CONTESTED FACTORS FOR SUSTAINABILITY: THE CONSTRUCTION AND MANAGEMENT OF HOUSEHOLD ONSITE WASTEWATER TREATMENT SYSTEMS

Contested Factors for Sustainability: The Construction and Management of Household Onsite Wastewater Treatment Systems

Jessica Kaminsky[1] and Amy Javernick-Will[2]

Abstract

Onsite sanitation systems experience a high failure rate with resulting environmental and public health implications. In the USA alone, the EPA estimates that 10% of the 26 million homes served by onsite systems have failed. If this failure rate is extrapolated to the 8% of the global population that the UN estimates have gained access to sanitation between 1990 and 2008, an additional 5 million failed systems have been constructed. To address issues like this, development theory currently emphasizes a blend of hardware (e.g. infrastructure, technology) and software (e.g. knowledge, institutions, education) in an effort to achieve sustainable development. However, we lack both theory that addresses this interaction and a definition of sustainable infrastructure. To begin to address this gap, an initial set of 40 factors that may contribute to sustainable onsite sanitation systems was identified from a literature review including the Web of Science, the Engineering Village, and the full record of ASCE from 2000 to July 2011. A panel of 14 experts including academics, regulators, international development practitioners, O&M providers, and manufacturer/designers was then assembled to identify any additional factors that may lead to resilient onsite systems and to evaluate each one using the Delphi method. The panel evaluated each factor iteratively in order to develop a measure of its importance to the sustainability of onsite sanitation infrastructure. Experts were also invited to provide and review comments explaining or discussing the ratings they provided, and to identify the factors they perceived to be the most and least important. Of the initial list of factors, 9 came to consensus as being important or very important, including factors such as owner occupancy, quality of installation or materials, and post-construction follow-up programs.

[1] PhD Candidate, Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, 428 UCB, Boulder CO 80309 USA

[2] Assistant Professor, Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, 428 UCB, Boulder CO 80309 USA

In addition, 10 factors provoked particularly diverse, or contentious, opinions with ratings that more than doubled the target criteria for consensus. These contentious factors are analyzed to identify trends and debates in expert opinion that showcase future research needs as well as issues that practitioners must address to build sustainable systems.

INTRODUCTION

One of the commonly noted features of the construction industry is the particular nature of its projects. Infrastructure projects in particular are typically large in terms of scope and cost, are intended to be used for long time periods, and are delivered by a temporary project team made up of multiple and transient organizations (PMI 2008). Each construction project results in a unique product designed and constructed for a particular confluence of people, the natural environment, and financial constraints. Another defining feature of infrastructure projects is the long asset lifecycle. Historically, assets may have been designed without much consideration of what would happen after the design life had been exceeded. More recently, an industry-wide focus on sustainability has led to consideration of cradle-to-grave design; in other words, design and construction may now consider disposal the end of an asset's useful life. More recently yet, cradle-to-cradle design suggests that this focus must be expanded further in order to consider repurposing materials and assets to better serve the fundamental goals of sustainable development.

Of course, there is still a substantial debate regarding both the means and the ends of sustainable development. This is true both at a macro level and more specifically in the context of construction and infrastructure (Levitt 2007). Generally, though, we may define development as "organized intervention in collective affairs according to a standard of improvement" (Pieterse 2001 p. 3) with *sustainable* development providing (still contested) criteria for that standard of improvement. Development theory and practice has moved away from the provision of just hardware (e.g. infrastructure, technology) to a combination of hardware and software (e.g. knowledge, institutions, education) (Pieterse 2001 p. 156). However, there is a dearth of research addressing what software is actually needed to support infrastructure development—in other words, what factors should be included in a definition of sustainability specific to the engineering and construction community. This paper contributes to the growing body of work in sustainable infrastructure by developing a preliminary list of those factors, focusing specifically on the subset of household onsite sanitation infrastructure. By this we mean any form of household sanitation infrastructure that meets international standards for improved sanitation (WHO 2012) that is not connected to a sewer. Some typical examples include septic tanks or ventilated improved pit latrines. Before presenting these results, we first discuss the research underpinnings in sustainable development, particularly as it relates to sanitation infrastructure.

Sustainable Development

The construction community has only relatively recently begun to engage with the concepts of sustainability (Levitt 2007). In a June 2012 title/abstract/keyword search of the online archives of the Journal of Construction Management (JCEM), the keywords 'sustainability' or 'sustainable' returned only 59 results. However, whereas prior to the year 2000 there were 1 or 0 articles each year, in 2010 there were 9 articles, and in 2011 there were 16. Clearly, the topic is of growing interest to construction researchers.

It is a common criticism that the term sustainable development means everything and nothing—in other words, that it is used for so many things that it has ceased to mean anything at all. For example, among the 59 articles appearing in our JCEM search, there are fundamental differences regarding exactly what is to be sustained by and for whom (for example, see Bakens 1997; Beheiry et al. 2006; L. Klotz and Horman 2009; Koo and Ariaratnam 2008; Laefer and Manke 2008; Shen et al. 2010; Valdes-Vasquez and L. E. Klotz 2012). However, while it may still be unclear as to what sustainable development means for the construction industry specifically, on a more general level the dominant (though certainly not only) theory is clear. The most commonly used definition should be credited to the Brundtland Commission (WCED 1987) and the economist Solow (1993). This combined view sees sustainability as something that preserves economic productive capacity for future generations while recognizing the needs of current generations and privileging the needs of the poor. The foundational concepts are consumption, intra- and inter-generational justice, and the commensurability of values. Also implicit in this definition are ideas of scarcity and a hard division between the natural (non-human) and social (human) units of analysis. This definition sees technology as an important tool to be used to improve economic productivity, but has little to say about how sustainable technology should be defined or operationalized.

