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Cultured Construction: Global Evidence of the Impact of National Values on Sanitation Infrastructure Choice

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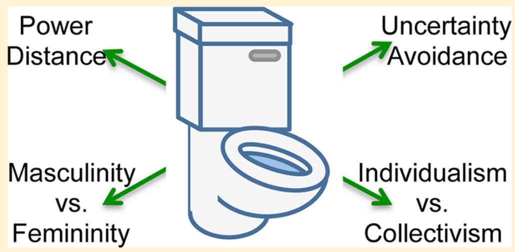
Supporting Information

ABSTRACT: Case study research often claims culture—variously defined—impacts infrastructure development. I test this claim using Hofstede's cultural dimensions and newly available data representing change in national coverage of sewer connections, sewerage treatment, and onsite sanitation between 1990 and 2010 for 21 developing nations. The results show that the cultural dimensions of uncertainty avoidance, masculinity-femininity, and individualism-collectivism have statistically significant relationships to sanitation technology choice. These data prove the global impact of culture on infrastructure choice, and reemphasize that local cultural preferences must be considered when constructing sanitation infrastructure.



INTRODUCTION

In this article, I claim to find quantitative, global evidence that national culture shapes aggregate sanitation technology choices. This is important as it may help us better understand how to design and construct culturally appropriate infrastructure worldwide. The findings (especially, as I will argue, regarding the cultural dimension of uncertainty avoidance) may be used to theoretically gound future project-level research that can discover how to apply these insights at the local scale.

The data that underpin these claims represent change in national level sanitation coverage between 1990 and 2010 for 21 developing nations. This time frame is historically important, as 1990 is the baseline year for the Millennium Development Goals (MDG). In other words, the data represent the gains in sanitation coverage that have been achieved during the tenure of the MDG. The MDG are a set of internationally agreed upon targets for global change[1] that were intended to be achieved by the year 2015. That year is now upon us, and while some of those goals have been met (for example, the target of reducing by 50% the percentage of the global population without access to safe drinking water[2]), others have not (for example, the target of reducing by 50% the percentage of the global population without access to basic sanitation[2]). As such, and recognizing that even those goals that were achieved leave substantial work to be done,[3] the international development community is hard at work developing a new set of Sustainable Development Goals (SDG).[4] Part of this effort is a review of progress and process to date.[5] For example, critics have noted that the MDG count households that are connected to a sewer as having improved sanitation, regardless of whether or not effluent is treated. Recent research has estimated that this concern applies to the infrastructure serving a full billion people worldwide.[6] To take another example, there is considerable evidence that onsite sanitation systems suffer from breakage rates far above what would be expected from a technical perspective.[7] However, these breakages are not considered in MDG estimates of sanitation coverage. Others have noted the need for water and sanitation infrastructure to focus on wellbeing rather than volumetric metrics.[8] These and other issues lend support to the need for research and discussion to ensure that the forthcoming SDG[4] are written such that they can achieve even more than the almost-expired MDG have. This paper should be understood as a contribution to this global discussion. For civil and environmental engineers, this appears as part of a larger discussion of global policy regarding environmental infrastructure and technology.

Generally speaking, although the sanitation MDG has not been met, there has been significant progress made; more than a quarter of the world's population has gained access to improved sanitation since 1990.[2] Virtually all of the change in access to sanitation infrastructure has occurred in the least developed and developing nations, as most wealthy nations had high levels of sanitation coverage in the baseline year. However, even in contexts with high sanitation coverage at the 1990 baseline, changes have been made in terms of the technologies used to achieve sanitation coverage; these are the metrics that interest us here. Instead of considering only the more aggregate change in access to improved sanitation, the current analysis makes use of newly available data[6] to break down this figure into change in access to (1) sewer connections, (2) sewerage treatment, and (3) onsite sanitation.

