Designing web-based designed for decision making process of upgrading slum sanitation

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Abstract. In Indonesia's slum areas, Inadequate sanitation is a major challenge. This study introduces an interactive web-based platform, UPSS ("Upgrading Slum Sanitation"), to aid in selecting appropriate sanitation technologies for these regions. UPSS integrates a Decision Support System (DSS) to streamline the decision-making process. Our objective was to create UPSS to facilitate the selection of suitable sanitation technologies, tailored to the specific needs of Indonesia slum areas. We employed a mixed-methods approach to develop UPSS, focusing on user-friendly interfaces and streamlined decision-making processes. The first screen will help identify the slum classification (high, middle and low slum) by using the questionnaire. The following screens will identify alternative sanitation technologies. After that we apply the UPSS in the case study area, Manado Indonesia. The application of UPSS in slum areas of Indonesia demonstrated its effectiveness in reducing planning time for sanitation improvement. The results, presented in an easily interpretable format, showed a range of sanitation options and were well-received by facilitators in these areas. UPSS proves significant in improving sanitation planning in slums. It offers a quick, efficient, and user-friendly tool for stakeholders to identify and implement the most suitable sanitation technologies, thereby addressing a critical need in urban sanitation management

1 Introduction

As human society continues to develop, urban areas are becoming home to an increasing number of people. Rapid urbanization poses one of the most pressing challenges for both the present and future generations. This phenomenon places immense strain on governments and urban planners, who struggle to keep pace with the rapid growth in urban population, rising poverty rates, the proliferation of informal housing in peri-urban areas and slums, water resource scarcity, and urban infrastructure deficits [1]. Consequently, the population living in slum conditions has continued to grow, exceeding one billion in 2019. The regions most affected by this issue include Eastern and South-Eastern Asia (370 million), Sub-Saharan

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Africa (238 million), and Central and Southern Asia (227 million), which collectively account for 80% of the global total [2]

Slum areas, characterized by densely populated settlements, represent a complex confluence of various factors. These areas often suffer from inadequate water and sanitation services, substandard housing, insecure land tenure, and susceptibility to climate change impacts. The lack of proper sanitation services has significant repercussions on health, the economy, the environment, and social well-being [3, 4]. According to the United Nations [5], more than one in four people worldwide, approximately 2.2 billion individuals, lack access to safely managed drinking water, including 884 million who do not have access to even basic drinking water services. Furthermore, approximately 4.2 billion people lack access to safely managed sanitation facilities, with an estimated 3 billion people lacking basic hand-washing facilities.

This study focuses on the one of the slums areas in Manado, Indonesia. Where these challenges are particularly evident. In Manado, as in many other slum areas, traditionally sanitation system are often unfeasible due to space constraint and typological areas.

The author contends that the sanitation challenge in slum areas primarily arises from "soft" factors such as inadequate government monitoring and evaluation, as well as inefficient planning, rather than solely being a matter of insufficient financing. It is imperative to merge the knowledge, experiences, and ideas of sanitation specialists and official decision-makers with those of the affected communities and users to address these complex aspects [7]. Neglecting these complexities often leads to the failure of projects initiated by international organizations and governments to meet their objectives, resulting in minimal and unsustainable infrastructure, as well as short-lived facilities.

1.1 Integrated communication: an element of the integrated water sanitation approach

In the past decade, the use of web applications for engaging multiple stakeholders in sanitation planning has gained prominence. These applications encompass a range of tools, from well-known public participation GIS (PPGIS) and participatory GIS (PGIS) to online collaborative mapping tools, Volunteered Geographic Information (VGI), social media in neighbourhood planning, and various simulation software [8]. The incorporation of computer technology in planning processes began in the 1960s with attempts to create computerized city models. This adoption of computers in urban planning has evolved in parallel with the transition from export-oriented planning to greater public involvement [8].

