Improved delivery of social benefits through the maintenance planning of public assets

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ABSTRACT

The prioritisation of public facilities' maintenance is a necessary but complex task due to the need of considering both physical and socio-economic criteria. This study addresses this problem by quantifying the improvement in the delivery of social benefits that the corrective maintenance of an urban area's public facilities could yield. Based on this, a decision framework is proposed to design and schedule corrective maintenance plans at a municipal scale. The methodology integrates multi-criteria assessment with an analytical method for evaluating the contribution of an area's public facilities to its sustainable urban development based on their type of social infrastructure and their maintenance condition. The decision framework is implemented as a software to facilitate its application to a case study, consisting in building urban regeneration strategies aligned with governmental guidelines. The results revealed that decision-making is more efficient when considering the facilities' type of social infrastructure. In addition, a cost-efficient prioritisation of corrective measures yields better results than neglecting the economy.

KEYWORDS
Social infrastructures; Sustainable urban development; Urban strategic planning; Corrective maintenance; Portfolio prioritisation; Facility management; financial planning; maintenance strategies

1. Introduction

Public facilities (PFs) are indispensable parts of cities' social infrastructures (SIs), and they therefore play a major role for municipalities' sustainable urban development (SUD) (Yigitcanlar & Teriman, 2015; Zavadskas, Turskis, Šliogerienė, & Vilutienė, 2021). PFs include social infrastructures such as schools, hospitals or social housing, cultural centres, shopping centres, parks, and sports areas (Fransen, Del Bufalo, & Reviglio, 2018; Latham & Layton, 2019; Zavadskas et al., 2021). The effective contribution of these assets to society largely depends on their maintenance condition (MC), which, on the other hand, is not always the most appropriate (Klumbyte, Bliudzius, & Fokaides, 2020; Latham & Layton, 2019). In effect, there are many urban areas with many facilities in a defective maintenance condition, i.e., in unsatisfactory, under-optimal conservation status, with a subsequent loss in the social benefits received by their inhabitants (Abu-Samra, Ahmed, & Amador, 2020; Arif, E., & Chowdhury,

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2016; Blázquez, Suárez, Ferrari, & Sendra, 2021; Josa & Aguado, 2019; Klumbyte et al., 2020; Nägeli, Farahani, Österbring, Dalenbäck, & Wallbaum, 2019). To remedy this situation, defective facilities require corrective maintenance actions to return them to a condition in which they can fully contribute to the well-being of society.

Ideally, measures for restoring all degraded facilities to a good condition status should be taken at once (Klumbyte et al., 2020). Real-life, however, imposes budgetary restrictions that prevent local authorities from simultaneously undertaking all the required measures, forcing them to prioritise among all the facilities demanding corrective maintenance (Della Spina, 2020; Gade, Larsen, Nissen, & Jensen, 2018; Klumbyte et al., 2020; Lozano & Sánchez-Silva, 2019; Ruiz, Aguado, Serrat, & Casas, 2019). As a consequence, it is necessary to articulate medium to long term management strategies prioritising actions across their asset portfolios (Abu-Samra et al., 2020; Christen, Adey, & Wallbaum, 2016; Gade et al., 2018; Höing & Kaempf-Dern, 2019; Klumbyte et al., 2020; Lu, 2017; McArthur & Jofeh, 2017; Nägeli et al., 2019; Randrup, Svännel, Sunding, Jansson, & Sang, 2021; Zavadskas et al., 2021).

This prioritisation between PFs, however, is not a simple task since both physical and socio-economic criteria should be taken into account (Arif et al., 2016; Josa & Aguado, 2019). In the case of PFs, local authorities would have to evaluate many assets with different characteristics such as their type of social infrastructure, their current MC, or the cost of restoring them to a good condition. Dealing with the renovation of multiple buildings is a relevant matter for municipalities and housing associations, requiring to decide which facilities to renovate and in which order (Nielsen, Jensen, Larsen, & Nissen, 2016; Pannier et al., 2021). To ask this question, it should be borne in mind that, on the one hand, improper functioning of different types of social infrastructure may have a different impact on SUD, which makes it necessary to evaluate the relative contribution to SUD for portfolio management purposes (Fathi-Fazl, Lounis, & Cai, 2021).

On the other hand, also the impact of the MC on the contribution yielded by the assets to SUD may vary according to the type of social infrastructure. In effect, an asset's MC would be more critical for its proper functioning in the case of a hospital than in that of a park or a sports court. Consequently, it is necessary to assess the impact of facilities' MC on their performance, considering their type of social infrastructure. Though some methods have been developed to rank building portfolios based on energy and indoor environmental quality issues, the degree of physical degradation, and the economic cost of the required actions (Caccavelli & Gugerli, 2002; Flourentzou, Brandt, & Wetzel, 2000; Jaggs & Palmer, 2000; Nielsen et al., 2016; Pannier et al., 2021), methods including the type of social infrastructure decision criteria are still lacking.

This study aims to respond to the following research question: when should corrective maintenance be carried out over public facilities in defective MC to maximise their contribution to SUD considering their MC level, type of SI, the cost of the corrective measures, and the availability of economic resources over time?. To this end, this research develops a methodology that is afterwards applied to a case study consisting in developing a regeneration plan aligned with the governmental guidelines. The methodology integrates multi-criteria assessment and an analytical framework for measuring the contribution of an urban area's social infrastructure to its sustainable development based on the type of social infrastructure and the MC of its PFs. Building on an existing inventory of public facilities requiring corrective maintenance, the presented approach prioritises the order in which the assets should receive it to maximize their contribution to SUD. Then, the methodology schedules the maintenance actions as a function of the building's maintenance condition, type of infrastructure, the cost of the corrective measures, and the yearly budget of the municipality.

The presented methodology has been implemented as a software application, called CRISDUSEC, to facilitate the evaluation by experts of the relative contribution of social infrastructure and MC to SUD during the application stage, and to enable them to check the consistency of their judgments. CRISDUSEC includes uses as input data of public buildings of the region of Valencia, Spain, and based on the expert's assessment, it automatically evaluates the potential improvement in SUD that may be achieved through corrective maintenance. Finally, the proposed tool facilitates a prioritised schedule at the municipal level of the assets needing maintenance according to their contribution to SUD and their economic cost. This way, the model articulates the idea that the faster the society receives the benefits associated with the restoration of any infrastructure to a good maintenance condition, the better, as opposed to the social cost related to a delay in this achievement (Lozano & Sánchez-Silva, 2019). Examples of this social cost are delays in the building of infrastructure assets, or having to postpone corrective maintenance over deteriorated roads due to financial unavailability (with the subsequent increase in the risk of accident). Based on these results, local planners can design medium to long term municipal strategic plans with more efficient delivery of benefits to society.

The remainder of this work is structured as follows: section 2 presents a brief literature review on the role of the different types of social infrastructure in sustainable urban development, based on multi-criteria assessment and decision-making methods. Section 3 describes the methodology proposed for evaluating the contribution of PFs to SUD based on their type of social infrastructure and MC and the identification and prioritisation of the corrective maintenance alternatives. Section 4 describes the application of the proposed methodology to a case study and presents the results, which are further discussed in section 5. Finally, in section 6 the main conclusions are drawn, and limitations and future research are suggested.

2. Literature review

2.1. Types of social infrastructure

According to the European Union (EU), investment in the so-called group of Basic social infrastructures, comprising Education Facilities, Health Facilities and Affordable Housing, is considered essential for the economic growth of the EU, the well-being of its people, and a successful move towards upward convergence (Fransen et al., 2018). Coincident with this idea, Grum and Kobal Grum (2020) regarded these types of facilities as the Fundamentals social infrastructure. In contrast, Rodrigues and Franco (2020) stated that health infrastructure, education, and others are inseparable components of sustainable urban development aiming to enhance residents' quality of life.

Along with the Basic social infrastructures, other types are also relevant for society. Grum and Kobal Grum (2020) referred to the recreational and cultural facilities within this group of "Other" types. In the same vein, Latham and Layton (2019) argued that libraries, restaurants, plazas and sidewalks, swimming pools and playgrounds are kinds of spaces and facilities that contribute to the public life of urban areas. Following these findings, the types of social infrastructure were structured into two groups: the Basic and the Extended categories (Figure 1).

