the 'Characterization dossier'. This standardization is particularly important if the set of structures is numerous and a comparative analysis of the results is required.

6. Application of RADAR-HF methodology

The RADAR-HF methodology was applied in the ASSIST research project (in Italian, ASSIST is the acronym of 'Ammodernamento delle Strutture Sanitarie con il supporto di Indicatori Situazionali Tecnico-economici'). The ASSIST research project aimed to assess the physical environment of existing hospital facilities of the Friuli Venezia Giulia region (North-East of Italy). The goal of the ASSIST project was to provide the local decision-makers with a strategic vision for defining a modernization plan [19].

An internal group of technicians of the regional healthcare system have used the RADAR-HF methodology for the situational assessment of the existing hospital facilities. The technicians have applied the methodology on one hospital facility after a short period of training and

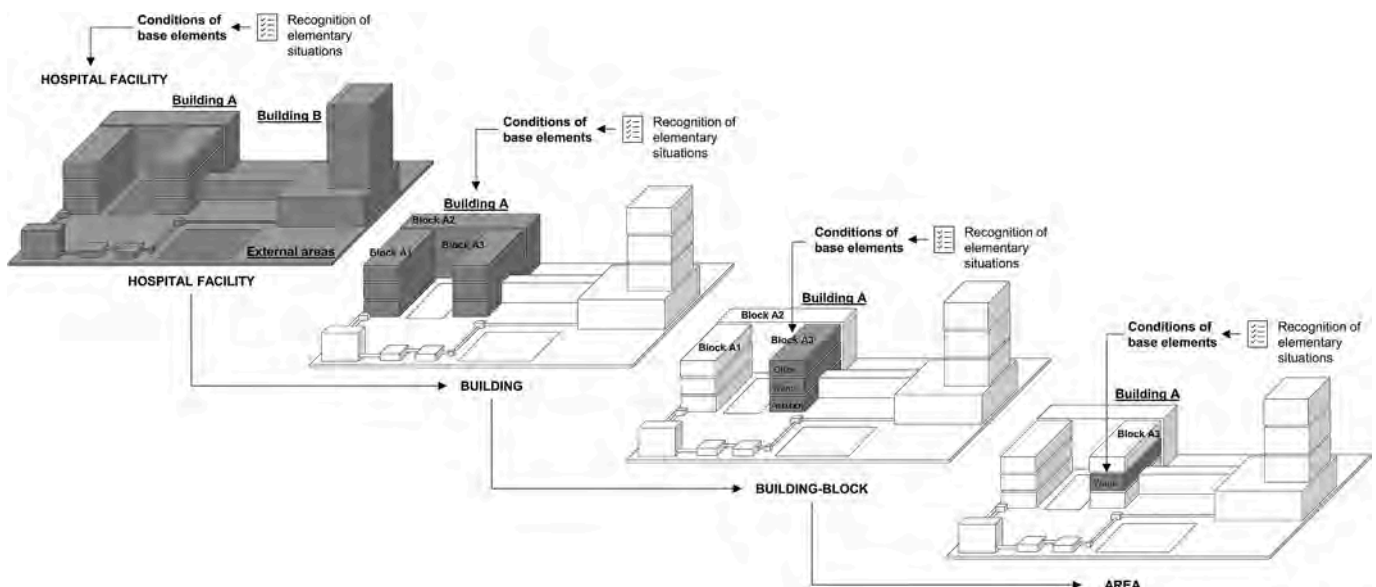


Fig. 9. Data assignment.