The advent of Web 2.0, blogs, new media, and mobile applications is currently reshaping urban planning practices, giving rise to new forms of e-planning, e-governance, and e-participation. Despite the growing number of experiences with Information and Communication Technology (ICT) in urban planning, the use of internet-based tools in planning exercises is less prominent compared to the ubiquitous use of technology in public administrations (e.g., e-forms, e-payments).

While digital participatory mapping technologies have been applied in various domains, their potential in sanitation planning remains underutilized on a large scale. Initiatives like the Water and Sanitation Program (WSP)'s Sanitation Hackathon have brought together IT developers and sanitation sector experts to propose innovative software solutions, including mobile phone apps, harnessing the power of growing connectivity through mobile phones and social media to enhance access to sanitation [9].

Numerous studies (e.g., [8–11]) have identified potential benefits of digital participatory mapping technologies in sanitation planning. These advantages include empowering local residents, fostering dialogue between citizens and planning professionals, democratizing

GIS, collecting valuable feedback for the planning process, increasing participation rates, and opening new avenues for engagement.

The outbreak of COVID-19 has underscored the need for online communication in sanitation planning. Internet technology became the primary means of communication and data exchange among relevant stakeholders during the pandemic. This shift represents an alternative paradigm that emphasizes enhanced stakeholder participation in sanitation development. Mobile phones and web-based applications are rapidly evolving to support the expansion of Water, Sanitation, and Hygiene (WASH) services. Apps have the potential to significantly enhance sanitation initiatives, programs, and regulations [9].

Sanitation-related apps typically fall into four main categories:

- Self-reporting of maintenance needs.
- Mapping of infrastructure and its requirements.
- Monitoring of sanitation programs.
- Education for behavioral change.

Many applications combine multiple functions, contributing to the success of projects that prioritize community participation, social marketing tools, and decentralized government programs that garner political support [12–14].

However, challenges persist in adopting digital mapping technologies in planning, including human capital requirements, hardware and software costs, the expert-driven nature of technology with a lack of user-friendly applications, keeping up with technological advancements, programming skills, and the digital divide. In slum areas, these challenges may be further exacerbated by social, political, and economic factors. Informal settlements often suffer from a lack of reliable data and information, as well as outdated maps. In light of these challenges, it becomes imperative to highlight the difficulties encountered during the development of the UPSS tool and to underscore the importance of stakeholder participation and engagement in the tool's development and testing phases

Harmonizing these aspects was pivotal in creating an open digital framework capable of addressing the specific barriers in different environments and accommodating the suitability conditions of any existing or potential sanitation system under the sustainability concept.

In summary, establishing an open platform for communication among stakeholders is crucial to ensure that planners fully grasp the primary needs and challenges facing slum areas.

2 Sanitation chain Concept

The sanitation provision should be perceived beyond the provision of just toilets and latrines. It aims at achieving an overall improvement in public health. As mentioned before, the sanitation chain always starts with the upper structure (the toilet). It includes the excreta collection unit, a method of transport from the site, the treatment process and finally, the end-user or disposal [15, 16]

For the definition of the five sanitation value chain processes, we generally follow those given in [15–17]:

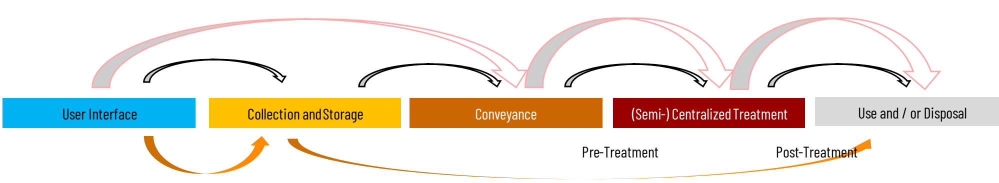

Fig 1. Sanitation chain process and distribution

The term "User Interface" refers to the method by which the user interacts with the sanitation system, typically referring to the type of toilet. Knowledge of water availability is critical for selecting an appropriate technological option for the 'user interface' step.