There are various reasons why households might be connected to either a centralized sewer system or an onsite

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sanitation system. Technically speaking, both types of technology can provide adequate treatment of waste in a variety of settings.[9] However, sewered sanitation is more prevalent in denser urban areas,[10] and with the world's population becoming increasingly urban[11] we might expect that this is where most of the increases in sanitation coverage are occurring. However, the rural population (still 46% of the global population[12]) is disproportionately poor and has disproportionately worse access to sanitation infrastructure.[13] This means that many of the gains in sanitation coverage are occurring in rural settings. As sewered systems are particularly costly in rural settings because of the longer distances involved, remote populations are often served by onsite systems. This is true even in wealthy parts of the world; for example, in the United States 20% of households are served by septic systems, and this figure is increasing for new construction.[14] Economic forces might thus be expected to push sanitation adoption toward onsite technologies. We might also expect economic forces to drive whether or not sewers are connected to treatment. However, after controlling for these economic and technical factors, in this research I hypothesize and show that sociocultural factors also impact the form of sanitation adoption. As described below, while case study research has often indicated the importance of these sociocultural forces, we lack research that attempts to operationalize and quantify the impact of such forces at the global scale with a national unit of analysis. This research addresses this gap, with the practical goal of empirically supporting policies regarding the development of more culturally appropriate sanitation infrastructure.

■ POINT OF DEPARTURE

To operationalize the research goal of discovering the impacts of culture on infrastructure at the national level, a validated measure of cross-cultural national values that is available for as many nations as possible is needed. Hofstede's cultural values framework[15] is one of several competing frameworks[16,17] that attempt to meet this theoretical need. Hofstede's framework is used here because it has arguably had the greatest impact on the practice and theory of cross-cultural management.[18,19] As an example of this impact, Google Scholar reports over 20 000 citations to Hofstede's book *Culture's Consequences*,[15] which describes his theory for an academic audience. As I conceptualize it here, international sanitation infrastructure development is undertaken through a series of variously sized global projects, making this body of literature an excellent theoretical framing.

The earliest version of Hofstede's framework included four dimensions. These were developed from a series of surveys from 88 000 employees working globally at IBM between 1967 and 1973. As a dominant model in the literature, this framework has been repeatedly both validated and criticized; some of these debates are discussed below. Still, Hofstede's framework has proven to have useful explanatory power for intercultural research and work. Hofstede's framework assigns numeric values to various cultural dimensions, including individualism, masculinity, power distance, and uncertainty avoidance. Figure 1 shows a comparison of the U.S. and China using these dimensions, which are defined below. In Figure 1, we see that in terms of national values, China is more comfortable with large power differentials (shown as a higher power distance score) while the U.S. is more highly individualistic (shown as a higher individualism score). However, the two are similar on the masculinity dimension. Hofstede emphasizes that his dimensions are only valuable in

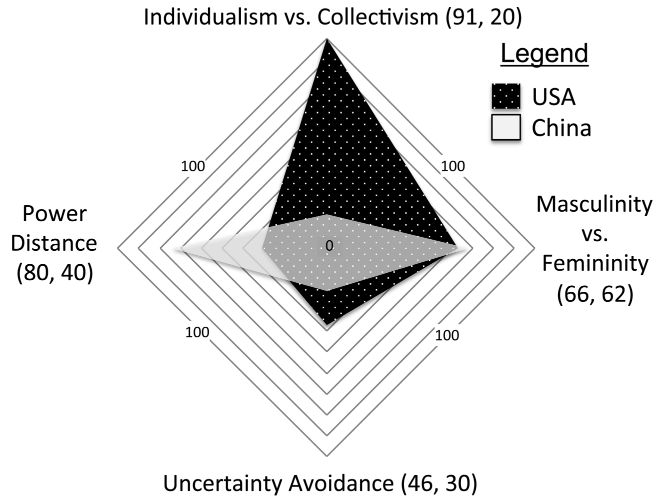

Figure 1. Sample Hofstede Dimensions (U.S., China).

comparison to each other.[20] While the individual numeric scores are not valuable in isolation, as a point of comparison they provide valuable cultural information.

The first of Hofstede's dimensions is *uncertainty avoidance* (*UAI*). The uncertainty avoidance dimension "expresses the degree to which the members of a society feel uncomfortable with uncertainty and ambiguity."[20] Past research has (for example) investigated the impacts of UAI on tourism practices,[21] ethical decision making,[22] and roles in innovation.[23] Of particular relevance to the current study is that a high UAI index has been related to high degrees of structure in organized activities[24] and to a high importance of rules.[25] This latter is related to strong cultural conceptions and treatment of dirt, purity,[26] and taboo, all of which are particularly relevant for sanitation infrastructure. With this background, I propose the first hypotheses:

H1: *At the national level of analysis, UAI is positively related to 1) sewer connections, 2) sewerage treatment, and 3) onsite sanitation.*

The next dimension is *masculinity vs femininity (MAS)*. The masculinity side of this dimension represents "a preference in society for achievement, heroism, assertiveness, and material rewards for success. Society at large is more competitive."[20] Its opposite, femininity, represents a "preference for cooperation, modesty, caring for the weak and quality of life. Society at large is more consensus-oriented."[20] A sense of connection (or, low MAS scores) may lend support to the more collective sewered sanitation technologies. At the same time, however, low MAS scores are also associated with a preference for smaller organizations,[15] which would seem to support onsite technologies. Based on these conflicting pressures, I propose the second hypotheses:

H2: *At the national level of analysis, MAS is not related to (1) sewer connections, (2) sewerage treatment, or to (3) onsite sanitation.*

The third dimension is *power distance (PDI)*, or "the degree to which the less powerful members of a society accept and expect that power is distributed unequally. The fundamental issue here is how a society handles inequalities among people."[20] For sanitation, sewered systems mean that each person has the same level of collection. If the system is connected to treatment, all people have the same level of treatment. Thus, I hypothesize that nations that are

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comfortable with high levels of inequality will be pushed toward the more disparate onsite sanitation systems:

H3: *At the national level of analysis, PDI is inversely related to (1) sewer connections, and (2) sewerage treatment, and is positively related to (3) onsite sanitation.*

The fourth dimension is *individualism vs collectivism (IDV)*. Individualism is defined as "a preference for a loosely-knit social framework in which individuals are expected to take care of only themselves and their immediate families."[20] In contrast, collectivism represents a "preference for a tightly-knit framework in society in which individuals can expect their relatives or members of a particular in-group to look after them in exchange for unquestioning loyalty".[20] I hypothesize that nations with high IDV are more comfortable with distributed onsite technologies, and are culturally more distant from the highly networked and collective sewered technologies:

H4: *At the national level of analysis, IDV is inversely related to (1) sewer connections, and (2) sewerage treatment, and is positively related to (3) onsite sanitation.*

More recent work by Bond[27] and Minkov[28] have added two additional dimensions to Hofstede's framework. Bond added a dimension called Confucian dynamism, which represents long-term vs short-term orientation.[27] More recently yet, Minkov added a dimension called indulgence vs restraint.[28] Indulgence "stands for a society that allows relatively free gratification of basic and natural human drives related to enjoying life and having fun."[20] Alternatively, restraint "stands for a society that suppresses gratification of needs and regulates it by means of strict social norms."[20] As these latter two dimensions have not had as many studies to validate them due to their relatively short existence, they are not included in the analysis presented here.

Hofstede's dimensions have been used empirically to explain phenomena ranging from information seeking in global social networks[29] to modes used by firms to enter new markets.[30] However, the framework is not without detractors. For example, in a study across 23 nations and provinces, Spector et al.[31] found that "the construct validity of these scales is suspect, and that they should be used with caution." Hofstede's response[32] notes that his scales were intended for use at the country rather than individual level of analysis. More typically, however, replication studies have supported Hofstede's framework[33,34] and studies have successfully used the framework as a tool beyond the context it was created for, including individual level studies and topics beyond the workplace behavior context it was created in.[35] Criticisms of the framework itself[17,18,36,37] have claimed that it oversimplifies culture, that it was created based on a sample drawn from a single multinational corporation (IBM), that Hofstede's samples were small and unrepresentative, that the country level unit of analysis ignores diversity within geographic regions, that the nation state is an arbitrary unit unrelated to culture, and that cultures change over time. For the current analysis, the most troubling of these criticisms is the use of surveys of technical workers at IBM (middle class individuals) who may have had very different life experiences than the poorer residents of those same nations who are more likely to lack sanitation services. However, Hofstede claims that his dimensions are statistically generalizable[15] and that his dimensions of culture are not limited to particular socioeconomic groups. In addition, as technical workers are often responsible for decisions regarding major infrastructure projects they are a key group for this research.