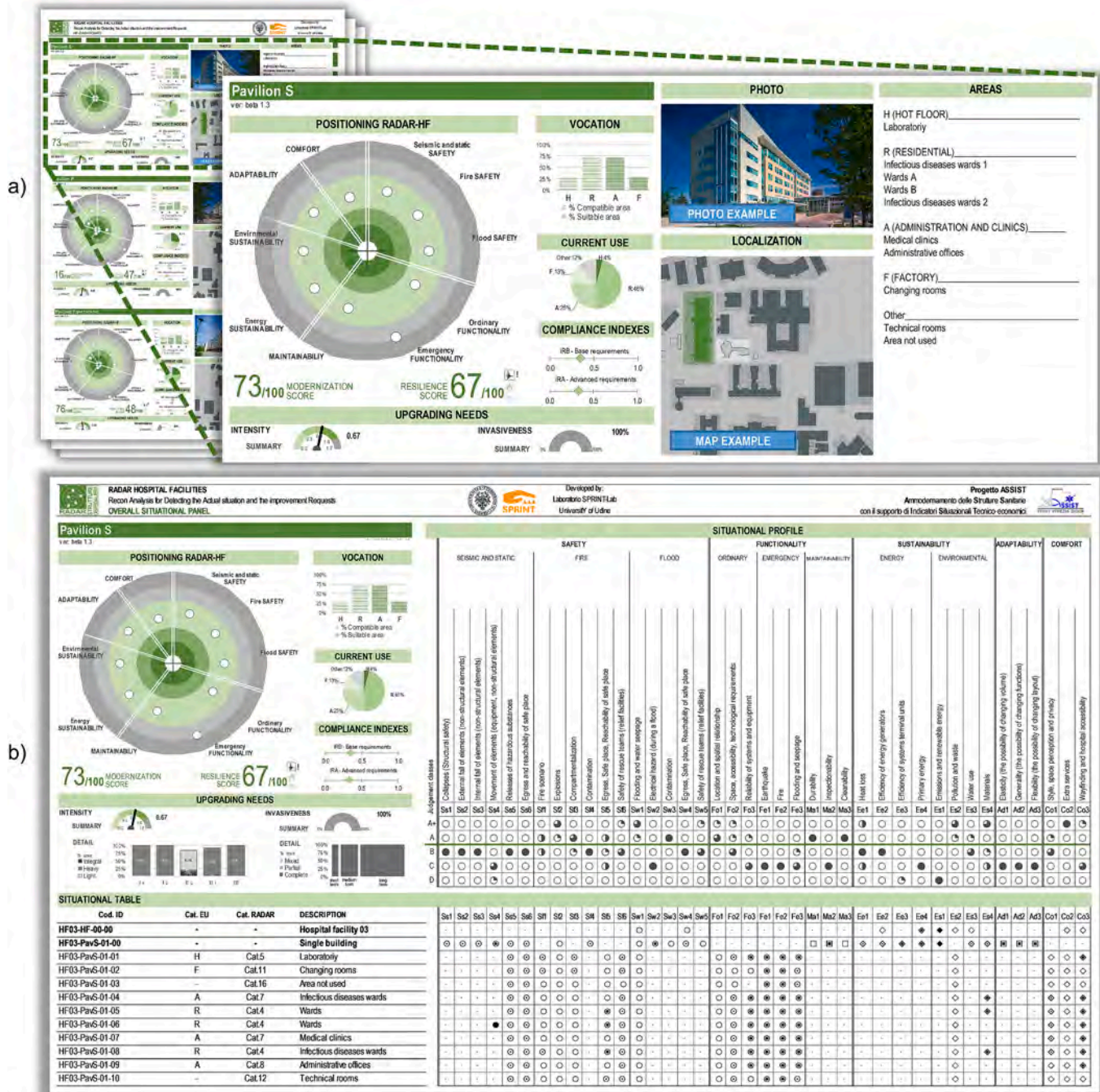


Fig. 10. Example of 'HF-dashboard' (a) and 'Overall situational panel' (b).

capacity building with the support and review of the authors. Then technicians have collected the data and have produced the outcomes using the RADAR-HF SW-tool for all hospital facilities of the region.