Various methods are used for the “Collection and Storage” of the user interface’s outputs. Some solutions just store it, others treat it on-premise. Such on-site treatment is usually passive and its dimensioning and type depends on the amount of excreta stored. Consequently, these pre-treated products often require additional treatment before being used or disposed of.

The movement of goods from one process to another is called “Conveyance” / emptying and transportation. For simplicity reasons, the conveyance in the model is limited to transporting products between the “Onsite collection, storage, and treatment” and “(Semi-) Centralized Treatment” stages, which is usually the longest and most significant (geographical) gap.

It is possible to treat large groups of people with the help of “(Semi-) Centralized Treatment” methods (i.e. multiple households). Operating, maintaining, and powering the equipment used in this process is more challenging than for the other steps.

A product's ultimate return to the environment as either helpful resources or low-risk materials is referred to as (re-)"Use/Disposal." Products can for example be reused in the system (e.g., treated greywater for flushing), or used for farming as fertilizers (in some cases even with less or no treatment).

Fig 1 shows the complete chain of five steps, and three possible paths from beginning to end. As a reminder: (i) the processes are not necessarily sequential, and (ii) interdependencies exist between different processes. The paths represented by the arrows are:

White arrows: The chain includes all steps, but not the second (collection and storage). That means, a collection at the interface site does not happen, but the products are directly moved to the second stage “conveyance”.

Black arrows: All five steps are included.

Orange arrows: This chain jumps from the interface-located storage directly to the last step “disposal”. That means, the products have to be treated sufficiently at the location of the interface (and storage), so that they can directly be released back into the environment. It should be emphasized, that this solution does not mean an unsustainable solution that dumps unsafe products into the environment, but an actual sufficient treatment.

3 Upgrading Slum Sanitation (UPSS)

The Methodology employed in this research aims to design web-based decision-making system for improving sanitation in slum areas. The research design is characterized by mixed-methods approach, incorporating both quantitative and qualitative elements to ensure a comprehensive understanding context of sanitation in slum area. This research we conducted in several stages. There are three main stages, first stage is research discover, second stage is research ideation and third stage is research delivery. In this paper we focus on research ideation.

How we translated the mentioned models, methods, functions and technologies into a software. This new UPSS software shall be a web application designed and make the acquired knowledge accessible to sanitation planners. In this paper, the implementation is described only roughly.

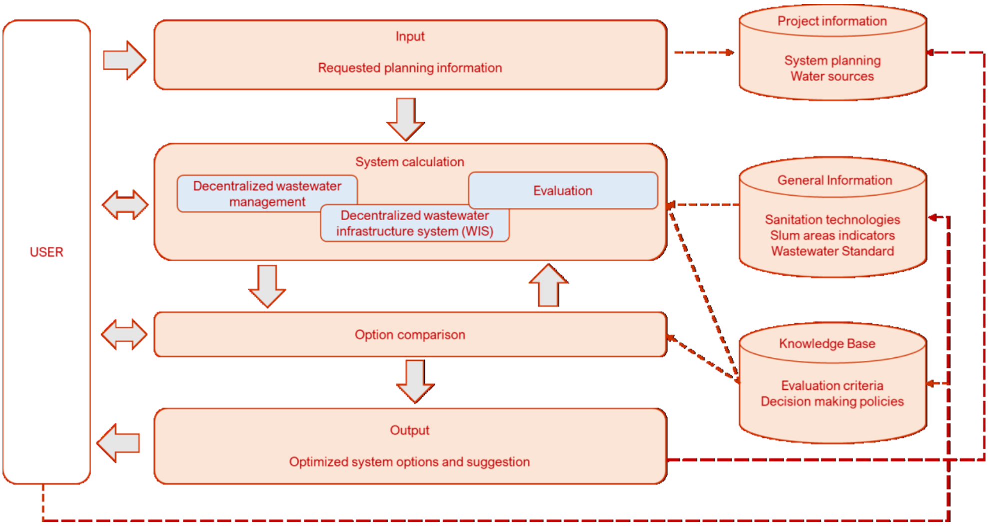

Fig 2. The system architecture of the UPSS web app

Fig 2. lays out the architecture of the decision support model for sanitation planning in slum areas. The block on the right represents the software components for managing and storing the information (data bases), while the middle block represents the steps of calculation (algorithms). Following the main procedure from the top, the project information is first requested, which needs input by the user. Then the calculation is performed, which considers three parts: Decentralized wastewater management, its infrastructure system, and the evaluation – this calculation determines, which technologies are unfit for the location and can therefore not be chosen by the user in the next step.