Sanitation

Sanitation infrastructure is an important subset of the larger construction market. In the US, the US EPA estimates that almost $300 billion will be needed for clean water infrastructure over the next 20 years; $24 billion of that is earmarked for decentralized (septic) systems (US EPA 2008). While these numbers are enormous, the global market is even larger. The UN estimates that 2.5 billion people have no access to improved sanitation infrastructure, including 1.2 billion who have no facilities whatsoever (WHO/UNICEF JMP 2008). A large percentage of this demand will be met by leveraging onsite sanitation technologies. This is especially true in rural contexts, where distances and increasing energy costs may make long force mains unsustainable, and to meet the demands of the exploding peri-urban and urban populations where issues such as land acquisition and tenure make the construction of new linear infrastructure a particularly complicated business (Nelson and Murray 2008).

Sustainable development has been criticized as offering second-class or outmoded technology, something that only those without other options would put up with while the wealthy choose more resource intensive technologies that are assumed to be intrinsically better. However, reducing the resources required to install or operate a technology does not make it fundamentally worse. This criticism is a particular problem for sanitation technologies, with onsite systems somewhat universally experiencing a reputation as a stopgap until a sewer connection can be made (Etnier et al. 2005). However, in theory onsite technologies can provide excellent treatment while greatly reducing resource use both in construction and in operation as compared to a sewered system, especially in mountainous, low density, remote or rural areas—wherever long pipe runs or lift stations might be required. Unfortunately, in practice onsite sanitation systems experience a high failure rate (EPA 2008). This research addresses this issue by identifying factors that impact the sustainability of onsite sanitation systems.

METHOD

This project used multiple methods including a content analysis of relevant literature and a Delphi panel intended to elicit expert opinion. In addition, experts were invited to rank the most and least important factors. This process, described below, identified and rated the importance of factors that are important to the sustainability of onsite sanitation systems.

LITERATURE REVIEW

As the first step in the process to identify factors impacting the sustainability of onsite sanitation systems, a literature review was conducted. This literature review included the Engineering Village, the full record of ASCE, and the Web of Science from 2000-July 2011. The searches were limited to English language journal articles and included permutations of the keywords (sanitation or wastewater), (onsite or on-site), and (factor*) in the abstract, title, keywords, or topic of the articles. This intentionally broad search returned 873 non-unique citations. For this research, we were interested in articles that dealt directly with onsite sanitation systems at the household level. As a result, although we did not disqualify articles based upon technology type or system location, centralized or semi-centralized systems were excluded from the analysis unless the article also treated decentralized household systems. Based upon these qualification criteria, 49 relevant articles were identified from the abstract review for full-text review. Using the same criteria, 20 of these were eliminated from the detailed content analysis, while 29 were qualified for further study. These 29 articles were imported into QSR NVivo for coding and analysis. Iterative and exploratory coding schemes were used to identify factors mentioned in the articles as determinants of sustainable sanitation technology. We avoided limiting the definition of sustainability or the rigor with which these factors were evaluated in the reviewed articles. Once theoretical saturation had been reached and no additional factors emerged from the text, factors were categorized into a broader analysis framework of macro-categories. These categories were reviewed by the Delphi panel and were used to organize and rate the importance of the final list of factors developed through the literature review and panel process as described below.

Delphi Panel

The Delphi Method was originally developed by the RAND Corporation (Helmer-Hirschberg 1967). In past years it has proven to be a useful tool for obtaining insights from experts on especially complex issues in engineering. By soliciting interactive expert opinion in several iterative rounds, it may enable experts to achieve consensus on complex topics. If consensus cannot be achieved, it collects information to understand why. Generally, this methodology asks expert panelists to independently rate the importance of a collection of factors. These independent ratings are done iteratively, allowing each expert to consider the opinions of other panelists with the ultimate goal of achieving consensus. This research follows guidance by Hallowell and Gambatese (2010) regarding methodological design for this use of this method in construction research.

Research Design and Data Collection

An expert panel was assembled to review, add to, and comment on the 36 identified factors and categories. Following Hallowell and Gambatese (2010) a list of criteria was developed to signify expert status, and each criterion was assigned points. Selection criteria for the experts may be seen in Table 1 below. In order to qualify as an expert for this study, each participant was required to score a minimum of 10 points.

TABLE 1: EXPERT QUALIFICATION CRITERIA

Points	Criterion
2	Each peer reviewed journal article about onsite sanitation
1/3	Member/Chair of a national committee about onsite sanitation
1	Year relevant professional experience in onsite sanitation
3	Faculty member at an accredited university with relevant research and/or coursework about onsite sanitation
2/4	Writer or editor of a book chapter/book about onsite sanitation
3	Professional registration such as PE relevant to onsite sanitation

After initial screening based on online information, a total of 19 potential experts were contacted. Of this number, 14 responded and were ultimately qualified to take part in the study. Two academics, two regulators, three international development practitioners, three O&M providers, and four manufacturer/designers are represented in the panel. These 14 experts have an average of 22 years each of experience in onsite sanitation. All 14 experts are currently based in the United States, although 4 of them reported significant experience working internationally. Four survey rounds were administered via an online survey powered by SurveyGizmo. In the first round, experts were able to comment on or add to factors identified in the literature review as well as suggest changes to the categorization. Each category of factors was presented on a separate page of the survey, which were randomized for each participant to minimize bias. Expert comments were considered to develop a comprehensive list of factors for the Delphi process. 40 factors were identified through the literature review and this first survey round. These 40 factors were organized into 6 categories, including Technical, Organizational, Economic, Knowledge, Motivation, and Other. These categories were developed through coding of the literature and were approved by the expert panel.