Next section illustrates the results at the regional level and Section 6.2 presents a case study to explain how the RADAR-HF methodology was used to check the effectiveness of interventions on a single building. The case study is a pavilion (named Pavilion P in this paper) that underwent a significant modernization. The Pavilion P was assessed before and after the modernization intervention. The intervention was planned before the beginning of ASSIST project, without using RADAR-HF outcomes. The available funding lines made it possible to carry out localized interventions despite an integrated one.

6.1. Results at regional level

Table 7 shows the 'Modernization score' and 'Resilience score' of the hospital facilities analysed in the ASSIST project and Fig. 12 synthesizes the results for the main aspects through a box-plot graphic.

Table 7 permits to identify the facilities with low scores of modernization and/or resilience. The results summarized in Fig. 12 highlight that most of the facilities do not reflect the latest standards and they need modernization, even if their ordinary functionality is tolerable. In particular, 'Ss – Seismic and static safety' highlights deficits due to new seismic standards introduced by the Italian seismic code. This is because they are significantly more severe than the standards adopted at the time of construction or last retrofitting. 'Sf - Fire safety' and 'Sw - Flood safety' show a better situation. The deficit of seismic safety is the main

Table 6
Graphical indicators present in the overview-tools for end-user.

Graphical indicators	HF-dashboard (Decision maker)	Overall situational panel (Technical staff)
Modernization score	x	x
Resilience score	x	x
Positioning RADAR-HF indicator	x	x
Vocation and current use indicators	x	x
Situational indexes (iRB and iRA)	x	x
Upgrading needs impact summary indicators	x	x
Upgrading needs impact detail indicators		x
Situational profile indicator		x
Overall situational panel		x

cause of the bad position of the 'Fe - Emergency functionality'. Very low seismic vulnerability of non-structural elements and systems are important to allow immediate occupancy and the full operativity after an earthquake. Instead, the results highlight good positions, with minor variability, for 'Es - Environmental sustainability'. This reflects the increased attention to this problem in the last decades. 'Ee - Energy sustainability' evidences a dispersion of situations ranging from bad and very good positions. New reference models for the hospital have contributed to increasing the adaptability of the facilities. Further efforts are necessary for improving the comfort aspects.

6.2. Results on a specific facility

During the ASSIST project, the Pavilion P was interested by improvement intervention. The building was assessed with RADAR-HF methodology at the pre-intervention and post-intervention status.

In detail, the intervention concerned only the fire safety and the functional requalification of some pavilion areas (constraints due to the types of available financing).

The functional intervention of the pavilion P consisted of moving the children's emergency room to the ground floor and creating direct access from the outside in accordance with the guidelines of the Italian health system. In addition, all the activities of births medical path (e.g., delivery rooms, maternity ward, intensive neonatal care unit) which used to be in various pavilions of the hospital are now concentrated inside the pavilion. This type of intervention follows the activities grouping criteria of the same medical path proposed by the Piano-Veronesi hospital model [16]. Although the realized intervention is not complete (i.e., not aimed at improving all the aspects of 'Positioning RADAR-HF'), the 'Modernization score' draws attention that the partial intervention is effective in terms of actual modernization.

The outcomes, synthesized in the graphical indicators in Fig. 13,

underline the aspects affected by the intervention and intervention effectiveness. In fact, the outputs that undergo the greatest variation are related to 'Sf - Fire safety' and 'Fo - Ordinary functionality'. In addition, the 'Modernization score' increase from 16/100 (pre-intervention situation) to of 76/100 (the post-intervention situation).

The improvement of 'Fo - Ordinary functionality' is due to a functional reorganization of the building. The functional reorganization of the pavilion moved essential activities (e.g., delivery rooms, maternity and intensive neonatal care unit) to a safer building, which is more suitable to contain activities that must guarantee operations even in an emergency. This case study shows how RADAR-HF methodology could be used to explore both technical intervention strategies and spatial and functional changes of the hospital activities layout.