The author recognizes and deeply appreciates these various theoretically well-founded criticisms. However, the current research is not interested in validating or criticizing Hofstede's framework itself. His framework is one way of comparing national values that has been shown to relate to multinational organizations and projects, of which international sanitation development is an example. As such, I am using his framework to see if an admittedly highly simplified representation of national difference has explanatory power for new infrastructure construction. If this relationship can be shown, the results quantitatively validate any number of smaller size, qualitative studies that have shown culture to be an important factor for individual cases.[9,38−40] I would suggest that if a significant relationship appears with this rough operational tool, more finely grained and local understandings of culture would show even more highly significant relationships. However, in the current study I am interested in seeing if cross-cultural differences impact aggregated national level technology choices, and to globally screen potential measures of cultural difference for use in future local applications. As I will show below, the results of this research provide quantitative, large-scale evidence that global infrastructure design and construction is indeed influenced by culture. I leave future research to determine the full complexity of how those social and technical factors interact, and how civil infrastructure should be modified accordingly. The relationships discovered here may also be a useful planning level tool that can be practically implemented on infrastructure construction projects; again, future research would be needed to test the relationships at the individual project level. Generally speaking, while Hofstede's framework has been empirically proven to be a useful tool for explaining global variation in workplace behaviors and organizational outcomes, this framework has never before been applied to infrastructure development projects, making this research an important contribution to the literature.

MATERIALS AND METHODS

Data Collection. This research uses a number of data sets gathered from various international databases and publications. Figures for sewer connections and sewerage treatment from 1990 and 2010 were published in a recent article.[6] As reported in that article, data for sewerage connections were developed from the World Health Organization/UNICEF's Joint Monitoring Program (JMP) Country Files[41] following JMP rules.[42] When sewerage connection data was not available in the JMP database, the United Nations Statistics Division (UNSD) figure[43] was used for a national coverage figure. This latter was considered lower quality data than the former, as the JMP data has disaggregated data for urban and rural sanitation. Sewerage treatment data is not as widely available. As such, Baum et al.[6] compiled data from the UNSD database,[43] Eurostat from the European Commission,[44] AQUASTAT from the Food and Agriculture Organization (FAO) of the United Nations, the Organisation for Economic Co-operation and Development (OECD) database,[45] and Internet searches. When data were unavailable, an empirical model was used to develop estimates of treatment prevalence as a function of various indicators. The reader is referred to Baum et al.[6] for further details of this model, but is generally cautioned that this means sewerage treatment data should be seen as less reliable than are the empirically measured connection data.

With these figures in hand, I next gathered statistics on total improved sanitation coverage at the national level for each

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Table 1. First Order Correlations between Change in Sanitation Coverage and Hofstede's Cultural Values (1990–2010)[a]

measure	mean	(std. dev.)	1	2	3	4	5	6	7	8	9	10
Outcomes												
1. % sewer connection change	12.6	12.9	–									
2. % sewerage treatment change	8.4	32.4	0.03	–								
3. % onsite sanitation change	1.7	13.0	−0.65**	−0.21	–							
Predictors												
4. PDI	66.5	18.2	0.40	−0.02	−0.02	–						
5. IDV	24.2	13.0	−0.19	−0.08	−0.15	−0.52*	–					
6. MAS	46.9	12.8	0.18	−0.45*	0.02	0.17	0.14	–				
7. UAI	69.2	26.8	0.27	0.32	−0.42	0.00	−0.03	−0.41	–			
Controls												
8. change in per capita GDP, 1990–2010, USD	6520.8	7482.2	−0.16	0.03	−0.27	−0.22	0.26	−0.06	−0.27	–		
9. % sanitation coverage, 1990	66.7	23.3	−0.26	0.18	−0.48*	−0.40	0.44*	−0.31	0.18	0.64**	–	
10. change in % urban population, 1990–2010	9.5	6.1	0.32	−0.21	0.12	0.15	−0.34	−0.18	0.00	−0.50*	−0.49**	–

[a]Note. Multiple regression analysis. Robust standard errors. $^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.