After this initial round, 3 additional rounds were completed through the Delphi process. Minor wording changes were made to 6 of the 40 factors between survey rounds 2 and 3 to clarify the meaning based on expert comments. Each expert rated each factor independently based on a 5 point Likert scale. For each round, the aggregate median and range of scores given by the panel for each factor and the expert's individual ratings from the previous round was reported back to each expert. Experts then reconsidered their previous ratings and provided comments indicating why they did or did not change their individual scores.   In the final two rounds, comments from the previous round were provided anonymously along with the new aggregate median and range of scores. It should be noted that the final survey round experienced some respondent fatigue; several panelists expressed frustration with revisiting and considering the same factors so many times. However, all 14 experts responded to all 4 survey rounds.

A 5-point Likert scale was used, with a 1 signifying Very Unimportant, a 2 signifying Unimportant, a 3 signifying Neither Important Nor Unimportant, a 4 signifying Important, and a 5 signifying Very Important. Consensus was measured by absolute deviation of scores from the median, according to the following equation, where X is equal to the panelist rating and N is equal to the number of ratings:

$$Abs.Dev. = \frac{\sum|X - Median|}{N}$$

The target absolute deviation was 0.25, which translates to a high level of consensus.

In a third approach to our research question, during the final survey round experts were also asked to identify the three most and least important factors across all categories. One expert declined to answer this question due to time constraints.

RESULTS

This research ultimately identified 40 factors from the literature and expert panel. Of these 40, 9 reached consensus as being either Important or Very Important. In contrast, 10 factors were particularly contentious, with absolute deviations double the target. These sets of factors are discussed here.

FRAMEWORK DEVELOPMENT

36 factors and 6 categories of factors that contribute to sustainability emerged from the literature. These categories included economic, organizational, knowledge, motivation, technology, and other. The technology category was observed most frequently, appearing in 23 of 29 articles. In addition, 12 articles, or about 40% of those analyzed, mentioned only technology factors. One article mentioned only economic factors. With the exception of these 13 articles, which only mentioned either technology or economics, the remaining articles discussed, a combination of factors. This is interesting as there is no reason to believe that these two operate in isolation while other categories interact. In addition, this division is suspect because it mirrors common disciplinary boundaries between the social and hard sciences.

After technological factors, economic and organizational factors were mentioned most frequently. Both of these categories appeared in 12 of 29 articles. After this, motivation, knowledge, and other categories appear with 10, 8, and 6 articles citing the categories respectively. The 36 factors and 6 categories identified in the literature review were presented to the expert panel for comment and amendment. While the panel made no changes to the categories, the factors themselves were sometimes modified. Modifications included the addition of examples and the splitting, combining, and rewording of factors. The final list of 40 factors includes 7 economic factors, 7 organizational factors, 6 knowledge factors, 10 motivation factors, 7 technology factors, and 3 other factors (listed in Figure 1). The text in this figure is abbreviated; for example, in the Technology category, the first factor (Inappropriate Site Conditions) was presented to experts as "*OWTS [Onsite Wastewater Treatment Systems] are negatively impacted by inappropriate soils, slopes, proximity to groundwater or surface water, etc. In other words, OWTS technologies are just inappropriate in some areas.*"

Factors

Consensus

Of the 40 factors presented to the expert panel, 9 reached consensus as being either Important or Very Important. These 9 are shown in Table 2. Immediately apparent is that these factors span the macro categories. Of particular interest are the technical factors, which deal with construction issues of material and installation quality rather than the actual technologies themselves. This is supported by comments supplied by the experts. For example, one expert stated, "*The current OWTS technologies are appropriate to address the potentially negative impacts of soils, slopes, proximity to groundwater or surface water, etc*." One O&M provider commented "*I agree that an OWTS can be affected by poor design, but do not run across many issues where the system is suffering due to a design error, generally the OWTS is negatively impacted by poor installation practices.*"

The non-technical factors that reached consensus often deal with post-construction issues. Emptying, how the system is used and by whom, and the organizations that exist to provide service or information for the systems are seen as universally important. These trends are particularly interesting given the diverse makeup of the expert panel. These factors appear to be highly relevant to sanitation workers, from small business owners (O&M providers in the USA) to international development workers managing multi-million dollar sanitation enterprises.

TABLE 2: FACTORS REACHING CONSENSUS

Category	Median* Range* Abs. Dev.	Factor
Economic	5 4-5 0.14	The costs of emptying the system negatively impacts OWTS. For example, systems may be allowed to overflow because of the cost of emptying.
Economic	4 3-5 0.21	Owner occupancy positively impacts OWTS. For example, if the household is not owner occupied, owners may not invest in appropriate system installation, repair, or emptying will occur. Alternatively, renters may not properly care for a system they do not own.
Knowledge	5 4-5 0.21	OWTS are negatively impacted because users do not know how to use them. For example, this might include what additives can or cannot be put through the system.
Organizational	4 3-4 0.14	The existence of local NGO/non-profits involved in sanitation issues positively impacts OWTS.
Organizational	5 4-5 0.14	The existence of local, for-profit businesses such as installers, pumpers, designers, repairmen, and spare parts suppliers positively impacts OWTS.
Organizational	5 4-5 0.14	Follow up programs after construction positively impact OWTS.
Other	5 4-5 0.14	OWTS are negatively impacted when it is difficult or inconvenient to properly dispose of septage.
Technical	5 4-5 0.07	OWTS are negatively impacted by poor quality installation.
Technical	5 4-5 0.21	OWTS are negatively impacted by poor quality materials.
*1 = Very Unimportant, 2 = Unimportant, 3 = Neither Important Nor Unimportant, 4 = Important, and 5 = Very Important		

DIVISIVE FACTORS

The following 10 factors were the most divisive; in other words, individual scores exhibited the highest absolute deviation from the median. These 10 factors had absolute deviations of at least twice the consensus threshold, or at least 0.5. Since experts held diverse opinions on these factors, their comments were coded and analyzed to determine major themes. We present these themes along with selected comments that illustrate the identified themes below. While contextual issues (most commonly developed vs. developing community perspectives) appear in many discussions, more fundamental disagreements on these factors drive the lack of consensus for most. In each case, the discussion of these divisive factors tends to hinge on interactions, as highlighted in the discussion below.