The 'Fe - Emergency functionality' shows a very poor improvement due to the concept of 'functional cluster' used in the evaluation. Pavilion P has a good level of safety, but some of the support activities and infrastructures are in buildings whose functionality and safety assessments are not adequate. In case of a natural hazardous event, potential non-operative support activities could compromise the functionality of Pavilion P. This condition impacts the 'Resilience score', which slightly

Table 7
'Modernization score' and 'Resilience score' of the hospital facilities analysed in ASSIST project.

Hospital facility	Building	Modernization score	Resilience score
H-F. 01	Pavilion I	64/100	64/100
H-F. 02	Pavilion C	73/100	69/100
	Pavilion PA	68/100	64/100
H-F. 03	Pavilion O	35/100	8/100
	Pavilion SM	36/100	7/100
	Pavilion C	35/100	7/100
	Pavilion PE	9/100	4/100
	Pavilion S	73/100	67/100
	Pavilion P (post intervention)	76/100	48/100
	Pavilion P (pre intervention)	16/100	47/100
	Pavilion IN	68/100	44/100
	Pavilion NM	35/100	5/100
H-F. 04	Building P	74/100	64/100
	Building Y	73/100	64/100
H-F. 05	Plate A	69/100	67/100
	Plate B	72/100	66/100
	Plate C	82/100	67/100
H-F. 06	Multiple blocks building	71/100	45/100
H-F. 07	Building G	65/100	64/100
	Building S	79/100	66/100
	Building D	67/100	66/100
H-F. 08	Tower	39/100	67/100
	Plate	72/100	46/100
H-F. 09	Pavilion R	29/100	63/100
	Pavilion M	30/100	5/100

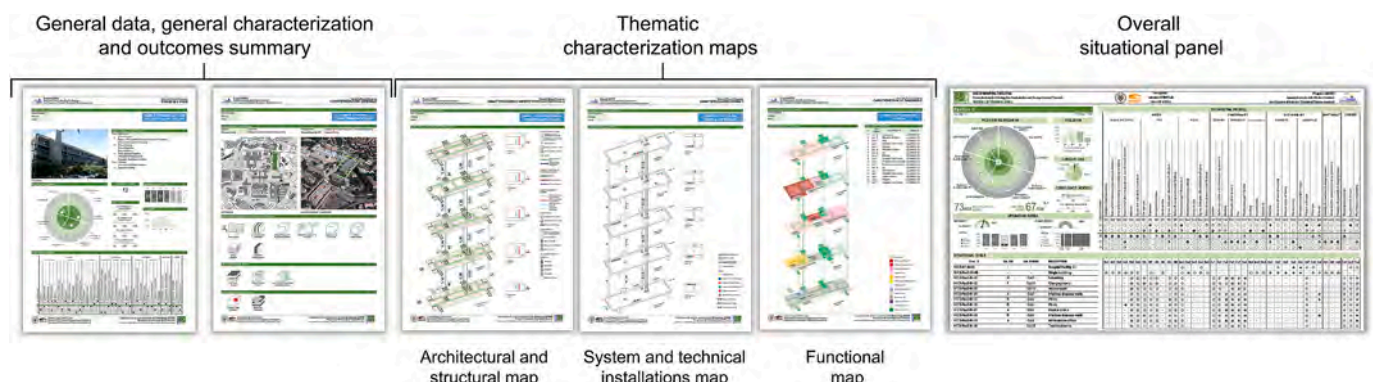


Fig. 11. Characterization dossier.