The related information, such as wastewater standards, etc., is acquired independently from the database. This information is taken from several guidelines, which are: Compendium of sanitation technologies in emergencies [18], compendium of sanitation system and technologies [21], Philippines sanitation sourcebook and decision aid [19], Indonesian regulation [20, 23]. All these sources showed a high level of consistency regarding the attributes they give to sanitation technologies, with some of them referencing each other.

During the application of the software, the information in the technology database must be supplemented regularly, so that the software stays up to date.

Following that, the user gets to choose sanitation technologies out of the technologies that are suitable for the area (technology comparison), and finally gets presented the result of his selection, as well as further recommendations.

The tool contains the following user-oriented databases: sanitation technologies, Questionnaire questions and user list and relevant user data. Additionally, the backend stores the compatibility algorithm and the algorithm to calculate the optimal solution. In this paper we only focus with the backend stores and how its imply into the UPSS.

3.1 Front end - user journey

Here, the software is described purely from the user perspective, as it was developed based on stakeholder interviews and feedback rounds. The user enters the UPSS website and first chooses between everyday planning (button "fill questionnaire") and expert planning (button "start planning") (shown in **Fig 3)**.

The user can see the two KPIs (Key Performance Indicators), "costs" and "complexity" per technology, gets to see an image and - if wanted - detailed information about the technology. He then chooses one by clicking on it, and the software moves on to selecting the following technology step. The process is repeated until a complete sanitation chain is created.

In the end, the user is presented with a result page, a graphic of the created solution, the combined KPIs "costs" and "complexity", and a textual summary. Additionally, the tool shows the theoretically most efficient options (lowest cost, lowest complexity), auto-generated based on the questionnaire input.

The user may now save the created solution to his profile and print or send it to colleagues as a PDF file. The user can always step back and change his inputs throughout the process. He can also log in later and adjust one of his previous creations. The process was measured to take 2 to 10 minutes with the current prototype version of the tool.

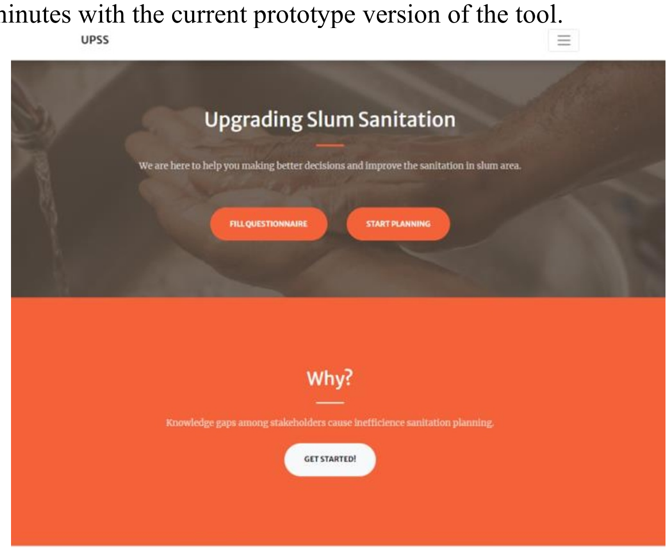

Fig 3. UPSS main page

3.1.1 How does the tool work with user input ?

In research we focus with the technology choices when creating the sanitation chain. When the user arrives at the step of choosing the first technology, For the background, pictures connected to sanitation success were chosen so that the goal of the software always stays in sight and the user potentially gets a small additional motivation. Text elements are short and precise to focus the user's attention on the actual planning.