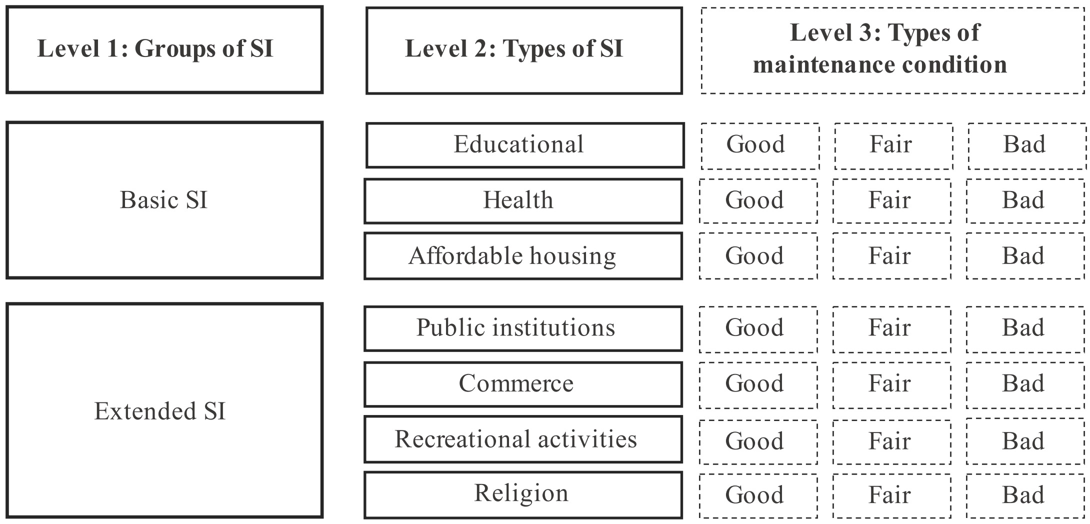

Figure 1. Hierarchical structure of criteria for assessing the contribution of social infrastructure to SUD based on their MC. Developed by the authors based on (Grum & Kobal Grum, 2020; Rodrigues & Franco, 2020; Zavadskas et al., 2021)

2.2. Contribution of public facilities to SUD by type of social infrastructure

The prioritisation of corrective maintenance has led to several methods for assessing buildings portfolios from a sustainability point of view (Arif et al., 2016; Klumbyte et al., 2020). Given the variety of types of social infrastructure present in any public facilities portfolio, its prioritisation requires accounting for the different contributions to sustainability that each type may yield. However, most existing assessment methods focus on evaluating sustainability for a given type, instead of multiple kinds of social infrastructures.

Mahmoud, Zayed, and Fahmy (2019) designed an assessment tool for existing facilities in which they developed a sustainability assessment method that included site-specific attributes along with others inherent to the building analysed. This work aimed to evaluate the impact of regional variations on sustainability assessment, but it did not consider the type of social infrastructure of the analysed asset. Gade et al. (2018) proposed an assessment tool based on a set of indoor and outdoor technical features of the facilities, which allowed them to evaluate a portfolio of 56 schools. Still, in this method, no attention was paid to the type of social infrastructure. Nägeli et al. (2019) evaluated buildings sustainability from a service life-cycle approach, while Klumbyte et al. (2020) developed a model that assessed sustainability in the management of an assets portfolio.

The above methods exclusively focused on residential buildings. Similarly, Klumbytė, Bliūdžius, Medineckienė, and Fokaides (2021) developed a multi-criteria method ranking investment alternatives related to the specific case of the management of residential buildings. In the same vein, Blázquez et al. (2021) addressed the potential for improvement of the urban building stock, in which they distinguished between "archetypes" of buildings. Still, again, their study was limited to residential buildings. Finally, Zavadskas et al. (2021) included four types of social infrastructure in their assessment,but did not provide a framework to evaluate their relative importance (e.g. education vs commercial facilities), nor does it take into account the assets' MC.

Therefore it provided only a partial solution to the assessment problem.

2.3. Contribution of public facilities to SUD by their maintenance condition

Equally crucial for assessing the contribution of PFs to SUD is the fact that the effect of MCs on the contribution of PFs to SUD may also vary from one type of social infrastructure to another. For example, the MC is more critical for the proper functioning of an asset in the case of a hospital than a park. This means that the loss in the contribution to SUD due to a defective MC will be different depending on the type, and it is therefore essential to account for such effect when prioritising asset portfolios covering different types. To reflect the impact of MC on assets' sustainability, some assessment methods have included criteria regarding assets' MC. Klumbyte et al. (2020) included a criterion referring to the good technical condition of the building for the assessment of residential assets, while Nägeli et al. (2019) resorted to the building's year of construction and year of renovation to reflect the building's MC and derive the corresponding maintenance actions. More explicitly, Gade et al. (2018) classified facilities' MC into the A-good, B-medium, C-worn out, and D-defective categories. However, none of these works differentiated by the type of social infrastructure when evaluating the effect on the sustainability of the assessed building's MC. Therefore, it is necessary to establish the relative impact of facilities' MCs for each type to properly evaluate public buildings portfolios.

2.4. Multi-criteria character of the assessment

As indicated above, prioritising the corrective maintenance of public buildings portfolios is a complex task requiring the assessment of the relative contribution to SUD of each facility, both by type of social infrastructure (Zavadskas et al., 2021), and by MC (Gade et al., 2018). At the same time, the economic cost also plays an essential role in prioritising PF portfolios, which makes it necessary to balance the contribution to SUD and the economic criteria (Christen et al., 2016; Klumbytė et al., 2021; McArthur & Jofeh, 2015; Randrup et al., 2021; Zavadskas et al., 2021). While some works already provide a sustainability assessment including some of these aspects, no method has yet been developed that addresses all of them.

3. Methods

The proposed methodology aims to answer the research question posed in this work, namely when should corrective maintenance be carried out over PFs in defective MC to maximise their contribution to SUD considering their MC level, type of SI, the cost of the corrective measures, and the availability of economic resources over time?. By following the reasoning embodied in the cognitive approach described in Figure 2, urban planners are enabled to assess the relative contribution of different types of social infrastructure to SUD based on their MC (section 3.1). This assessment implies answering two different, though interconnected, questions, namely:

- What is the relative contribution different types of social infrastructure may make to an urban area's sustainable development? (Figure 2, Question/Model 1)

- What is the relative effect that different MCs may have on the contribution of each type of social infrastructure to SUD? (Figure 2, Question/Model 2)

The methodology also includes an analytical framework which, based on the weights yielded by the multi-criteria assessment, provides a metric, called SUD_{Gain}, to evaluate the potential contribution of an urban area's public facilities to its SUD through corrective maintenance (section 3.2). Based on this, planners could realise to what extent the assets' MC is undermining their contribution to the SUD of the analysed urban area. This, together with the economic cost of the corrective actions required to restore PFs to a good condition, is employed to generate, via a multi-criteria decision technique, a prioritised queue of the assets that should receive maintenance in the first place (section 3.3). Then, this queue is employed to schedule the potential maintenance actions, which allows evaluating the efficiency of the delivery of benefits to society from a temporal point of view (section 3.4).

Finally, the whole process was implemented as a Multiple Criteria Decision Aiding software, called CRISDUSEC, to guarantee judgment consistency (Salas & Yepes, 2019), and to support the assessment and decision processes required for the application of the proposed methodology to the case study (section 4). Based on the results of this application, different balances between contribution to SUD and economic cost for the ranking of PFs are considered to evaluate the trade-off between preference for SUD or economic cost (section 5.1). As well, an ANOVA model is fitted to investigate the effect of an increase in SUD over economic cost (section 5.2).

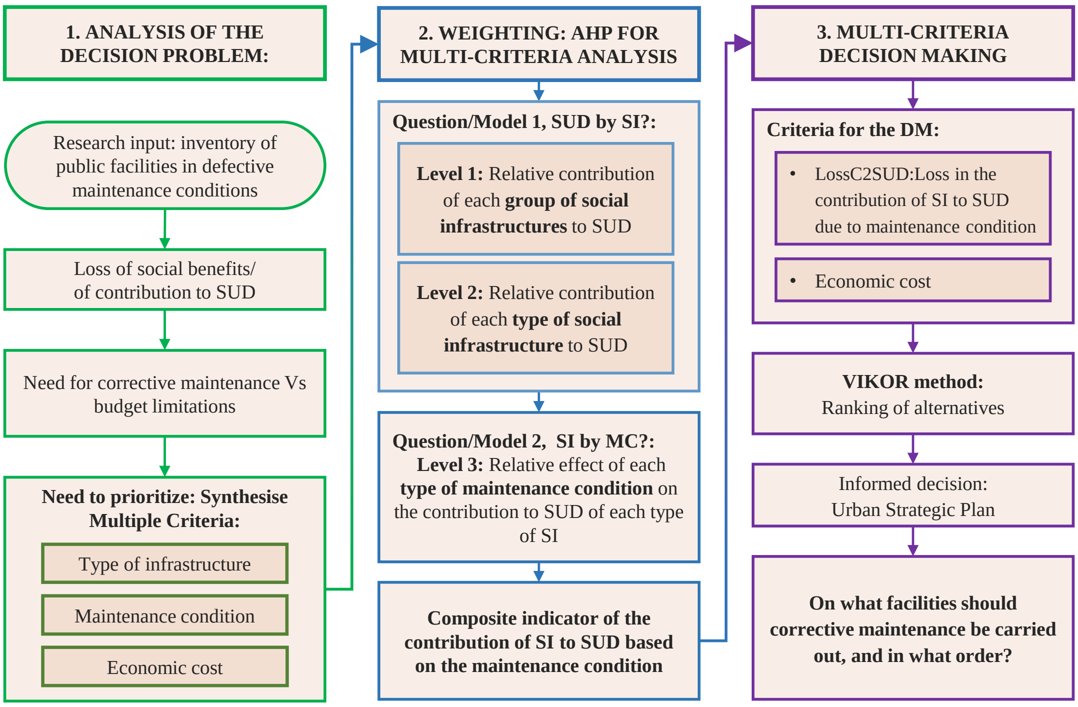

Figure 2. Problems identified and evaluation framework required to improve PFs' corrective maintenance contribution to SUD

3.1. *Assessing the relative contribution of an urban area's public facilities to SUD*

3.1.1. Multi-criteria assessment method

Researchers have proposed many multi-criteria decision-making methods and techniques in the past decades for the evaluation of building sustainability (Della Spina, 2020), among which the Analytical Hierarchy Process (AHP) is recognised as the most commonly used method for determining the weights of criteria (Saaty, 1990; Zavadskas, Govindan, Antucheviciene, & Turskis, 2016).