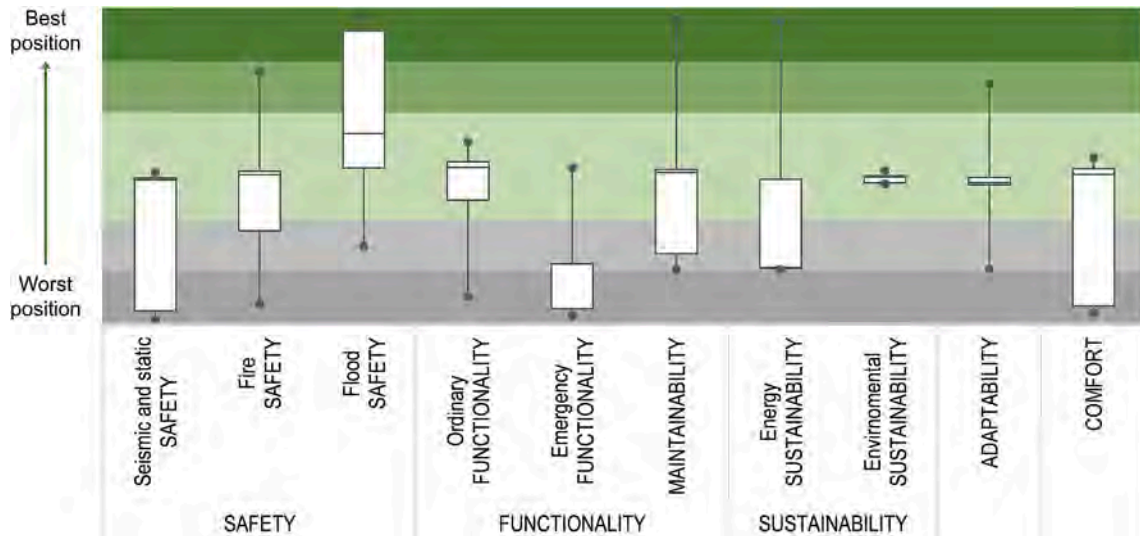


Fig. 12. Synthesis of results of RADAR-HF aspect evaluations in ASSIST research project.