Economic: Extreme poverty negatively impacts OWTS. For example, poor households may be less able to install, empty, or repair OWTS than a wealthier household. Assume neither is reached by a sewer connection. (Median: 4 Range: 3-5 Absolute Deviation: 0.50)

The first major theme identified for this factor is the recognition that being extremely poor correlates with not having a sanitation system or having an onsite system rather than a sewer connection. For example, one expert stated *"Globally, the bottom 40th of income groups by and large do not have access to hygienic and durable sanitation facilities. So yes, poverty is a major factor in the use and sustainability of onsite sanitation."* However, the second theme recognizes that this correlation does not signify causation; in other words, user poverty does not mean that sanitation systems fail, and nor does user wealth mean that sanitation systems will be successful. For example, *"Even the wealthy or well off are motivated to shop for the cheapest installation price. Few users truly invest the time to understand critical treatment process differences or the performance capabilities and limitations between alternatives, and even fewer consider the differences in long-term life-cycle costs or payback periods."* The final theme is a contextual one; these comments assume that one must have sanitation rather than considering contexts where this may not be the norm: *"If the person is at the poverty level they still need to ensure they have a working system which could cost them money."* This discussion emphasizes the interaction between the economic resources invested in sanitation and the varying motivation required to make that investment, perhaps contingent upon competing demands for resources.

Economic: The availability of installation subsidies negatively impact OWTS. For example, subsidies might cause households to not feel system ownership, might drive an inappropriate technology choice, or might not be equitable. (Median: 4 Range: 2-5 Absolute Deviation: 0.64)

Four major themes were identified in the comments regarding installation subsidies. The first group of opinion was that subsidies are helpful tools. For example, one expert noted that *"It will not be a negative impact - if two systems out of 10 are repaired, then this is an improvement."* However, at least one expert who advocated this theme appears to have been thinking of recent experience with large infrastructure projects rather than onsite systems. *"I actually disagree with this statement. Experience with the construction grants program which generated large subsidies for plant design and construction were largely very successful. Undoubtedly there may have been inappropriate technologies selected, but I think that has been true regardless of subsidies. The only inequitable concern I see would be if the subsidies were not either uniform or applied on a consistent scale."* The second theme is exactly opposite to this one; namely, that subsidies hurt the sustainability of onsite sanitation infrastructure. For example, *"30 years of subsidies taught that only wanted latrines are used latrines. Non-use is a negative impact."* The most common reason given for subsidy failure was *"Distorting of markets worldwide, a mess."* The third theme is concerned with the management of subsidies, including timing, equity, and implementation. *"This is important, but who manages the subsidies and how do we make the decision about which system gets subsidized."* Another expert noted that *"Financing approaches - including capital subsidies can have a profound impact on the use and sustainability of sanitation infrastructure. In developing countries, subsides for onsite sanitation have by and large not been properly implemented resulting in a process that undercuts effective demand for sanitation by the households which in term leads to limited use of the facility."* Finally, a contextual theme emerged. This fourth theme deals with comments stating that subsidies are typically not available for onsite systems in the geographical context that particular experts have experience in. Notes reflecting this perspective included comments such as, *"As far as I know there is not access to any subsidies to offset the costs of design or installation."* This discussion once again emphasizes the relationship between economic resources (in this case, external to households) and user motivation for sanitation. Both this and the previous theme imply that both economic and motivation factors are necessary but not sufficient for sustainable sanitation.

Motivation: OWTS are negatively impacted because they are "Out of Sight, Out of Mind" until there is a problem. For example, this could mean that the process chain is underground and easy to ignore until there is a problem. (Median: 4 Range: 1-5 Absolute Deviation: 0.50)

Four themes were identified in comments given regarding this factor. The first and most prevalent was that this is a major *"90% of mentality"* issue for onsite sanitation systems. At least one expert believes that *"Out of sight and mind is the source of most problems not involving design."* These comments suggest that not only are users unaware of issues but rather that they may refuse to engage with sanitation technologies. "*Nobody wants to deal with their toilet other than for what it is intended for. And everyone hopes other than the occasional cleaning they do not have to pay more attention to it."* A second theme was a single expert who repeatedly stated that he did not understand what the factor was trying to address. A third was a single expert who repeatedly stated that he strongly disagreed that this was an issue while recognizing that it was a commonly held opinion: *"It's a totally overstated assumption and is commonly held - hence my major divergence from the median."* Finally, a fourth theme emerged from an expert who felt that it was a design flaw if systems were permitted to be invisible when there were problems. *"I prefer less "out of sight and mind" by having lids near the surface for accessibility, and vent pipes to define limits of field and aware of problems, if there are problems."* This discussion may address a management issue particular to sanitation. If indeed "*nobody wants to deal with their toilet"* it may mean that households are unlikely to seek knowledge about systems or even to pay enough attention to notice that there are issues. Alternatively, this discussion can be framed as treating the far larger issue of inadequate infrastructure maintenance and asset management. In other words, this discussion concentrates on the relationship between motivation and knowledge. This could impact the way infrastructure software such as O&M contracts should be constructed and regulated. Although this factor deals with systems that are already installed, it may also apply more generally to sanitation adoption practices in infrastructure poor communities.