The analytic hierarchy process (AHP) is a structured technique for organising and analysing complex decisions, which was previously employed in the multi-criteria assessment of sustainability-related issues of infrastructures and urban planning (Navarro, Yepes, & Martí, 2020; Sierra, Pellicer, & Yepes, 2017; Zamarrón-Mieza, Yepes, & Moreno-Jiménez, 2017). Della Spina (2020) used AHP for assigning weights to the criteria employed in the evaluation of strategies for the recycling of cultural heritage assets, while Salas and Yepes (2018) resorted to AHP for the selection of indicators for evaluating urban vulnerability. Specifically, AHP has also been used by researchers for the assessment of sustainability in PF portfolios, as well as for informing decisions regarding maintenance actions (Gade, Jensen, Larsen, Nissen, & Andresen, 2021; Gade et al., 2018; Klumbyte et al., 2020; Klumbytė et al., 2021; Makoond, Pelà, & Molins, 2021; Zavadskas et al., 2016).

As stated in section 2.4, for the evaluation of the contribution of PFs to SUD, it is necessary to respond two different, though interconnected, questions:

- what is the relative contribution different types of social infrastructure may make to an urban area's sustainable development?.
- what is the relative effect that different MCs may have on the contribution of each type of social infrastructure to SUD?

To respond these two questions, the proposed approach includes two hierarchical models (Figure 2), each addressing one of them based on the criteria described in Figure 1. After completing the assessment process, the proposed methodology connects the results of these models in the following way: the results of model 2 are used to assess to what extent a PF is delivering to society the intended social benefits based on its type (e.g., to what extent a PF is performing its task as a hospital when it is in good, fair or bad MC). Then, this PF's performance is weighted based on the results of model 1, which evaluated the relative contribution to SUD of PFs by different types. Using the latter step, the proposed methodology makes it possible to assess the contribution to SUD of a PF portfolio composed of facilities of various kinds based on the PF's MC.

Once the relative preferences of the criteria within each PCM have been obtained, they have to be aggregated for the elicitation of the composite indicator. To do so, the hierarchical composition principle was followed, multiplying successively the relative preferences of the dependent elements by the weight of the component on which they depend (Level 2 depends on Level 1 and so on) to obtain the total priorities. Before calculating the absolute weight score, at Level 3 the weights assigned to the good, fair and bad maintenance condition criteria were normalised by the weight of the good maintenance condition. This way, we modelled the assumption that in the good status, the MC is not undermining assets' delivery of social benefits to society. In other words, in good condition the PF's performance is 100% of its potential.

3.2. Analytical framework for assessing the contribution of an urban area's PFs to its SUD

3.2.1. Composite indicator of the contribution of an urban area's public facilities to SUD

The absolute weight scores yielded by the proposed multi-criteria assessment process described above afforded the construction of a composite indicator for evaluating the contribution of an urban area's social infrastructure to SUD based on the maintenance condition of its PFs. Starting from the proportion of each type of social infrastructure and each type of maintenance condition, it is possible to calculate, based on the maintenance condition physical attributes of the assets, how much of the potential contribution of PFs to SUD is actually being achieved. To this end, it is necessary an inventory of public facilities indicating, for each asset of an urban area, its type of SI, maintenance condition and surface. It is critical to include all the buildings in the analysis since the method provides a relative metric, which therefore depends on the total built area. Accurate and reliable databases providing the required information in a structured way, covering all the assets in the area being analyzed, is essential. As owners, public bodies are called to develop and maintain that kind of database. In the EU zone, the development of an overview of each country's national building stock is required to establish long-term renovation strategies supporting the renovation of their national building stock (European Union, 2020). In Spain, for example, the government has developed the EIEL, an inventory of urban infrastructures of municipalities periodically updated including the required information (Spanish Government, 2019).

The proposed methodology aims to determine the relative contribution of each public facility to an urban area's sustainable development based on their maintenance condition and type of social infrastructure. The procedure is formalized as follows: first the ideal contribution SUD_{Max} is calculated for each asset as the product of the relative contribution of its type of SI and built area (2).

Then, this ideal contribution is normalized by the sum of the ideal contributions of all assets (3), so that the sum of all asset's contributions equals to one. Then, the actual contribution SUD_{Real} is calculated as the product of the ideal contribution and the normalized weights of the maintenance condition specific to each asset's type of SI (4) . The analytical formulation is given as follows:

Let U be a given urban area with $PF(U)$ public facilities, composed of facilities of the types described in Figure 1:

$$PF(U) = \{PF(SI_1), \ldots, PF(SI_n), \ldots, PF(SI_m)\} \tag{1}$$

where m is the number of SI types in U urban area, and $PF(SI_n)$ is the n social infrastructure type inventory in U. The potential contribution of each type to SUD was calculated as the product of the proportion of each type by its absolute weight at the assessment Level 2 (Figure 2, Model 1):

$$SUD_{Max}\,(PF(SI_n)) = \frac{S(PF(SI_n)) \times W_n^{L2}))}{\sum(PF(U))} \tag{2}$$

where $S(PF(SI_n))$ is the built area of each type of the n type of social infrastructure, and W_n^{L2} is the absolute weight score obtained through the multi-criteria assessment at Level 2 (Figure 2, Model 1) for the n type.

Since this study is focused on the impact of the maintenance condition of the existing social infrastructure, the contribution of each type to SUD could be normalised by its sum. This way, it is possible to assimilate the SUD_{Max} potential contribution to a 100% efficiency in the delivery of social profits from a temporal point of view:

$$SUD_{Max}\,(PF(SI_n)) = \frac{SUD_{Max}\,(PF(SI_n))}{\sum_{n=1}^{m} SUD_{Max}\,(PF(SI_n))} \tag{3}$$

Conversely to the potential contribution3, we calculated the actual contribution ($SUD_{Real}\,(PF(SI_n))$) by taking into account the actual condition of the facilities, and the weights assigned to them for each type of social infrastructure (Figure 2, Model 2, Level 3). In this case, the composite indicator is formulated as the product of the potential contribution by the proportion of each type of social infrastructure in each j maintenance condition, and by the absolute weight score of the types of maintenance condition of each type at Level 3 (W^{L3}):

$$SUD_{Real}\,(PF(SI_n)) = SUD_{Max}\,(PF(SI_n)) \times \sum_{j=1}^{k} \frac{s(PF(SI_j^n)) \times W_{n,j}^{L3}}{s(PF(SI_n))}, \tag{4}$$

$$MC = \{Good, Fair, Bad\} \tag{5}$$

where $s(PF(SI_j^n))$ is the built area of PFs with n type of social infrastructure in j type of MC, k is the number of elements in MC.

3.2.2. Loss in the contribution of public facilities to SUD due to defective maintenance condition

The above described analytical framework made it possible to calculate the potential (SUD_{Max}) and the actual (SUD_{Real}) contribution of social infrastructure to SUD in any urban area. Since SUD_{Real} includes the depreciation of the contribution to SUD due to having facilities not in good condition, it is possible to calculate the loss of contribution (SUD_{Loss}) in an urban area as the difference between the potential and the real contribution:

$$SUD_{Loss} = SUD_{Max} - SUD_{Real} \tag{6}$$

Moreover, this formulation can be extended to the calculation of the SUD_{Loss} of any facility, which on the other hand, also represents the potential gain in the contribution to SUD that can be achieved by restoring facilities to a good condition (since SUD_{Loss} is a consequence of their defective condition, and by their restoration SUD_{Loss} will be cancelled):

$$SUD_{Gain} = SUD_{Loss} \tag{7}$$

SUD_{Gain}, together with the economic cost, can be used as a criterion for the prioritisation of corrective maintenance in the urban planning decision-making stage as explained below.

3.3. Ranking of the corrective maintenance alternatives

To address the problem of having multiple criteria (gain in the contribution to SUD and economic cost) for prioritising corrective actions in PF portfolios, the presented assessment process resorted to the VIKOR method (Opricovic & Tzeng, 2004). This method has been chosen for two reasons: on the one hand, the VIKOR technique is beneficial to make a sensitivity study of the results by varying the strategic factor VkW_{SUD} as a function of the preference to its two metrics (Sánchez-Garrido, Navarro, & Yepes, 2022), as proposed in section 5.1.

On the other hand, the VIKOR technique has already been employed in connection with AHP in several works relating to prioritising infrastructure alternatives in urban and regional planning (Anelli, Santa-Cruz, Vona, Tarque, & Laterza, 2019; Canto-Perello, Morera-Escrich, Martin-Utrillas, & Curiel-Esparza, 2018; Lin et al., 2020; Martin-Utrillas, Juan-García, Canto-Perello, & Curiel-Esparza, 2014; Martin-Utrillas et al., 2014; Muñoz-Medina, Romana, & Ordoñez, 2019).

VIKOR calculates the S, R and Q values and ranks the alternatives according to these metrics to rank alternatives. While the S and R metrics are exclusively employed to determine the number of alternatives included in the compromise solutions, the Q metric is the sole criterion used to rank the alternatives in the set of compromise solutions. Therefore, the Q metric can be employed as a valid prioritisation criterion. Consequently, this metric was adopted to order the facilities on which maintenance alternatives must be carried out.