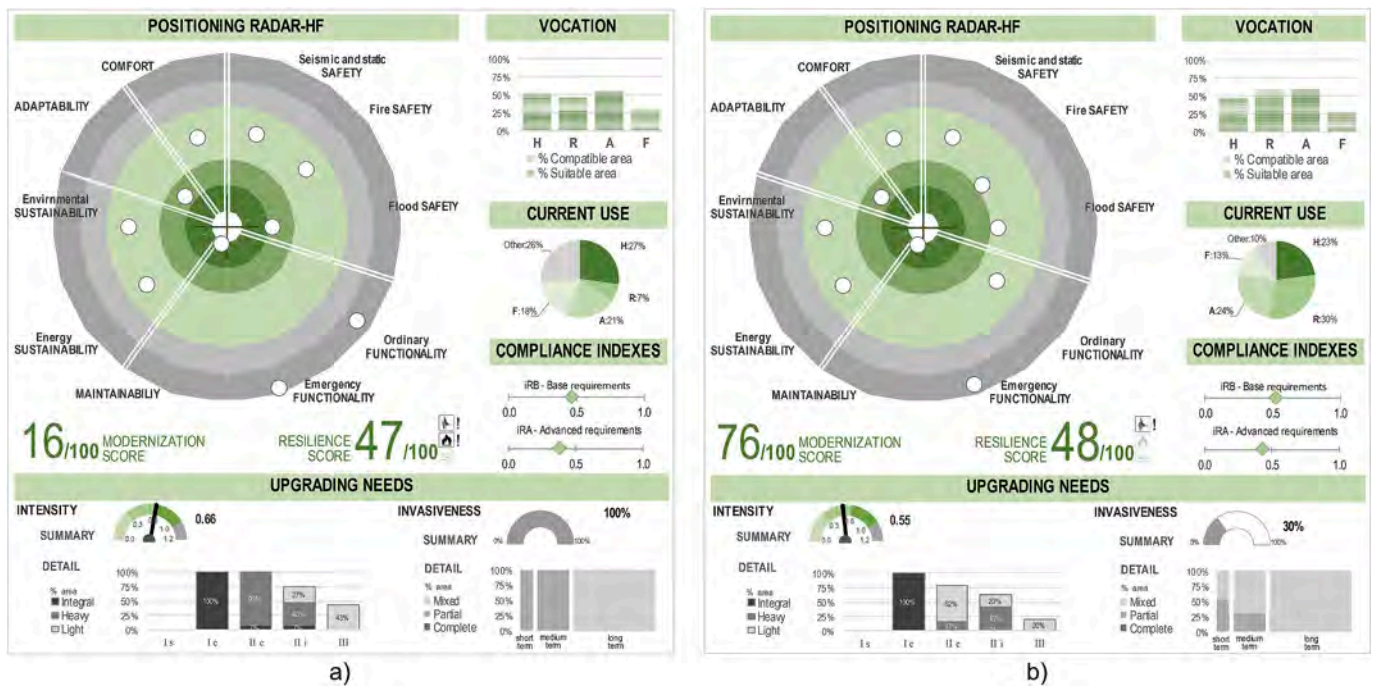


Fig. 13. Outcomes of Pavilion P in the pre-intervention situation (a) and in the post-intervention situation (b).

increases from 47/100 to 48/100 thanks to interventions in firefighting field. At the same time, the 'Resilience score' doesn't exceed the value of 60/100, due to criticalities in 'Fe - Emergency functionality' during earthquakes. The different increase of modernization and resilience score is typical of non-integrated interventions.

It is worth noting that, compared to the first implementation, after the intervention only the 16% of data was updated. In this case subsequent assessment was faster.

7. Discussion and remarks

The experts involved in the charrettes evaluated the results obtained by applying the RADAR-HF methodology, both at regional and at facility level. They considered the results coherent with their reasoning process. Moreover, the ex-post discussions allowed to formulate some

considerations concerning how to use the results of the methodology for strategic planning purposes, summarized as follows.

A rational and complete modernization strategy aims to plan an integrated intervention on all facilities, by giving priority to the ones with the most severe criticalities. However, planning a comprehensive integrated intervention to resolve all critical issues is often not practicable. Moreover, the most serious problems may be in buildings with low medical interest. Using the outcomes of RADAR-HF and depending on the available funding lines, local decision-makers could plan an improvement strategy based on tailored priorities and divided into intermediate stages. The intervention priority may depend on the criticalities found on each aspect, the situation of multiple aspects, or on particular activities types (essential or not). For example, in the case of financing aimed at energy efficiency, it is possible to identify the buildings that have a worse energy sustainability rating but the

overview allows to consider the situation of the other preparatory aspects (e.g., safety). Energy efficiency can be improved on safe buildings and at the same time, it must be subordinated to safety adjustment for buildings that are not sufficiently safe. Likewise, interventions aimed at improving comfort should presuppose an adequate level of safety, functionality, and sustainability. The experts recognized that outcomes of the methodology and their graphical representation support the decision-making process, taking into account the above mentioned considerations.

The applications on the pavilion P evidenced that the data updating is minimal when a subsequent assessment with the methodology is required. Therefore, the methodology can be easily used for monitoring purposes. The outcomes permit to evidence the relative improvements before and after the intervention.

Overall, the methodology has received good feedback. Decision-makers and technicians appreciated the interdisciplinarity of the methodology and the exhaustive set of outcomes as knowledge support both to define intervention strategies and monitoring the situation of the facilities. They recognized that the collection of substantial data in the 'Characterization dossier' can be used for quickly transferring information about hospital facilities in case of turn-over of technicians.

The methodology was used during the COVID-19 pandemic. It provided support for a fast hospital layout changing and it was used to find spaces where intensive care units were created. Although this does not represent a real validation, it gave a practical evidence to be a useful support tool for the rapid definition of a contextualized action plan.

It is important to underline that the results and the considerations are referred to the first application of the methodology which is customized for a specific territorial context. Therefore, a more extensive application is required in order to verify its general usefulness and wider applicability.