Buttons: The buttons are big, need to give clear information about the function and have a colour contrasting the rest of the page; to highlight them as action elements.

Technologies: When choosing technologies, the user can choose by intuitively clicking on a technology. The user can intuitively change his choice by clicking on another technology. When ready with one step, the user can click the "next" button to proceed (which proved better than a previous prototype version, where the tool automatically moved to the next step after a technology choice). The layout of the technology choice site is shown in Fig **4.**

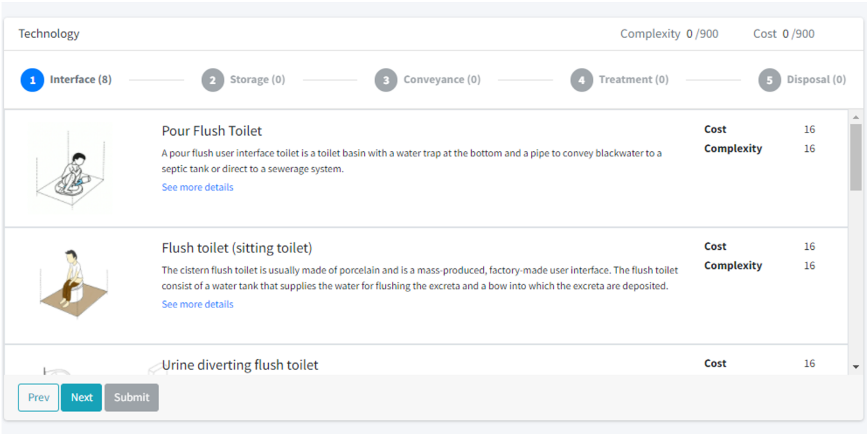

Fig 4. Technology was chosen – Page

The "submit" button stays grey and non-clickable until the user chooses to form a complete sanitation solution. The button colour changes to blue, indicating the completion of the selection process.

The "see more details" text is in a different colour (Shown in **Fig 5)**, helping the user identify it as an active element to see more information about the technology.

Result page: On the result page, the user finds a handy print button Underneath every graphic, the change of mouse-over symbols and different colours help the user identify the technology graphics and text as action buttons, where the user can access the detailed information if needed.

At all the steps, the user can use the menu to directly jump to the starting page, the planning and selection process, so he does not have to click the button "back" several times if he wants to start over.

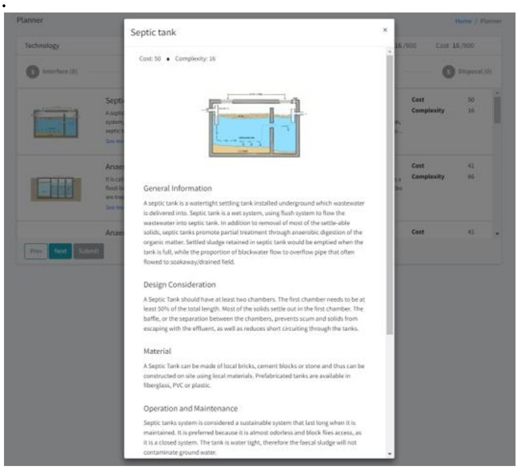

Fig 5. "See more detail" – Page

4 Result and Discussion

4.1 Compatibility sanitation generation

In order to select a manageable sanitation system, the remaining (available) sanitation technology options must be chosen for each step (column) in the sanitation chain. In each step, a technology option must be selected. Unfortunately, there are no rules or guidelines for generating potential alternatives. Thus, UPSS considers all possible combinations a potential alternative, that constitute a fully compatible sanitation chain.