3.4. Scheduling of the corrective maintenance

Fast delivery of well-maintained facilities to the people and the use of minimal monetary resources due to budget restrictions are two key criteria in maintenance policy decision-making (Lozano & Sánchez-Silva, 2019). To enable this trade-off,a method for scheduling the maintenance actions based on the prioritised queue described above is presented in this section. Be $A(U) = \{A_1, A_2, \ldots, A_k\}$ the ranking of the actions of the k PFs of the U urban area, H_U the scheduling horizon, and $C(U) = \{C_1, C_2, \ldots, C_j\}$ the set of the costs of the actions included in $A(U)$. The following rules are employed to set up the schedule:

- All the urban area's PFs must be restored to good condition within the scheduling horizon.
- The urban area's affordable expenditure in each period (E_t) will be the same along the scheduling horizon. Therefore, $E_{t_0} = E_{t_1} = \cdots = E_{t_{H_U}} = \frac{\sum_1^k C(U)}{H_U}$
- The MC activities will be executed sequentially, following the order of the $A(U)$ ranking, and distributed along the schedule horizon so that in every period, the investment (cost) will meet the maximum affordable expenditure E_t.
- The contribution to SUD yield by each MC activity will not be effective until the activity is completed, which means that in activities distributed along two or more periods, the whole contribution to SUD of this asset will be allocated in the last period.

By implementing these rules, it is possible to obtain, for each urban area, an investment schedule and a contribution to SUD schedule. Based on this, the method calculates the net present value of the investment (NPV_{Cost}) and of the contribution to SUD (NPV_{SUD}) as the metrics to assess the efficiency in the return to the society of the benefits yield by the schedule.

4. Application

Rehabilitation and maintenance are recognised as key drivers for the sustainability of constructions and a possible means to improve the resilience of the built environment, thus fitting SDG 11 (Barrelas, Ren, & Pereira, 2021; Izaddoost, Naderpajouh, & Heravi, 2021). Therefore, governments worldwide are issuing specific frameworks for designing an implementation plan of corrective measures focusing on rehabilitation and maintenance. This study proposes testing the usefulness of the presented methodology for developing an urban regeneration strategy (URS) aligned with a government's urban regeneration strategies as a case study.

4.1. Case study: Assessing the contribution of corrective maintenance to SUD in the Region of Valencia, Spain

The Region of Valencia has developed a regional URS to help local governments achieve the EU's and UN's Sustainable Development Goals (SDGs) (European Union, 2015; United Nations, 2015b). Among others, one of the lines of action proposed in the URS is the *"execution of works or maintenance and intervention works in single-family homes and facilities, including inside homes, fixed installations, equipment own and common elements, to adapt them to the standards provided by the regulations"*. Consequently, the prioritised queue of corrective maintenance provided by the proposed methodology can be used to design local URSs including that type of intervention.

4.1.1. Guidelines for urban regeneration strategic planning

The Region of Valencia has developed its "Guidelines for developing urban regeneration strategies" (GDURS) (Government of the Region of Valencia, 2018), which provides a methodology that local authorities can systematically use to design urban regeneration processes. This methodology includes a series of steps (Figure 3) which, in essence, correspond to those of the multi-criteria analysis and decision-making process proposed in our study (Figure 2). First, an initial stage in which the problem and potential solutions are identified (Stage A); second, an assessment stage in which the potential solutions are evaluated (Stages B and C); and third, a decision stage in which the alternatives to be implemented are selected and prioritised (Stage D).

On the other hand, each municipality of the Region of Valencia has to develop and submit its urban plan of municipal actions (UPMA), a document conveying the strategic vision of future works and services included in the municipal agenda. This plan should cover *"Investment in restoration and conservation of facilities with marked cultural or patrimonial value, that pursues its enhancement and effective use or putting at the service of the citizenship."*, to achieve the SDG 11 (Provincial government of Valencia, 2020; United Nations, 2015a). To elaborate this plan, the provincial government of Valencia proposes a methodology similar to the GDURS, which includes a preliminary analysis and diagnosis stage, a results stage, and an implementation stage. Unlike the GDURS, however, the provincial methodological framework does not have any integrated analysis providing insights on the effect of the proposed measures on SUD or urban vulnerability, a gap that can be overcome using the results provided by the assessment and decision-making process presented in this work.

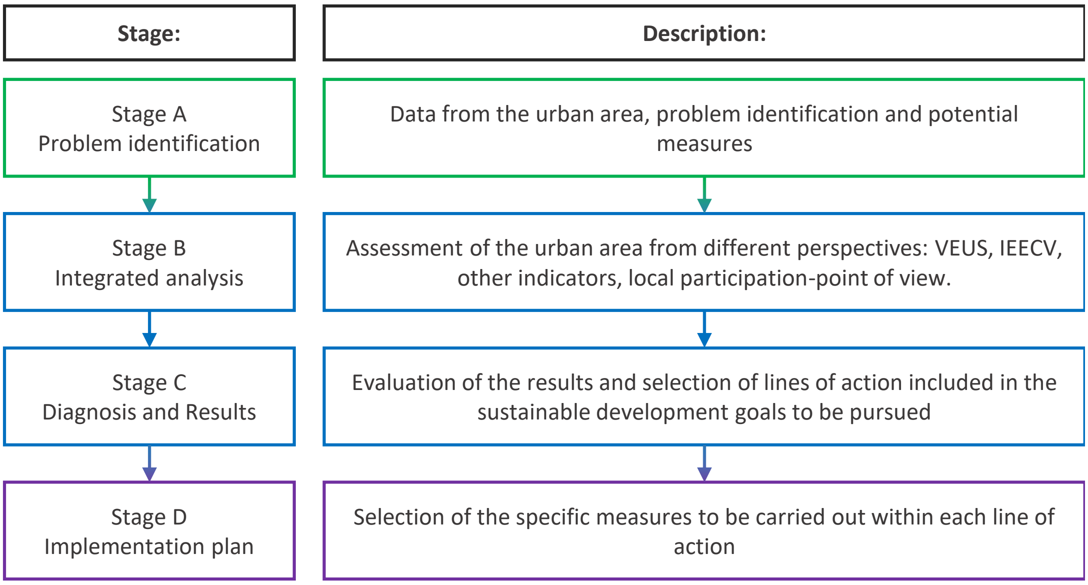

Figure 3. Stages in the formulation of URS according to the government of the Region of Valencia

4.1.2. Input of information

To identify the problems arising from a defective maintenance condition of PFs in the area of study, the quantitative information relating to the municipalities of this region was compiled from the Local Infrastructure and Equipment Survey (EIEL) (Spanish Government, 2019). The EIEL is an inventory of urban infrastructures of municipalities of 50,000 inhabitants or less in most Spanish regions. This study used data for 2019 since it contained the most up-to-date data of the three provinces composing the Region of Valencia. The EIEL includes a range of infrastructures, of which those corresponding to the types of social infrastructure listed in Figure 1 were selected, as shown in Table 1.

To determine the relative contribution of PFs to SUD by the type and type of MC, a team of 12 experts was recruited to complete the required pairwise comparison. Candidates had at least five years of experience in civil engineering or urban planning, and a master's degree or higher. Each expert had to complete the process embodied in the CRISDUSEC software, which enabled them to navigate through all the judgments to be performed and complete them with the aid of the consistency index.

4.2. Results

4.2.1. Identification of the decision problem

Figure 4 shows the heterogeneity of the maintenance condition in the Region of Valencia across the types of social infrastructure, and provinces. Across the types, the proportion of facilities in fair or bad condition, and therefore needing corrective maintenance, ranges from 5% in Care Facilities to 72% in Public Housing for the case of the province of Alicante. On the other hand, the contribution to SUD in the province of Valencia by types ranges from 3% in the case of Care Facilities, to 52% in the case of Public Housing.

Table 1. Types of social infrastructure (SI) selected from the EIEL-2019, assessment of their relative contribution to SUD according to the experts' panel, and costs of corrective maintenance

Group of SI	Types of SI		Maintenance Condition (*)		Maintenance Cost €/m2 (**)	
	Name	Weight	Fair	Bad	Cost	**Bad**
Basic SI (Weight=0.768)	Educational facilities (EF)	0.181	0.381	0.162	160.93	330.33
	Health facilities (HE)	0.352	0.293	0.106	258.64	530.89
	Care facilities (CA)	0.141	0.345	0.142	195.42	401.12
Extended SI (Weight=0.232)	Public housing (PH)	0.096	0.529	0.249	109.2	224.15
	Cultural facilities (CU)	0.079	0.554	0.262	189.67	389.32
	Public markets (PM)	0.053	0.368	0.221	166.68	342.13
	Sport facilities (SP)	0.048	0.525	0.309	172.43	353.93
	Public parks (PP)	0.050	0.576	0.317	12.64	25.95

(*) Weights normalized by "Good" score after the AHP process
(**) Fair/Bad rehabilitation coefficients (over construction construction) = 0.19/0.39, based on costs by type of SI of the Government of the Region of Madrid (2020) and the Basic Building Cost in the province of Valencia (Valencian Building Institute, 2018)

In the same vein, the contribution to SUD by type of maintenance condition also shows significant heterogeneity in some types of social infrastructure: in the province of Valencia, for example, 29% of Public Housing is in bad condition while only 1% of Care Facilities are in this condition. In Alicante, 48% of Public Housing is in bad condition while all Health Facilities are in good or fair condition.At any rate, Figure 4 shows that in the case of Public Housing, Public Markets, Educational Facilities, Sports facilities and Educational Facilities types, more than 15% of their facilities are in fair or bad condition, with the subsequent loss of benefit for the inhabitants of this region.