Table 2. Hofstede's Cultural Dimensions and Sanitation Technologies[a]

	R^2	b	(SE)	t	p
1. Change in onsite sanitation (n = 21 countries)	0.54				
IDV		0.11	(0.19)	0.59	0.56
MAS		−0.53	(0.21)	−2.58	0.02*
UAI		−0.31	(0.08)	−3.96	0.001***
1990% improved sanitation coverage		−0.27	(0.14)	−1.99	0.07
change in percent urban population, 1990–2010		−0.85	(0.45)	−1.88	0.08
change in per capita GDP, 1990–2010, USD		0.00	(0.00)	−2.42	0.03*
2. Change in sewerage treatment (n = 21 countries)	0.34				
IDV		−0.17	(0.53)	−0.32	0.75
MAS		−1.33	(0.78)	−1.70	0.11
UAI		0.11	(0.27)	0.40	0.70
1990% improved sanitation coverage		−0.11	(0.38)	−0.28	0.78
change in percent urban population, 1990–2010		−2.41	(1.34)	−1.81	0.09
change in per capita GDP, 1990–2010, USD		0.00	(0.00)	−0.92	0.38
3. Change in sewer connection (n = 19 countries)	0.60				
IDV		0.01	(0.24)	0.05	0.96
MAS		0.70	(0.21)	3.26	0.007**
UAI		0.34	(0.09)	3.80	0.003**
1990% improved sanitation coverage		−0.16	(0.11)	−1.44	0.18
change in percent urban population, 1990–2010		1.34	(0.45)	2.98	0.01*
change in per capita GDP, 1990–2010, USD		0.00	(0.00)	4.19	0.001***

[a]Note. Multiple regression analysis. Robust standard errors. $^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.

country in the data set.[41] As for the data above, this was compiled for both 1990 and 2010, and a single figure representing change in coverage was calculated. Next, a figure for change in onsite sanitation coverage was developed by assuming that figures for change in improved sanitation coverage less sewerage connection change equaled onsite sanitation change. In addition to these data, Hofstede cultural dimension figures were collected[46] and paired with the sanitation coverage metrics. Next, I matched country data so that any data gaps were removed from the data set. This resulted in 43 countries with data for all of the sanitation and cultural metrics. While as comprehensive as possible, this data set has serious limitations. One concern is that there are no African nations represented, as Hofstede's dimensions are rarely available for these countries. However, the countries that do appear represent Europe, Asia, North America, South America, and various small island nations. Twenty-one of the nations are classified by the United Nations[47] as developed economies; one is classified as an economy in transition, and 21 are classified as developing economies. As my interest is in developing contexts, and per reviewer comments, the results I present here treat just those 21 nations that are classified as having developing economies.[47] This data is shown in Table SI1 of the Supporting Information.

Data Analysis. Using the complete data set of 21 countries, I used STATA 13[48] to examine first order correlations (Table 1), check for outlying data points, and finally to perform robust multiple linear regression to test for the hypothesized relationships (Table 2). Before these regression runs were performed, graphs of the residuals were examined to ensure that assumptions of linearity, normality, and homoscedasticity were met. However, the measure for change in connection appears slightly right skewed. As such, a robust multiple regression analysis is reported. As part of the checks to ensure

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the data were appropriate for linear regression, I also calculated variance inflation factors (VIF) to check for multicollinearity. The highest observed VIF for any variable in the regression runs I considered was 2.86, meaning the data also pass this check.[49] As I suspected that change in wealth (measured here by change in per capita gross domestic product (GDP) between 1990 and 2010), the 1990 baseline level of sanitation coverage, and the change in the percentage of the population living in an urban environment from 1990 to 2010 might impact the results, I statistically controlled for these variables in the analysis presented here.

■ RESULTS

The first order correlation table (Table 1) indicated collinearity between PDI and IDV. To evaluate which of the two dimensions to keep in the multiple regression analysis, which allows me to identify independent contributions from each of the cultural dimensions, and to improve validity, I performed a leave one out cross validation analysis on the change in sewer connection analysis. The change in sewer connection analysis was used for this test because it uses empirically measured data, rather than the fitted values (as described above) used for the change in treatment data. This procedure iteratively leaves out one data point and calculates the model on the remaining data points. After this analysis, I selected the model with the lowest root mean squared error. This resulted in dropping PDI and keeping IDV in the analysis. Of further note in the zero order correlations table above is that change in per capita GDP and change in the percentage urban population from 1990 to 2010 do not have a significant relationship with any of the cultural dimensions.