Motivation: OWTS are positively impacted because users perceive them to be safe (structurally sound, hygienic, children can't fall in, etc.) (Median: 4.5 Range: 4-5 Absolute Deviation: 0.50)

While this factor did not reach consensus, it was not due to fundamental disagreement on the issue. Instead, responses were split evenly (7 and 7) between rating this as a 4—

“Important” and a 5—“Very Important”. A representative comment provided for this factor is *“If they [users] believe the systems are unsafe structurally or if they are going to have a negative impact on their and their family's health they are going to be reluctant to have them. Education is the best way to inform them about how they can stay safe how best to keep their system safe and healthy.”*

Motivation: OWTS are positively impacted if users have a range of aesthetic/amenity options to choose from (styles, materials, colors of the above ground installation). (Median: 4 Range: 2-5 Absolute Deviation: 0.57***)***

Four themes were identified for this factor. The first were experts who generally agreed that aesthetics especially improve user satisfaction, create demand for systems, and thereby drive system sustainability: *“It is all about creating and meeting demand and creating more demand. Aesthetic aspects probably more than amenity options figure highly - see the parallel in virtually any other commercial product of lasting value.”* However, a second theme recognized the importance of economics. This group of experts believed that *“Cheap dominates over aesthetics.”* The third theme separates the aesthetics and amenities of the lavatory itself (used here to mean a room or structure with a toilet and possibly washing facilities that users interact with on a regular basis) and the underlying treatment infrastructure. *“Unsure about aesthetics and security questions. OWTS are generally below ground and not visible, unless you are talking about the WC itself - as in a pit privy. Then I think aesthetics/amenities and privacy/security are very important.”* It is interesting to note that this discussion further differentiates between the onsite technologies by suggesting that aesthetic options for the latrine’s lavatory are more important than for septic or similar installations. Underlying contextual and experiential assumptions regarding typical minimum standards of lavatory installations for various technologies (for example, a septic tank in a US home vs. a latrine in a US park) may drive comments like *“I have a great collection of outhouse pictures, but for the most part this [factor] is not relevant in U.S.”* Finally, the fourth theme notes that aesthetics ought not impact the technical performance of the infrastructure and therefore rates the factor as less important**:** *“I am assuming the aesthetic amenities do not have an effect on the goal of an OWTS (to treat wastewater prior to dispersal back into the environment). Therefore, the aesthetic amenity is neither important nor unimportant.”* This comment explicitly assumes that technical performance is never compromised for aesthetic reasons. This discussion again focuses on the relationship between economic and motivational factors. Additionally, the fourth theme suggests that there may be a relationship between motivational and technical factors, while emphasizing that expert's belief in which of these factors should dominate.

Motivation: OWTS are positively impacted if users have a range of level of service provision to choose from. For example, this might be the type of treatment or how much treatment is possible with the technology. (Median: 4 Range: 2-5 Absolute Deviation: 0.57)

Three themes were identified for this factor. The first simply agrees with the stated factor. The second notes that *"there is not much selection in service"* and that therefore this factor is less important. The third theme is that users often do not care much about the technology itself and just want it to work, with various definitions of what that means. *"I don't think most users of OWTS want information on the technology itself to insure performance. They may want information instead on the reliability, ease of operation, health benefits - performance factors that result from the technology."* This discussion relates the type of knowledge that motivates users. Specifically, performance factors, such as convenience, are cited over technical as motivators for users.

Organizational: Government involvement in areas other than regulation (such as financing, installation, etc.) positively impacts OWTS. (Median: 4 Range: 2-5 Absolute Deviation: 0.50)

Four themes were identified for this factor. The first were experts who agreed that government involvement in areas other than regulation were beneficial for the sustainability of onsite sanitation systems. Noting the varying opinions on this topic, one expert commented *"I continue to disagree [with the rankings of other experts] because my experience shows that government involvement is a critical factor in large scale and sustainable programs."* The second were experts who believed either that government involvement beyond regulation tended to have negative impacts (*"Matters in the sense of regulation, not financing or implementation (messes it up too often)),"* that it was unnecessary (*"I need an example in which government involvement, other than regulation, is needed,"*) or even inappropriate (*"Government's role is to govern, not finance, install, etc.").* The third theme, mentioned by just one expert, was that regulation actually encompassed the other areas identified in the factor; *"Installation is part of the regulatory process."* As such this factor did not make sense to this expert. Finally, the fourth theme was the recurring contextual issue of experts not having experience with government involvement other than regulation and thereby ranking it as less important. For example, one expert noted that the impacts of this factor are *"country specific - in U.S. other government involvement is limited."* This discussion hinges on the proper relationship between government and market forces in the provision of basic infrastructure services. While all experts place regulation as a government responsibility, they are split regarding other aspects. As most of the experts involved in this research are professionally involved in the provision of these services either from the private or public spheres, inadvertent bias may be a particular issue with the responses to this factor.

Other: OWTS are negatively impacted by natural disasters. (Median: 4 Range: 1-5 Absolute Deviation: 0.64)

There were three themes identified for this factor. The first is a recognition that disasters do indeed negatively impact OWTS through physical infrastructure damage. *"This is a major contributor to poor sustainability of less durable onsite sanitation built by poorer households. Not just major natural disasters but annual flooding (as in Bangladesh, the Amazon, etc.) regularly and consistently wash away onsite sanitation facilities."* The second theme notes that although onsite sanitation systems are indeed impacted by disasters, they "*actually might be more resilient since they are inherently more redundant"* than other, more centralized, sanitation technologies. These experts rated this factor as less important due to this relative comparison. The third and final theme was a contextual issue of experts working primarily in areas largely unaffected by natural disasters: *"In our region, natural disasters are not real common & thus do not have a high percentage rate of impacting OWTS."* This discussion suggests the need for research quantifying environmental discharges from decentralized systems after disasters. While it may be true that initial damage and discharge due to these systems is less, it could also be true that over the long run discharges would be greater due to the larger challenge of repairs to decentralized, privately owned systems. This in turn suggests a relationship between technical, regulatory, and organizational factors in sanitation performance.