As to the variation of the maintenance condition across provinces, in the case of Public Housing, the proportion of facilities needing corrective maintenance ranges from 31% in Castellon to 52% in Valencia and 72% in Alicante. Also in Public Parks there is significant variation among provinces, with 2% of parks needing corrective measures in Alicante, and 24% in the province of Valencia. Such heterogeneity suggests an important impact of the relative contribution of PFs to SUD by their type of social infrastructure, maintenance condition, and location. Therefore, an adequate weighting of the relative importance of each type becomes a critical issue for a correct analysis and prioritisation of the alternatives.

4.2.2. Assessment of the contribution of public facilities to SUD

For the collection of expert judgment, the CISDUSEC software integrating the proposed methodology was disseminated among the selected experts. Then, the overall assessment of the contribution of social infrastructure to SUD was elicited as the non-normalised geometric mean of all individual assessments (Klumbyte et al., 2020; Salas & Yepes, 2018), the results of which are shown in Table 1. Regarding the effect of the social infrastructure maintenance condition, on average social infrastructure in "Fair" condition contributed to SUD 44.69% than it would do in "Good" condition. In comparison, those in "Bad" condition contributed 22.15 % than in "Good" condition. The results show that in some types, such as Health Facilities, the sum of the contribu-

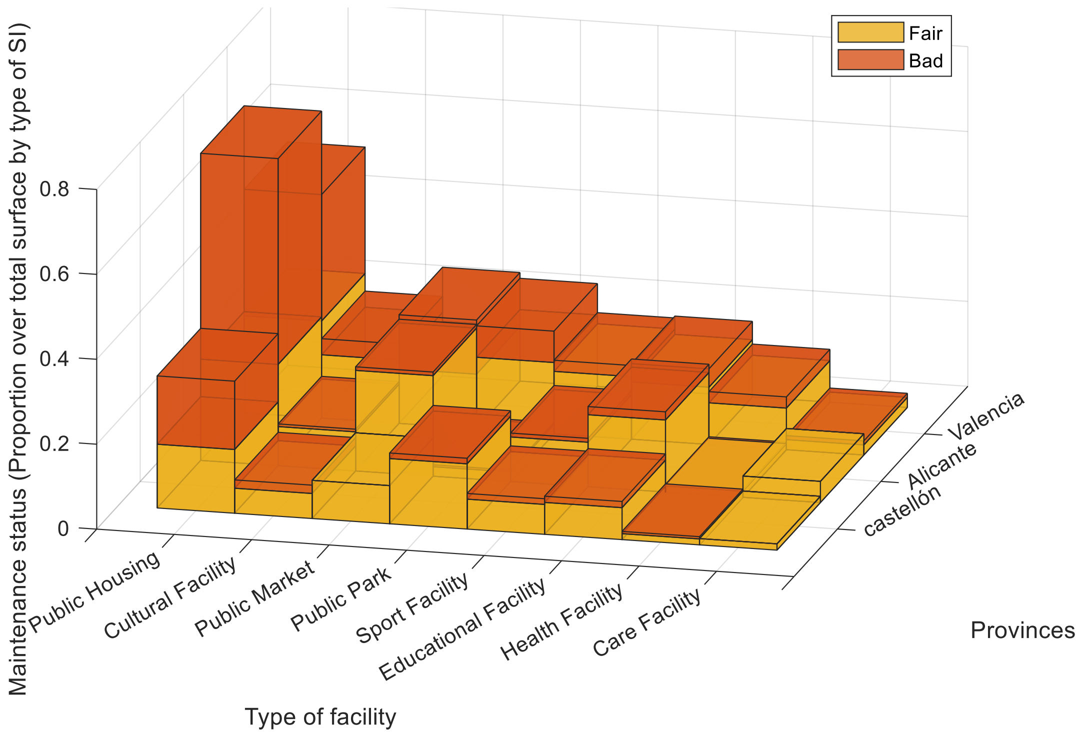

Figure 4. Proportion of facilities needing corrective maintenance by type of social infrastructure in the Region of Valencia

tion to SUD of this type of PF in Fair or Bad maintenance conditions is much lower $(0.381 + 0.162 = 0.543)$ than in others like Public Parks $(0.576 + 0.317 = 0.893)$.

All the above supports the idea that a defective maintenance condition has a higher negative impact on their functioning for some types, such as Health Facilities. Besides, Table 1 shows that for the experts consulted, there is high variability in the contribution of social infrastructure to SUD by type, which stresses the need to take this variable into account in the assessment process. Specifically, for the experts, Health and Public Market facilities are the most sensitive to the maintenance condition, while Cultural and Educational facilities are the most robust to the maintenance condition.

Based on the weights obtained in the previous step, CRISDUSEC provides the contribution of social infrastructure to SUD at regional, provincial and municipal levels, in terms of the potential (SUD_{Max}), the actual (SUD_{Real}), and the loss of contribution due to defective maintenance condition (SUD_{Loss}). Figure 5 represents the results of the contribution of social infrastructure to SUD by type and MC, and it shows the impact of incorporating the experts' judgment on this assessment. In the case of Care Facilities, for example, the potential contribution to the regional SUD (SUD_{Max}) increases from nearly 10% when assigning the same relative importance to all types (unweighted SI), to almost 25% when considering the weights assigned by the experts (weighted SI). In the same vein, Health Facilities grows from 5% to 20%. In contrast, Public Parks drop from 27% to 9% in the cases of unweighted and weighted social infrastructure, respectively.

Figure 5 also shows the effect of the PFs maintenance condition on SUD by type of social infrastructure, and how this impact changes depending on whether types of social infrastructure are ignored (Figure 5 (a)) or taken into account (Figure 5 (b)). In the case of the Health Facilities, for example, the difference between the

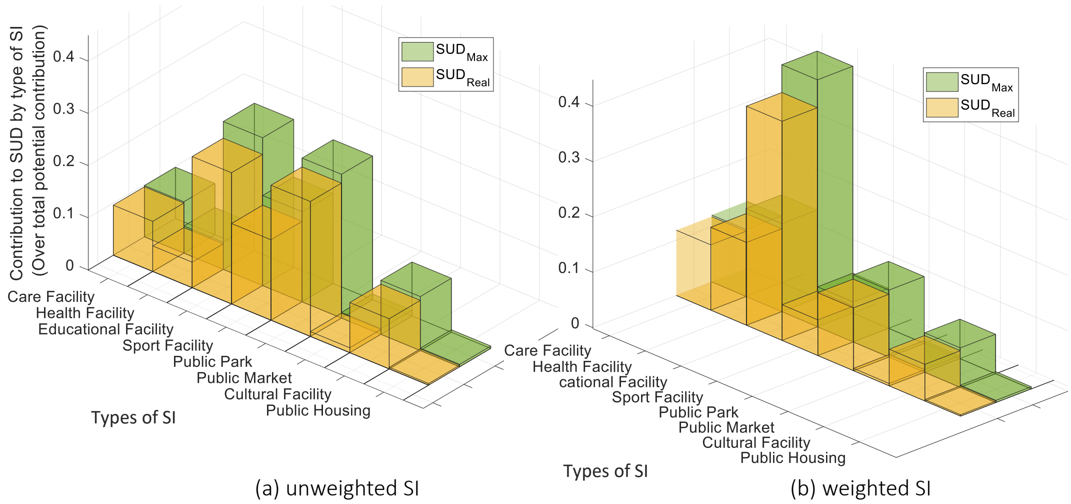

Figure 5. Potential (SUD_{Max}) and actual (SUD_{Real}) contribution of PFs of the Region of Valencia to its sustainable urban development based on PFs maintenance condition, results before (a) and after (b) multi-criteria analysis

potential and the actual contributions, i.e., the loss of contribution (or potential gain of contribution), changes from nearly 0.4% in the case of unweighted SI, to 1.2% in that of weighted SI.

Figure 6, on the other hand, shows the differences in the relative contribution of each type of social infrastructure to the area's SUD depending on the location selected. At the provincial level, in the areas of Valencia or Castellón the contribution of Care and Health Facilities to the provincial SUD is much more significant than in the case of Alicante, in which Public Parks plays a much more critical role. This illustrates the risks of developing detailed planning relying exclusively on regional analysis and the importance of basing the detailed planning on local (municipal) analysis. In this way, it is possible to acknowledge local singularities and enable adaptation at the local scale required for more resilient planning (Salas & Yepes, 2020).

4.2.3. Prioritisation and planning of the corrective maintenance of PFs at the municipal level

To be eligible for financial support from the regional government, the municipalities of the Region of Valencia have to develop and submit their own UPMA plan, a document conveying the strategic vision of future works and services included in the municipal agenda. In this section, the assessment results at the local scale are used to build a prioritised queue of maintenance actions, which can be used as the backbone of the required UPMAs.