Compatibility is a combination of technologies to a complete sanitation chain, without incompatibility between any two technologies. When two technologies are incompatible, it indicates an unresolvable conflict, at least shortly where the decision-making process occurs. The concept of products is essential to the compatibility evaluation of technological options. The term "products" refers to both human waste and the products made from it. In this way, the ability to handle specific products is defined as a property of two technologies when they are combined. The UPSS conducts a compatibility verification test, using rules that compare the selected technologies' input and output. It follows the rule:

A technology B is compatible to the previous technology A, if the inputs of B can handle all (or more) products, than A produces as outputs.

Each time the user selects a technology A, the web app automatically discards any (potentially following) technology that is incompatible with A. In order to select a manageable sanitation system, the remaining (available) sanitation technology must be chosen for each step (column) in the sanitation chain.

The compatibility of two technologies is based on the matching of input and output of those two technologies (for an example see **Fig 6**). If the sanitation option “pour flush toilet” is selected, UPSS determines the compatible sanitation option for the following steps. Consequently, this leads to the available user choice of the “Septic tank” as the onsite collection system, as the septic tank can manage the blackwater from the previous technology.

However, the septic tank has two different outputs “effluent” and “sludge”. If there is no technology in the following step that can handle those two outputs, the user can choose a combination of two technologies, that cover the two outputs when combined. **Fig 6** shows as following technology for the conveyance: "transfer station and storage”, that only covers sludge. UPSS will offer the user a combination of this technology with another, that can cover “effluent”, so that are products are handled.

This technology selection continues, until the user reaches the last step “disposal”.

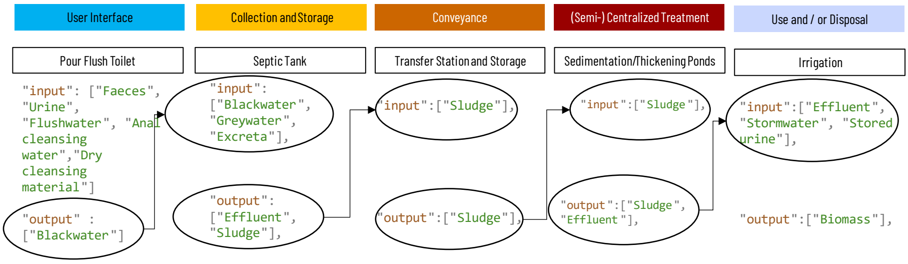

Fig 6. An Example of the compatible sanitation chain

Following this step of unbiased combination of technologies, the sum of all possible UPSS sanitation chains consists of 7929 wet-base, 1375 dry-base and 1589 urinal solutions. This full spectrum of options is only accessible, when the user chooses to skip the questionnaire, thus does not allow UPSS to use location data to limit the technologies to only the feasible ones. If the user indeed fills the questionnaire with location-specific data, UPSS will narrow down the possible choices, so that the user is left with significantly less – but significantly better fitting – options to choose from.

4.2 UPSS Evaluations by the slum facilitators

After the UPSS developed it needs to be evaluated by the facilitator in slum areas. In this case we chose Manado cities as a facilitator, because of the variation of the typology. So we were expecting the different result from the facilitator. The feedback results show that UPSS is very helpful for facilitators in slum areas in sanitation planning. According to them, sanitation planning currently takes six months for one slum area. With the support of UPSS, they achieved comparable results in 30-60 minutes.

According to the planner, it would be better if UPSS already had spatial data on the homepage, so that the facilitator or the donor can find out where the location of the area to be built is. Additionally, it would be useful, if UPSS could help calculating the resulting investment volume.

UPSS was very helpful in planning sanitation in Manado. However, some aspects have not been considered, for example areas with brackish water.

All planners agreed that it was exciting to select technologies witch UPSS. The facilitator preferred to choose a pour flush toilet with a septic tank, of the many technologies presented, since this technology was the most familiar to the slum area inhabitants. According to the sanitation planners, sustainable technology should focus mostly on standard technology, so that non-expert can operate it.

UPSS provides many options other than a septic tank, such as aqua privy, twin pit with pour flush, and biodegradable bags. However, they were not chosen by the planners, because the regulations in the study case area (especially SNI) had to be followed and didn't allow such technologies. This does indeed not make UPSS an inefficient tool. Some sanitation planners have come to understand that there are many other options besides septic tanks, and can benefit from the various options in UPSS.