Knowledge: OWTS are negatively impacted because designers have insufficient knowledge of soils, slopes, proximity to groundwater or surface water, etc. (Median: 4 Range: 2-5 Absolute Deviation: 0.50)

Most experts rated this factor as either 4-Important or 5-Very Important. However, two experts rated this factor as 2-Unimportant. Two themes are apparent in the expert comments; the first agrees that onsite systems have been negatively impacted by insufficient designer knowledge. One expert noted *"There have been few designers with a thorough background in OWTS until recently."* The second believes that as this knowledge is required by regulation (*"Knowledge of designers should be trumped by knowledge of regulators")* or designer reputation (*"Don't feel it is an issue because if care is taken in choosing a good reputable designers they WILL have the knowledge of soils, slopes, etc."*), it is a given. Therefore this group believes that this factor is less of an issue, though one expert calls attention to contextual importance by commenting that *"Most counties that regulate OWTS permits require knowledge of these. May not be true where there is no institutional oversight either as a permit system or designer/installer certification. Without these importance of #5 [the factor] would be much higher."* Both of these groups believe that expert knowledge is important to building sustainable systems. This factor is likely most important in locations where regulation of decentralized systems is weak due to greater variability in knowledge. Generally, this discussion is based on the relationship between knowledge and regulatory motivation.

Technology: OWTS are negatively impacted by inappropriate soils, slopes, proximity to groundwater or surface water, etc. In other words, OWTS technologies are just inappropriate in some areas. (Median: 4 Range: 2-5 Absolute Deviation: 0.50)

There were two themes identified for this factor. Expert comments indicated that there was general agreement that "*for any of the above factors there are engineering designs that can be utilized to ensure there is an appropriate design.*" In other words, experts believe that existing onsite sanitation technologies are sufficient to provide treatment in virtually every situation. However, others noted that these technologies must be designed and constructed appropriately; for example, *"If it is poorly located, the best design will not work."* Both these themes appeared in comments from single experts (*"The appropriate technology needs to be used for the area. An educated designer and installer should be able to identify if an area needs more or possibly less technology"*); difference in ratings appears to pertain to which theme the expert prioritized. Generally, experts believe that while adequate technology exists, it may not necessarily be applied correctly. In other words, it describes a relationship between technical performance and knowledge.