At the local scale, the CRISDUSEC tool enables the selection of any of the municipalities included in the study and visualises the facilities of the selected area needing maintenance. Then, based on the potential gain of contribution to SUD ($SUD_{Gain} = SUD_{Loss}$, Eq. 6), the software provides a prioritised queue of assets needing corrective maintenance. To estimate the economic cost, CRISDUSEC employed the costs included in Table 1. This table calculated the maintenance costs as the basic construction cost's product and the maintenance's ratio to the construction cost. The basic construction cost represents building a new asset obtained from Valencia's Institute of Housing (Valencia's Institute of Housing, 2020), while the Fair

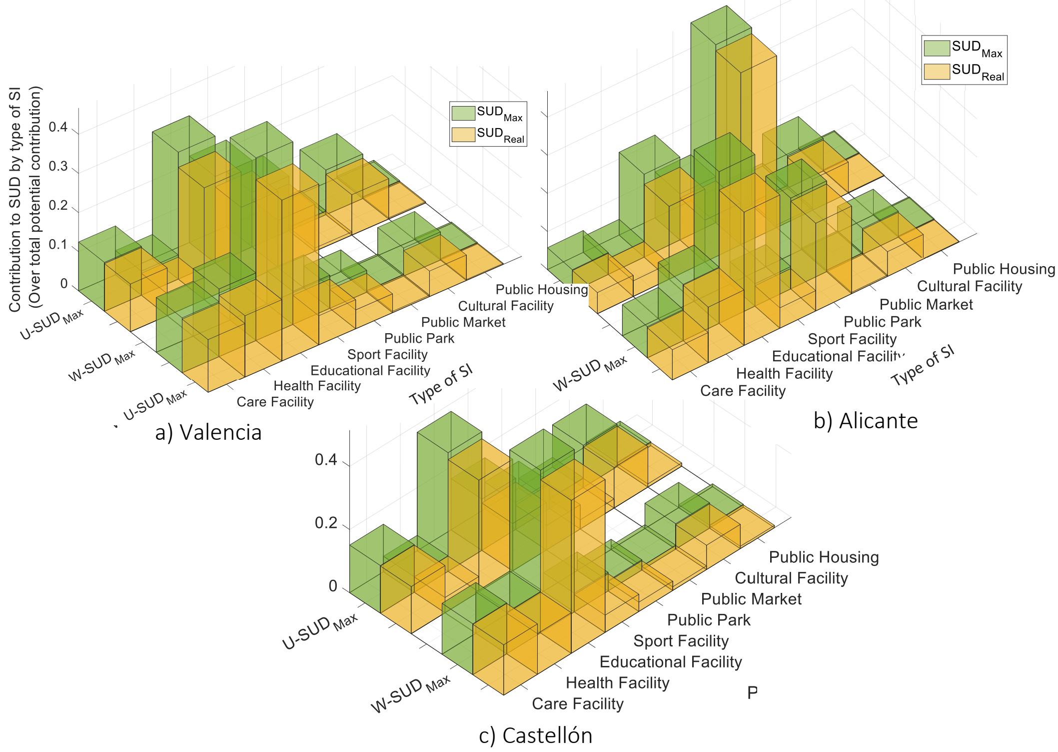

Figure 6. Potential (SUD_{Max}) and actual (SUD_{Real}) contribution of PFs of the Region of Valencia to its sustainable urban development based on PFs maintenance condition; results before (a) and after (b) multi-criteria analysis

and Bad maintenance costs represent the cost of corrective maintenance of assets in a fair and bad state respectively. These costs are calculated as the product of the Fair and Bad maintenance coefficients, and were obtained based on the estimations of the Autonomous Community of Madrid for different types of building rehabilitation (Government of the Region of Madrid, 2020). As a result, the VIKOR method ranked the set of potential maintenance actions based on their contribution to SUD and economic cost (Figure 7). This affords to select the set of most convenient actions given the city's budget restrictions to configure the city's UPMA. Based on this, the proposed methodology quantifies the contribution to SUD of each plan as the sum of the contributions yielded by each of the included actions.

Figure 7 shows the capacity of the proposed methodology to make explicit the impact of the relative contribution to SUD by type. In the case of the municipality of Buñol, for example, the total potential gain in the contribution to SUD would be much more significant in the case of considering the relative contribution of social infrastructure to SUD ($TOTAL\ SUD^{WSI}_{Gain}$) than in the case of ignoring it ($TOTALSUD^{USI}_{Gain}$). In the same vein, the effect of the relative contribution of PFs to SUD by type of SÏ also applies to individual assets. According to the consulted experts, facilities of the Health type are far more critical to SUD than other types (Table 1), and therefore received larger weights (Table 1). As a result, Health Facilities such as the "PF-17" had a SUD^{WSI}_{Gain} almost three times the SUD^{USI}_{Gain}. In contrast, types with a low relative contribution to SUD present a SUD^{WSI}_{Gain} much lower than the SUD^{USI}_{Gain} (e.g. facility "PF-11", of the "Sports facilities" type).

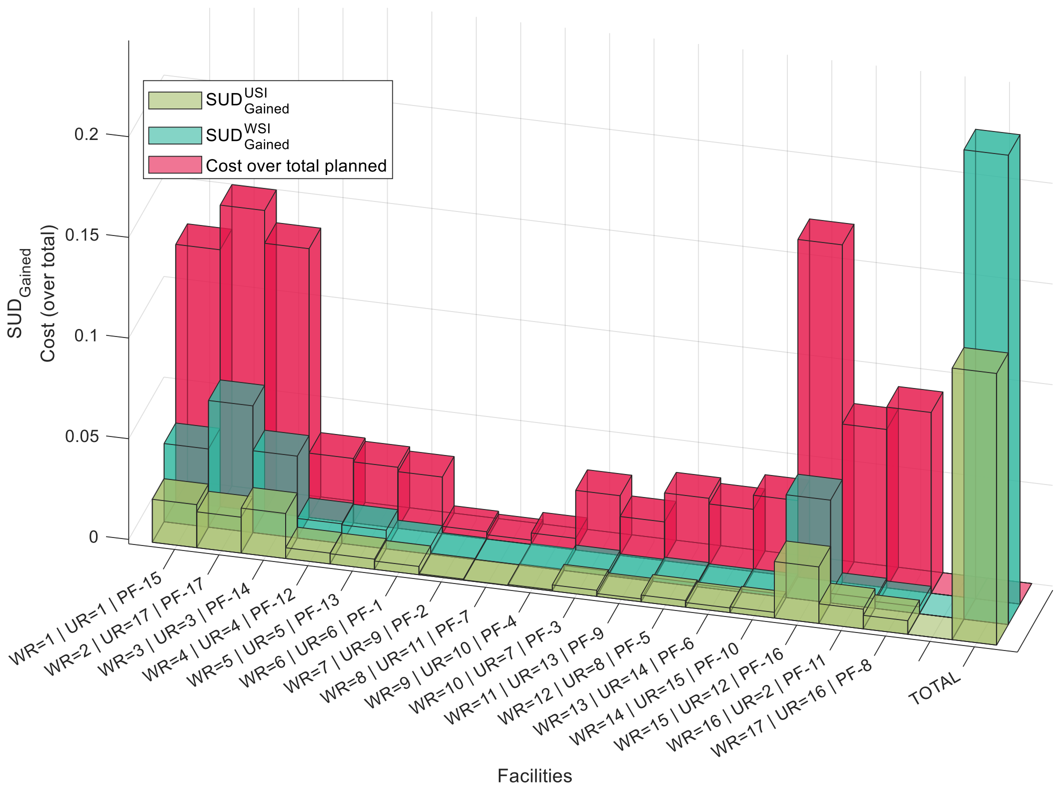

Figure 7. Potential gain in the contribution to SUD in PFs of the municipality of Buñol and position of assets in the weighted(WR) and unweighted (UR) rankings

Consistent with the above idea, the ranking of PFs requiring CM also varies from considering or not the relative contribution of social infrastructure to SUD. Figure 7 shows that the "PF-17" facility is ranked second in the weighted ranking (WR), while it was assigned 17^{th} position in the unweighted rank (UR). Conversely, the corrective maintenance of the "PF-11" facility is a top priority in the UR (2^{nd}), but it is far less important in the WR. On the other hand, the 15^{th} position of the "PF-16" facility in the WR ranking is disproportionately bad compared to its SUD^{WSI}_{Gain} value. This is because of the high cost of restoring this asset to a good condition, which the Vikor method, employed in the ranking process, penalised. As described in section 3.3, the ranking of alternatives was made based on their SUD^{WSI}_{Gain} and $Cost$, which in the VIKOR method, have to be a priori weighted. In the case of Figure 7, $SUD^{WSI}_{Gain} = Cost$, i.e., they received a weight of 0.5. However, different weights in these criteria may lead to other positions in the ranking. as will be shown in section 5.1.

These findings reveal the impact of considering, or not, the experts' evaluation of the relative contribution by type of social infrastructure in the ranking of alternatives. Also, they suggest that different balances between the criteria employed in the ranking process may lead to assets occupying various positions in the ranking. To verify the practical implications of these effects for planning, the next section compares the results obtained from using both rankings (WR and UR) in scheduling the required maintenance.