Next, I checked for outlying data points that might bias results. I first did so with the graphical tool proposed by Rousseeuw and van Zomeren[50] using the procedure presented in Verardi and Croux,[51] and note this procedure depends on iterative, randomly selected data subsets. For each data point, this test plots robust standardized residuals on the vertical axis against the Mahalanobis distance (a measure of the multivariate outlyingness) on the horizontal access. I define the vertical cutoff for outliers at −2.25 and +2.25, which represents values from the normal 2.5% furthest from the central mass of the distribution. On the horizontal access, the cutoff for outliers are defined as $(\chi^2_{p,0.975})^{1/2}$, as the squared Mahalanobis distance is normally distributed as χ^2_p. Generally speaking, outliers on the vertical axis may be understood as having more or less change in the sanitation metric than would be expected by the model, but are not outliers in terms of Hofstede's metrics. Outliers on the horizontal access can be considered statistically as good leverage points,[52] because while the cultural metrics are somewhat different than other countries, the change in sanitation metric is in accordance with the model. Outliers in both vertical and horizontal dimensions are more problematic as they are located further from the regression line and may significantly impact estimates of the intercept and slope. In addition, Cook's distance values were calculated and examined as an additional check for outliers. These tests were used to identify outliers for each model, and the regression was run to determine if removing these data points significantly impacted the model. Only in the case of sewer connections did removing the identified deviant data points change which cultural metrics were significant or not. In this case, the MAS metric went from insignificant ($p = 0.08$) to significant ($p = 0.007$). Therefore, all countries were retained in the models for change in sewer connection and change in sewerage treatment, but two outlying countries (Chile and Isarel) were removed from the sewer connection analysis shown below in Table 2. These countries may present an excellent opportunity for case study research to investigate how and why these deviant sanitation outcomes came to be.

■ DISCUSSION

In the regression analysis shown in Table 2, after controlling for the level of sanitation coverage attained by 1990, change in the percent urban population from 1990 to 2010, and change in per capita GDP from 1990 to 2010, there are statistically significant relationships between the UAI and MAS Hofstede dimensions and rates of onsite sanitation coverage and sewer connections. As discussed below, the IDV dimension shows an interesting pattern of first order correlations with sanitation coverage that suggest sanitation infrastructure is now built to serve more communal interests. Sewerage treatment rates are not related to the cultural dimensions.

Control Variables. Change in connections to sewer systems does, as might be expected, have a significant and positive relationship with change in per capita GDP in the regression model. Unsurprisingly, nations with larger changes in per capita GDP are also more likely to have increased onsite sanitation coverage. Interestingly, there is not an observed relationship between increased per capita GDP and sewerage treatment. It is possible that the developing economies included in this analysis are below a threshold value of wealth where we might see this type of Kutznets relationship. Supporting this idea, if the analysis is rerun to include both developed and developing nations and use gross GDP instead of the change in per capita GDP, a statistically significant relationship ($p = 0.005$) is observed. Alternatively, the missing relationship (as well as the lack of relationship between sewerage treatment and the various cultural dimensions) could be an artifact of the modeled, rather than empirically measured, source of the values of sewerage treatment.[6]

None of the sanitation metrics show a significant relationship with the 1990 level of improved sanitation in the regression analysis, although (negative) change in onsite sanitation is close at $p = 0.07$. If I relax the significance requirement to consider this result, it suggests that nations that had higher levels of improved sanitation in 1990 are less likely to have adopted onsite sanitation. This suggests that nations are unlikely to shift from sewered to onsite systems. Using a similarly relaxed significance criterion, change in percent urban population is significantly related to shifts away from onsite technologies and toward sewer connections. However, even after controlling for change in per capita GDP, change in urban population, and the 1990 baseline level of sanitation coverage, there are significant relationships between MAS, UAI, and sanitation outcomes.

Cultural Dimensions. UAI was the most important predictor for change in onsite sanitation and change in sewer connections. As hypothesized, a high level of UAI corresponds with statistically significant increases in the change of sewer connections and the level of sewerage treatment. Correspondingly, but directionally opposed to my hypothesis, a high UAI index is also associated with a significant drop in the percentage of the population covered by onsite sanitation technologies. UAI is a measure of how uncertainty is dealt with, and how structure (technology, law, or religion) is used to manage those uncertainties.[15] The results show that at an aggregate level, high UAI drives technology adoption toward sewers. To explain this,