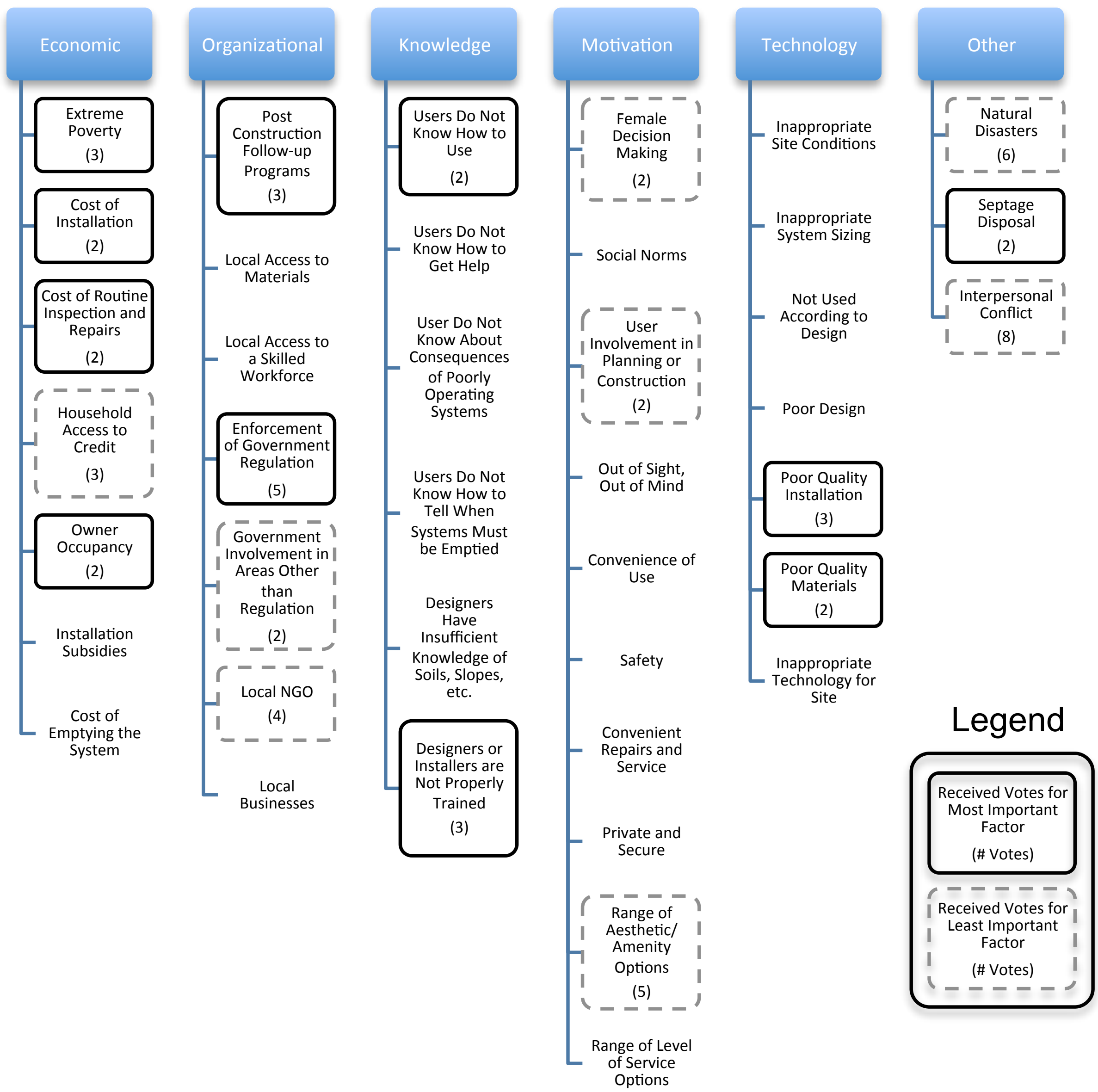
Most/Least Important

After the Delphi process was complete, each expert was asked to select three *most important* and three *least important* factors. One expert chose not to answer this question. Figure 1 shows the factors that received at least 2 votes for either Most or Least Important. Factors within the Economics and Organizational categories received many votes for both Most and Least important. The Organizational category received the highest number of votes for Most Important. Factors in the Economic and Knowledge categories also received a high number of votes for Most Important. The specific factor that received the most votes for Most Important deals with the enforcement of government regulation. Interestingly, a regulator cast only 1 of the 5 votes for this factor.

Factors in the Motivation and Other categories received the highest number of votes for Least Important. Votes for the Least Important factors were heavily skewed towards the 'Other' category; specifically, factors of natural disasters and interpersonal conflict received a large number of least important votes. None of the factors in the Technology category received Least Important votes.

Experts with the same professional designation tend to vote the same way. Specifically, academics and regulators often vote for the same categories, as do O&M providers and manufacturer/designers. This is an interesting trend, as it may indicate a disconnect between OWTS professionals in the field and those who regulate systems or educate students. The international development practitioners do not tend to vote with other expert categories. It is possible this is due to contextual differences between US domestic and international experience. However, the single expert with international experience who does not work in international development does not tend to vote with the international development experts. Specific factors that received votes for both Most and Least important are discussed below and listed in Figure 1.

FIGURE 1: MOST/LEAST IMPORTANT FACTOR MAP



Seven factors, shown below in Table 3, received votes in both categories; that is, some experts rated these factors as most important while other experts rated them as least important. In each case, there is a single expert who is in opposition to others; there are no cases where a large number of experts disagree about these extreme characterizations. In addition, there are no cases where experts within a single professional designation disagree with each other. For example, there are no cases where different regulators thought the same factor was most and least important. The international development experts were most likely to disagree; they were the single opposing vote in 5 of the 7 factors below. In addition, they provided opposing votes for both of the factors that received 5 votes from professionally diverse experts. It is possible this is due to the difference in international versus domestic experience. Unfortunately, only one expert other than the international development practitioners reported international work experience. This expert voted for the factor regarding enforcement of government regulations as most important while an international development expert voted for this factor as least important. This single instance at least demonstrates that international experience does not always explain the differences in voting seen below.

Finally, the factor describing NGO presence received 4 votes for Least Important although it came to consensus as an Important factor. This is due to one expert who felt that all but three factors should be 'very important' (for this expert, the NGO factor was 'important' but less so than other factors). Yet another expert stated he did not have sufficient experience with NGOs to oppose the group rating, but still chose NGO presence as least important when the choice was forced by question format. In addition, several experts commented on the variability of quality of NGO and therefore impact.

TABLE 3: FACTORS WITH CONFLICTING MOST/LEAST IMPORTANT VOTES

Votes for Most Important	Votes for Least Important	Category	Factor
2	1	Economic	Cost of routine installation and repair
2	1	Economic	Owner occupancy
5	1	Organizational	Enforcement of government regulation
1	2	Organizational	Government involvement in areas other than regulation
1	1	Knowledge	Users do not know how to tell when systems must be emptied
1	1	Motivation	Social Norms
1	5	Motivation	Range of aesthetic/amenity options

Study Limitations

This research project, like all others, has limitations due in part to inherent characteristics of the chosen methodology. The Delphi Method is useful in situations where there are many interacting factors. The results of this method identify areas where future research may be profitable. However, the results cannot be generalized in the manner of a large-scale statistical survey. Similarly, the research design purposefully included experts from diverse fields. However, the results do not permit generalizations regarding the opinions of certain types of respondents and are limited by the dominance of US-based expertise on our panel. The most obvious example of this are the differences in responses between the international development practitioners and the other groups, or between academics and regulators and O&M providers and manufacturer/designers. Additionally, this methodology did not address interactions between factors, although both the literature review and expert comments note the importance of these relationships.

The list of factors developed through this process is likely not exhaustive despite the literature review and expert comments. Indeed, during qualitative coding an additional factor emerged from expert comments regarding various factors: identity creation through infrastructure type. This factor was not identified until after the Delphi process was complete and as such was not evaluated in this research. This factor may be especially relevant to OWTS. In other words, it may be that part of the resistance to OWTS is that users identify modern, high-status people in legitimate communities with sewered technologies and therefore aspire to the same.

Finally, because this research relies upon content analysis and the subjective judgments of experts, future work should empirically evaluate these factors and their relationships between one another. This may be particularly fruitful for the divisive categories, and would serve to alleviate disagreement so that practitioners can be better informed when designing, construction and maintaining sanitation infrastructure in the field.

Conclusion

Theory suggests that both hardware (e.g. infrastructure, technology) and software (e.g. knowledge, institutions, education) is required to achieve sustainable infrastructure—and although we may still lack a definition of what is sustainable, we largely agree that our current practices are not. Sustainable development suggests criteria that impact the best practice design of both hardware and software. This research project contributes to the existing body of work in development theory by identifying factors involved in infrastructure sustainability—in other words, working towards theory defining what is necessary to achieve sustainable infrastructure. This project demonstrates the necessity of crafting technical designs that fit diverse and complex social situations, taking the latter as fundamental design criteria rather than a peripheral concern outside the demesne of engineers.