5. Discussion

5.1. Increased efficiency in the delivery of benefits to the society through public facilities corrective maintenance

As explained above, the municipalities of the Region of Valencia have to develop and submit their own UPMA to be eligible for financial support. CRISDUSEC implements a method for scheduling the required maintenance actions over PFs of the evaluated urban areas (Section 3.4). Based on this, the method calculates the net present value of the investment (NPV_{Cost}) and of the contribution to SUD (NPV_{SUD})as the metrics to assess the efficiency in the return to society of the benefits yielded by the schedule. To reveal the implications of using or not the relative contribution of PFs to SUD by type of SI as assessed by the experts consulted, the following approach has been employed:

(1) for every one of the 542 municipalities included in the dataset, SUD and Investment schedules were built using both the WR and the UR rankings described in the previous section.
(2) The overall SUD and Investment schedules were obtained as the mean of the schedules calculated in the last step.
(3) The overall SUD and Investment NPV were accepted as the sum of the NPVs calculated in the previous step. Then, the improvement in NPV was calculated as:

$$NPV_{WR-UR} = \frac{NPV_{WR} - NPV_{UR}}{NPV^{UR}} \tag{8}$$

Based on Eq. 8, and considering an annual discount rate $DR = 8\%$, the NPV^{SUD}_{WR-UR} and the NPV^{Invest}_{WR-UR} were calculated.
(4) To check out the consistency in the behaviour of NPV^{SUD}_{WR-UR} and NPV^{Invest}_{WR-UR} across different values of DR, also the NPVs for $DR = 18\%$ and for $DR = 24\%$ were calculated
(5) To check out the consistency of the schedules across different the relative weights of SUD and $Cost$ in the Vikor ranking process described in section 3.3 (initially $VkW_{SUD} = VkW_{Cost} = 0.5$), also the rankings for a $VkW_{SUD} = 0.7$, and a $VkW_{SUD} = 0.9$, were calculated.

Figure 8 shows the progression towards SUD yield by the UPMAs automatically generated by the software for the region of Valencia. At the same time, it reveals that the gain in the contribution of PFs to SUD (SUD_{Gained}) is higher when considering the relative importance of social infrastructure (WSI) than when disregarding it (USI). In practical terms, this means that improving the delivery of social benefits to society through corrective maintenance is more efficient (faster) when considering the relative importance of social infrastructure. This relation is moreover consistent across the considered range of VkW_{SUD} values, and across all the years of the planning horizon.

As to the cost, Figure 8 shows that the results of the scheduling method are consistent with the rule of evenly distributing the cost of all the maintenance actions of each municipal plan (UPMA) across the planning horizon (Section 3.4). Consequently, there is little effect in the share of relative weights between the SUD and cost criteria over the cumulative investment/cost of the maintenance plans, which shows a constant slope.

In contrast, the weighting of the SUD and cost criteria is relevant in the speed of

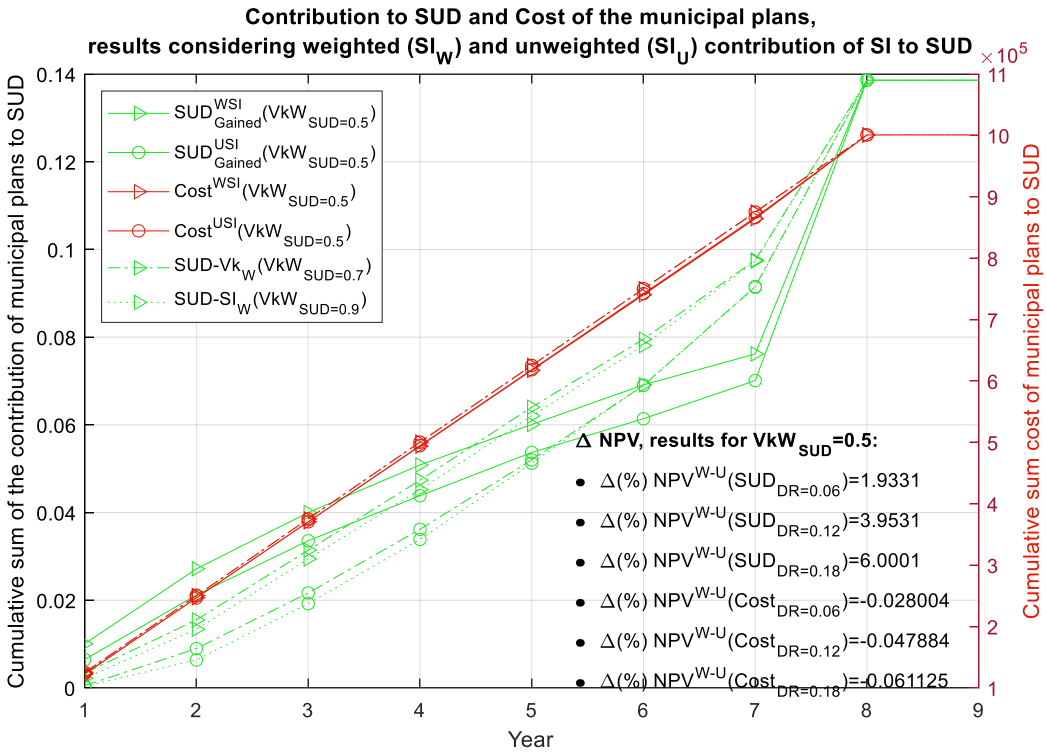

Figure 8. Cumulative mean contribution to SUD and Cost of UPMAs of municipalities in the Region of Valencia by year. Results consider rankings based on the weighted (SI_W) and unweighted (SI_U) contribution of social infrastructure to SUD. Variants include different weighting of SUD vs $Cost$ in the Vikor ranking process (VkW_{SUD}), as well as other discount rates (DR) in the calculation of the improvement both in SUD and $Cost$ NPV ($\Delta(\%)NPV^{W-U}(SUD)$ and $\Delta(\%)NPV^{W-U}(Cost)$) when using the SI_W instead of the SI_U ranking .

the delivery of social benefits yielded by the maintenance plans. A as shown in Figure 8, the SUD_{Gained} is higher in the case of VkW_{SUD} values closer to 0.5. This can be explained by the fact that the maintenance actions affording higher SUD_{Gained} also entails,in most cases, high costs. As illustrated in Figure 7, the actions ranked 1, 2 and 3 in the WR are also among the most costly. Since the delivery of SUD takes effect in the last year (Section 3.4), and that finishing the most expensive measures would take several years, the delivery of social benefits to society is faster when the weights of SUD and cost are balanced $VkW_{SUD} = 0.5$. Although the inverse relation between VkW_{SUD} and the effective delivery of SUD_{Gained} would seem counter-intuitive, when carefully analysed, it provides meaningful evidence of the importance of balancing SUD and $Cost$ in the decision-making process.

As to the behaviour of the scheduling method across the range of discount rates (DR), Figure 8 reveals a direct relation between improvement in the NPV of the social benefits ($\Delta(\%)NPV^{W-U}(SUD)$) and increased discount rates. This can be interpreted in the following way: the more significant the importance attributed by society to anticipating the gains from the required corrective maintenance, the greater the relevance of taking into account the relative contribution of types of social infrastructure to SUD.

5.2. Trade-offs between the type of social infrastructure, cost and priority of the corrective maintenance

In the previous section, the results of the ranking of maintenance actions in the municipality of Buñol was used to support the idea that actions affording higher SUD_{Gained} also entail, in most cases, high costs. To validate this idea, an ANOVA model was fitted based on all the actions in the UPMA plans of the 542 municipalities included in the dataset. In this model, the WR ranking (case (a)) and the $Cost$ (case (b)) were the dependent variables, while the type of social infrastructure and maintenance condition were the independent variables. Figure 9 shows the results of this analysis for the case of the type variable, which was the only variable with a p-value lower than 0.05 in models a) and b). Moreover, to analyse the effect of VkW_{SUD} over the WR, two models were built, using 0.5 and 0.7 as VkW_{SUD} values.

The results of the ANOVA analysis show that the first, second and third types with the highest weights according to the expert judgment process (Table 1, Health (HE)=0.352; Education (ED)=0.181; Care (CA)=0.141), have an economical cost above the average (Figure 9(b)). This is specially true in the cases of Care and Education facilities. Therefore, it is possible to establish a relationship between a high contribution to SUD and economic cost in the Region of Valencia municipalities, which supports the reasoning presented in section 5.1.