Among the chosen technologies are not only single technologies (like the pour flushing toilet), but also combined technologies (e.g. surface disposal and fish pond).

It is remarkable that, despite the effort to choose two areas with different typology, the resulting sanitation chains are similar. When discussing this finding with the planners, they explained, that despite the government asking for safely managed sanitation solutions, many less common technologies (like floating toilets or latrines) rarely get approval by the regulators. Since planners want to avoid discussions with regulators and a potential replanning, they tend to always plan with pour flush toilet and septic tank, even if other known technologies could lead to a more sustainable system. To improve this situation, it would be necessary to improve the knowledge of the regulators, that currently disapprove most uncommon technologies, simply because they do not understand them well enough to approve them.

With one exception, all suggested solutions consist of not five, but only three steps: User Interface, Collection / Storage and Use / Disposal. The transport to a (semi-) centralized treatment was not considered feasible by UPSS. The lesson learned from that is, that sustainable sanitation planning – in these areas – should not be made with a large-scale centralized system, but must stay on a residential scale.

Based on the planning results with UPSS, it was concluded that designing a pour-flush toilet connected to a septic tank would be compatible with a wide range of conveyance, treatment and disposal options and, therefore, flexible to different situations that would be encountered in Indonesia.

The author was surprised: Even though the users came from different locations, they tended to choose the same option. The main reason is the expected disapproval of regulators for unusual solutions, as was explained above.

Pour flush + Septic tank/biofilter/anaerobic baffled reactor + surface disposal and sanitary landfill; irrigation

They choose the sanitation chain above, because it is familiar to the community in slum areas and easy to operate and maintain. Additional to the user choices, UPSS provided the recommendation for the sanitation chain with the lowest complexity, which is:

Pour flush + Twin pit pour flush + application of pit humus and compost;

and for the lowest economical cost:

Pour flush + Single pit latrine + Surface disposal and the sanitary landfill (-or open dumping).

Although the UPSS web application only refers to the complexity and economic aspect, the author would like to prove that the automatically generated solutions would lead to more sustainable sanitation, than the sanitation chains built by the user. As mentioned in previous chapter. UPSS currently highlights the economic aspect (favoring inexpensive technologies) and the social aspect (favoring non-complex technologies). However, for the mentioned sustainability comparison, we also need to check the ecological impact of these technologies. Since the current version of UPSS does not cover that calculation, the author used expert judgment to determine the impact of each sanitation solution (scenario) on the environment.

5 Conclusion

The application of the UPSS tool in two study case areas was the "proof of concept" for the tool, and the tool widely succeeded in being a useful support for slum sanitation planners. Two slum areas with different typology were chosen, but similar sanitation solutions were selected by the planners. This revealed two constraints currently limiting the sustainability of slum sanitation planning in Indonesia:

- Slum planners tend to choose from only few well-known technologies, since their greater experience with those technologies biases their decision.
- Slum planners tend to choose from only few well-known technologies, since any unusual choice is likely to fail during the approval process, due to limited technology knowledge of the regulators responsible for the approval.

While the first of these aspects can potentially improve by extended use of UPSS (with its information texts on rarer technologies, and continuous suggestion to use them), the second aspect needs an approach outside UPSS, for example trainings with regulators.

The sustainability comparison of the manually chosen solutions with the automatically generated solutions by UPSS revealed, that the sustainability rating is not necessarily the best metric to determine the optimal sanitation chain for a given area. Depending on the weights that local inhabitants and planners give the various aspects of sanitation, a solution might prove optimal that is not the most sustainable, but - for example - has the lowest maintenance costs. To address that, the UPSS tool could be further improved, so that it factors in such local weights, for example through another set of questions, designed to evaluate the relative importance of different sustainability attributes to the stakeholders. This would likely improve the fit between UPSS results and stakeholder needs.

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