For example, experts agreed that factors such as user knowledge, installation and materials quality, and organizational support through businesses or NGO are important for onsite sanitation sustainability. Alternatively, factors such as government involvement in areas other than regulation are still contested as to how or if they contribute towards system sustainability. Generally, this research finds system software is more likely to be the root cause of system failure than the hardware itself, which experts believe is sufficient to meet the need so long as the software is in place. Additional research is needed to further explore the contributions and interactions of these factors as technology failure due to software is just as real a failure as that due to hardware.

The disagreement described here suggests that the pathways to sustainable infrastructure are multiple and varied. Some factors doubtlessly did not reach consensus due to the diverse contexts that the experts work in. In fact, expert comments call attention to factors that may be contingent upon context. For example, comments included statements like "*This is one that is potentially country specific*." Along these lines, it must be emphasized that neither this study nor the expert panel intend to suggest that local context does not matter, and nor do we support universal cookie cutter solutions to sanitation or sustainable development. However, this research identifies some factors that are so important they tend to transcend these boundaries; in other words, they may be low hanging fruit that should be targeted in any project. These results describe areas where additional research would be particularly profitable. In addition, these contentious factors should be examined empirically to evaluate their importance.

OWTS that perform admirably under controlled conditions and poorly in the real world emphasize the need for technical research aimed at matching technology to the larger system in which it operates. The theoretical lens of sustainable development, while contested and evolving, provides scientists and engineers with a valuable new approach to building better theory and better infrastructure.

ACKNOWLEDGEMENTS

The authors would like to thank the anonymous experts and reviewers who generously donated their time and knowledge to the project. This paper was developed under STAR Fellowship Assistance Agreement no. FP917283 awarded by the U.S. Environmental Protection Agency (EPA). It has not been formally reviewed by EPA. The views expressed in this paper are solely those of the authors, and EPA does not endorse any products or commercial services mentioned in this paper.

GREEN ACCESS COPY

This version of this paper has been made available under green open access policies; it is a post-print copy. The version of record may be found at
http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000757

To cite this paper, please reference the version of record:

Kaminsky, J., and Javernick-Will, A. (2013). "Contested Factors for Sustainability: Construction and Management of Household On-Site Wastewater Treatment Systems." *Journal of Construction Engineering and Management*, 139(12), A4013004.

References

Bakens, W. (1997). "International Trends in Building and Construction Research." *Journal of Construction Engineering and Management*, 123(2), 102–104.

Beheiry, S. M. A., Chong, W. K., and Haas, C. T. (2006). "Examining the Business Impact of Owner Commitment to Sustainability." *Journal of Construction Engineering and Management*, 132(4), 384–392.

EPA. (2008). *Septic Systems Factsheet*. EPA.

Etnier, C., Willets, J., Mitchell, C. A., Fane, S., and Johnstone, D. S. (2005). *Decentralized Wastewater System Reliability Analysis Handbook*. National Decentralized Water Resources Capacity Development Project, Washington University, St. Louis, MO.

Hallowell, M. R., and Gambatese, J. A. (2010). "Qualitative Research: Application of the Delphi Method to CEM Research." *Journal of Construction Engineering and Management*, 136(1), 99.

Helmer-Hirschberg, O. (1967). *Analysis of the Future*.

Klotz, L., and Horman, M. (2009). "Counterfactual Analysis of Sustainable Project Delivery Processes." *Journal of Construction Engineering and Management*, 136(5), 595–605.

Koo, D.-H., and Ariaratnam, S. T. (2008). "Application of a Sustainability Model for Assessing Water Main Replacement Options." *Journal of Construction Engineering and Management*, 134(8), 563–574.

Laefer, D. F., and Manke, J. P. (2008). “Building Reuse Assessment for Sustainable Urban Reconstruction.” *Journal of Construction Engineering and Management*, 134(3), 217–227.

Levitt, R. E. (2007). “CEM Research for the Next 50 Years: Maximizing Economic, Environmental, and Societal Value of the Built Environment.” *Journal of Construction Engineering and Management*, 133, 619.

Nelson, K. L., and Murray, A. (2008). “Sanitation for Unserved Populations: Technologies, Implementation Challenges, and Opportunities.” *Annual Review of Environment and Resources*, 33, 119–151.

Pieterse, J. N. (2001). *Development Theory: Deconstructions/Reconstructions*. SAGE.

PMI. (2008). *A Guide to the Project Management Body of Knowledge: PMBoK*. Project Management Inst.

Shen, L., Wu, Y., and Zhang, X. (2010). “Key Assessment Indicators for the Sustainability of Infrastructure Projects.” *Journal of Construction Engineering and Management*, 137(6), 441–451.

Solow, R. M. (1993). *An almost practical step toward sustainability*. Resources for the Future Press.

US EPA. (2008). “Clean Water Needs Survey 2008 Report to Congress.” <http://water.epa.gov/scitech/datait/databases/cwns/2008reportdata.cfm> (May. 15, 2012).

Valdes‐Vasquez, R., and Klotz, L. (2012). "Social Sustainability Considerations during Planning and Design: A Framework of Processes for Construction Projects." *Journal of Construction Engineering and Management*, 1(1), 429–429.

WCED. (1987). *Our Common Future*. Oxford University Press, USA.

WHO. (2012). "WHO | Key terms." *WHO | Key terms*, <http://www.who.int/water_sanitation_health/monitoring/jmp2012/key_terms/en/index.html> (Aug. 31, 2012).

WHO/UNICEF JMP. (2008). *Progress on Drinking Water and Sanitation: Special Focus on Sanitation*. World Health Organization, United States of America.