On the other hand, Figure 9(a) also shows that the HE and ED types, together with Public Housing (PH, weight=0.096,Table 1), are the priority types for planning corrective maintenance. However, the CA type is not a significant priority, despite having the third-highest weight in the contribution to SUD. This can be explained because it also has the second-highest cost (Figure 9(b)), which penalises its positioning in the ranking process. In effect, as a higher weight is assigned to the SUD criteria in the ranking process ($VkW_{SUD} = 0.7$), the CA type's penalty due to its high cost is relaxed and PFs of this type get closer to the first position (Figure 9.a). As a consequence, UPMA plans based on rankings with high VkW_{SUD} values (and therefore low VkW_{Cost} requirements) will allocate more costly maintenance actions in the initial

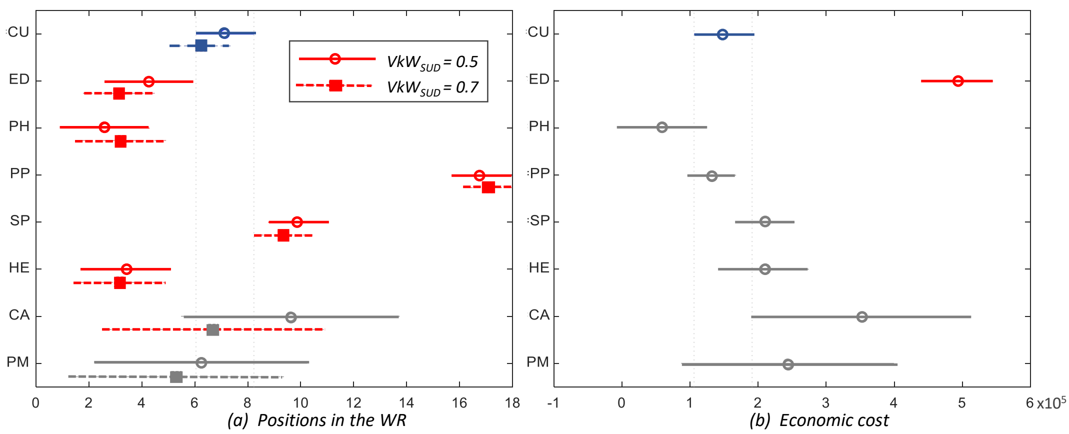

Figure 9. ANOVA main effects plot of the *Type of SI* variable (Table 1), results using the positions in the WR (case a)) and the *Cost* (case b)) as dependent variables, and the *Type of SI*, and *Maintenance condition*, as independent variables. *Types of SI* in red have marginal means significantly differing from *CU* (average type)

years than in the case of using rankings with balanced VkW_{SUD}. This, as argued in section 5.1, leads to the counter-intuitive outcome of slower delivery of social benefits when using VkW_{SUD} values higher than 0.5.

5.3. Alignment of the methodology with the guidelines for the elaboration of municipal strategic plans

Following the guidelines for the formulation of urban regeneration strategies (GDUR) issued by the government of the Region of Valencia (Figure 3), the presented methodology facilitated the completion of the next stages:

a) Problem identification: the method enabled the visualisation of data from the analysed urban areas (Section 4.2.1). This enabled the identification of large portions of the stock of PFs in defective maintenance conditions, with the subsequent loss in the benefits received by society, which makes it necessary to undertake the maintenance of the affected PFs. On the other hand, the data reflected the heterogeneity of PFs maintenance condition by type, which stressed the need to consider the different relative contributions of types of social infrastructure to SUD for proper prioritisation of maintenance actions.

b) Integrated analysis: the proposed assessment method provides a metric representing the loss in the contribution of an urban area's public facilities to its SUD due to their defective maintenance condition (SUD_{Loss}). This metric complements those already taken into account by the GDUR, thus contributing to a more integrated analysis of the analysed urban area's problems (Section 4.2.2).

c) Diagnosis and results: the methodology identifies all PFs in defective maintenance condition, and therefore candidates in the plan of corrective maintenance, and evaluates the SUD_{Gained} and $Cost$ metrics for each of them (Section 4.2.2). Based on these metrics, the methodology provides a prioritised queue of maintenance actions on public buildings (Section 4.2.3, which, as described in section 4.1, contributes to the SDGs' attainment.

d) Implementation plan: finally, the methodology schedules the maintenance actions in a given time horizon, and provides metrics to measure the efficiency in the delivery of social benefits produced by these actions from a temporal point of view (Section 5.1).

Overall, the research showed that the results provided by the tool are consistent with the experts' evaluation. By using the proposed approach, the yield to society can be improved in terms of anticipating the social benefits associated with restoring PFs to a good maintenance condition.

On the other hand, urban infrastructures such as dams, reflective structures near the shoreline, or sanitation infrastructures in coastal regions of Spain, are jeopardising the quality and sustainability of these region's beaches. These are essential natural assets for the well-being of its population (Yepes & Medina, 2005), and therefore, the incorporation in future work of the maintenance condition of these infrastructures, will afford a more integrated analysis, and expand the potential impact of the decision-making.

As to the applicability or adaptability to other regions or classes of properties, it should be highlighted that the results regarding the relative preference of maintenance by type of public building apply to portfolios of any location, provided they are composed of the categories included in the presented method (Figure 1). Regarding to this, it should be noted that the set of types of public facilities adopted in this work has been obtained through a literature review including relevant works worldwide, which guarantees a high degree of applicability in other regions. However, the relevance attributable to each type of social infrastructure may vary from region to region due to singularities regarding urban configurations and complex settings that may. This makes it necessary to develop specific assessments based on the judgment of experts familiarized with that area in order to account for singularities regarding urban configurations and complex settings that may. As to eventual interconnections between types of SI and maintenance conditions, the presented model cannot handle them. To overcome this limitation, additional research would be needed to verify the applicability of other multi-criteria techniques, such as the ANP method, to solve this problem. Finally, the results provided by the presented method makes it possible to identify the worst-performing buildings that should be targeted by the policies and actions to be considered in the long-term renovation strategies of UE countries (European Union, 2020). Further, these results could also be used to complement those provided by different portfolio ranking approaches, based on energy and indoor environmental quality issues or the degree of physical degradation (Caccavelli & Gugerli, 2002; Flourentzou et al., 2000; Jaggs & Palmer, 2000; Nielsen et al., 2016; Pannier et al., 2021).

6. Conclusions

This study aims at improving the contribution yielded by the corrective maintenance of an urban area's PFs to its SUD. To this end, a methodology is presented integrating multi-criteria assessment with an analytical method for evaluating the contribution of PFs to SUD based on their type of SI and their MC, and for the prioritising of the PFs that should first receive corrective maintenance. As a result, the proposed methodology provides the SUD_{Gain} and $Cost$ metrics, which are employed first to build a prioritised queue of the PFs needing maintenance based, then to select the measures to be included in the urban regeneration plan, and finally to schedule is implementation.

As concerns the experts' judgment process, the results of this study reveal significant variation in the relative contribution of different types of SI and in their maintenance condition. The type is a critical aspect in assessing the contribution to SUD. According to the experts consulted, Health, Education, and Care facilities are the essential types concerning their contribution to SUD. By types of social infrastructure, the results showed that for some types, such as Health and Care facilities, a defective maintenance condition has a higher negative impact on their functioning, while the Sport Facilities and Public Parks are the most robust to the maintenance condition. Together, these findings stress the need to consider the type of SI variable in the assessment process.

As to the analytical formulation of the contribution to SUD and the prioritisation process, the results showed that the improvement in the delivery of social benefits to society through corrective maintenance is more efficient (faster) when considering the relative importance of SI. Besides, this research demonstrated that the improvement in the NPV of the contribution to SUD when considering the relative contribution of the types of SIto SUD becomes higher as the discount rate increases. This suggests that the greater the importance attributed by society to anticipating the gains from the required maintenance, the greater the relevance of taking into account the relative contribution of types to SUD. Also, the research showed that a balance between economic and SUD aspects leads to a more efficient delivery of social benefits.

As to its practical implications, the proposed methodology is capable of affording local planners a medium to long term plan for the corrective maintenance of PFs of their municipalities. Based on their own (or other experts') evaluation of the relative contribution of types of social infrastructure to SUD, their maintenance condition, and their assets' portfolio, municipalities can prioritise PFs' corrective maintenance. It was shown that by using the proposed approach, the yield to society could be improved in terms of anticipating the social benefits associated with restoring PFs to a good maintenance condition. Therefore, the methodology can help them design and support the UPMA plans required by municipalities to be eligible for the financial support programs aimed at achieving the SDGs.

Despite the remarkable contributions of this work, there are still some limitations to be addressed in future research. More comprehensive dissemination of the survey embodied in the CRISDESEC software, structured on regional, provincial and municipal scales, must be carried out to improve the participatory aspect of the decision-making process. In this way, it will be possible also to work around essential questions such as whether regional, provincial and municipal points of view are coincident or divergent, and what implications this may have for multi-level governance. This future work would also provide feedback from practitioners regarding the improvement rendered by the method's result with respect to usual practice.

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Notation

SUD_{Gain} Gain in a defective public building's contribution to an urban area's SUD due to its restoring to a good maintenance condition.
SUD_{Loss} Loss in a public building's contribution to SUD due to its defective maintenance condition.
SUD_{Max} Maximum (potential) contribution of a public bulding to an urban area's SUD.
SUD_{Real} Actual contribution of a public building to an urban area's SUD based on its maintenance condition.
$TOTALSUD_{Gain}^{USI}$ Unweighted gain (without considering the different contribution to SUD by type of SI) in an urban area's SUD due to the restoring of a set of defective public facilities.
$TOTAL\ SUD_{Gain}^{WSI}$ Weighted gain (considering the different contribution to SUD by type of SI) in an urban area's SUD due to the restoring of a set of defective public facilities.
UR Ranking of public facilities planned to receive corrective maintenance based in the SUD_{Gain}^{USI} (without considering the different contribution to SUD by type of SI).
WR Ranking of public facilities planned to receive corrective maintenance based in the SUD_{Gain}^{WSI} (considering the different contribution to SUD by type of SI).
$\Delta(\%)NPV^{W-U}(Cost)$ Economic cost, in terms of increase in the net present value of the contribution to SUD based on the W (weighted SI) instead of the U (unweighted) ranking.
$\Delta(\%)NPV^{W-U}(SUD)$ Social benefits, in terms of increase in the net present value of the contribution to SUD based on the W (weighted SI) instead of the U (unweighted) ranking.

MC Maintenance condition.

PF Public facility.

SI Social infrastructure.
SUD Sustainable urban development.

URS Urban regeneration strategy.

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