In this perspective, it is helpful to summarize the following remarks:

- The methodology has been conceived as a support tool for strategic planning instead of a detailed evaluation for specific interventions.
- The methodology is parametric and can be adapted. The adaptation can be done for different territorial contexts with different hazards (e.g. typhoons, tsunamis), or to change reference standards (e.g. new hospital organizational model). The adaptation can be performed through focused charrette meetings with local experts, technicians and stakeholders, repeating the process illustrated in this paper.
- The methodology permits obtaining a resilience index for the physical environment of hospitals facilities. For a more comprehensive assessment of resilience, it is necessary to consider also the organizational and behavioural dimensions that characterize the healthcare system and activities.

8. Conclusions

Implementing modernization strategies of hospital facilities to ensure high standard care is one of the duties of the decision-makers. Moreover, international action programs, including the 2030 Agenda for Sustainable Development, urge to pursue a resilient response of hospital facilities during emergencies caused by biological, environmental, geological or geophysical, hydrometeorological, societal and technological hazards. The RADAR-HF methodology has been conceived to support decision-makers with a situational assessment of hospital facilities for modernization purposes and resilience improvement.

In order to develop the RADAR-HF methodology, the authors customized the multi-parameter RADAR method carrying out an inter-sectoral collaborative process with experts and sectoral specialists. This process aimed to elicit expert reasoning by using the charrette technique. The customization has concerned objectives of the assessment, main aspects, algorithms, metrics, and outcomes representation.

RADAR-HF considers different main aspects as safety, functionality, sustainability, adaptability, and comfort. The algorithms evaluate the

aspects with reference to specific established goals and they are based on a hierarchy of main indicators which assign greater importance to safety and functionality. In addition, the algorithms take into account the relationships between the hospital facilities parts, considering them as complex systems. Graphical indicators and overview-tools represent the outcomes. These have been specifically designed to outline the status-condition of one or a set of existing healthcare facilities, the upgrading needs impact, and the best occupancy of the facilities. RADAR-HF has been structured even to be a monitoring tool optimizing and minimizing the input data.

The methodology has been applied in the ASSIST research project. The application of RADAR-HF has allowed an overview of the situation of the physical environment of the existing hospital facilities of the Friuli Venezia Giulia region (North-East of Italy).

The paper presents the results obtained for the hospital facilities of the region and it explains how to use the methodology in a set of buildings in order to plan modernization strategies. In addition, the article presents, as a case study, the application of the methodology on a pavilion which underwent modernization during the ASSIST project. This pavilion was evaluated with RADAR-HF before and after the interventions. The case study points out how it is possible to check the effectiveness of interventions, even if they were not planned using this methodology. Moreover, it highlights the effectiveness of the methodology even when it is applied to a single building. This because the methodology considers each building as a part of the hospital system.

The outcomes of the RADAR-HF methodology provides an overview of the hospital facilities through substantial information and key elements in multiple aspects of modernization. The outcomes could support decision-makers in defining and exploring integrated modernization strategies. In particular, they pointed out that the tailored overview-tools and building dossier obtained applying the RADAR-HF methodology, allowed having a simple and comprehensive overview of the situation, as well as positioning the current situation respectively to specific desired targets.

Lastly, the COVID-19 pandemic underlines the importance of knowing the physical environment of hospital facilities, to adapt it as quickly as possible in case of impending situations. Decision-makers and technicians of Friuli Venezia Giulia region health system used RADAR-HF as support to face the problem of increase intensive care units. Furthermore, the pandemic is generating many actions at the international level, including Next Generation EU [89] that suggests modernization and resilience increase of hospital facilities.

It is important to underline that, in the form presented in this work, the methodology is customized for the Italian context where it contributes, already at this stage, to creating a useful and contextualized knowledge base to support decision-makers in defining modernization and resilience improvement strategies. Therefore, despite the positive feedbacks in its first application, RADAR-HF methodology requires wider use and new customizations for verifying its effectiveness and exportability.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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