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I again refer to Hofstede, who notes that technologies may not actually create certainty in an objective sense,[15] but may instead only seem to do so (or not to do so) from the perspective of a particular cultural frame. As both sewers and onsite technologies are able to provide treatment of waste, the impact of UAI would appear to be founded on perceptions of technology. For example, sewers may seem more reliable because virtually all of the operation and maintenance of sewered systems is passed off to a central plant operator. Previous work has suggested that onsite sanitation technologies, at least, may be adopted and even used symbolically[53] as a type of rational myth[54] intended to protect health and pursue modernity (among other goals). The strong significance of UAI in the current findings (and the surprising directionality of the relationship with onsite technologies) suggest that this may also apply to other types of sanitation technology. Practically speaking, this means that worldwide, sanitation technology should be understood as a collective (or, organizational) strategy for managing uncertainty (for example, avoiding illness). However, our understanding should also recognize that symbolic technology adoption might not actually enable the protection the technology is intended for, resulting in the use of sewers unconnected to treatment or overflowing onsite technologies.

MAS was significant for change in both sewer connections and onsite technologies. The observed coefficients show that highly masculine cultures tend toward sewer connections and away from onsite technologies, while the opposite is true for more feminine cultures (low MAS scores). This is a particularly interesting finding given the many known connections between gender and sanitation.[55] Nations with high MAS scores are characterized by highly differentiated gender roles;[15] thus we expect that women are even more disproportionately responsible for the majority of the sanitation work in these nations[55,56] than in those with low MAS scores. As men are disproportionately responsible for infrastructure decisions worldwide, we might have expected their lesser involvement with sanitation work would disincentivize the larger investments needed for sewered systems.[57] However, the data presented here suggest otherwise. Perhaps the tendency for nations with high MAS scores to prefer larger, more centralized organizations (such as centralized sanitation systems) dominates impacts of the gendered sanitation workload; case study research is needed to validate this explanation of the surprising relationship observed here.

In opposition to the hypotheses, IDV is not significantly related to any of the sanitation metrics in the regression models. Technology's implicit bias regarding IDV—toward either the collective or the individual—has been previously implicated in attempts at international technology transfer.[15] While I hypothesized that onsite technologies would be more attractive to individualistic nations while networked sewers would be more attractive to collective nations, this was not observed in regression analysis. However, IDV has a significant positive first order correlation with both the 1990 baseline percent coverage in sanitation (p = 0.04) and an almost-significant but negative first order correlation (p = 0.06) with the overall change in sanitation coverage, although not with any particular technology choice. This surprising combination suggests that, in the past, sanitation infrastructure was typically built for individual benefits such as convenience. More recently, however, it has been built for collective benefits (such as public health). Case study fieldwork is needed to unpack the reasons for this change; one possible explanation is that the public health based framing of sanitation initiatives over the past decades have borne fruit and changed public perception of the benefits of sanitation infrastructure. In any case, our results suggest that currently, sanitation's collective benefits drive its adoption independently of the technology that is employed to achieve those benefits.

PDI was collinear with UAI and was dropped from the regression analysis. It is possible that a different approach such as a set theoretic analysis would discover relationships between these dimensions and change in sanitation infrastructure coverage; however, this analysis is outside of the scope of this paper.

■ CONCLUSION AND POLICY IMPLICATIONS

The results presented here provide quantitative, global scale evidence that global infrastructure design and construction is *cultured*, much as engineering workplaces may be said to be *gendered*.[58,59] While any number of case studies have identified culture as a factor in infrastructure development, there has not been any previous research that has proven this relationship at an aggregate, global level. To summarize the findings, for change in sewer connection, UAI and MAS are positively related. For change in onsite sanitation, UAI and MAS are inversely related. Of these two, UAI is the most statistically robust and is also the easiest to imagine applying at the project level; as such, I claim it should be the focus of future, project level work on this topic. While certain nations or communities may be more or less comfortable with uncertainty, I would propose that in almost every setting more reliable sanitation services are preferred to less reliable services, making this strategy broadly applicable. In addition, while sanitation technology choice is not related to the IDV metric, the overall level of sanitation coverage is. In the past, this relationship was positive; presently, it is negative. In other words, it seems that sanitation infrastructure is now constructed for collective benefits, although this was not true in the past. This analysis has discovered global relationships between UAI, MAS, IDV, and sanitation technology construction. The next step is local work to discover how communities make these connections, and to learn how our designs can change to better meet these socially based infrastructure criteria. In other words, founded on the results of the current analysis, the next step will be multisited fieldwork to learn how to locally apply this new knowledge in sanitation marketing, education, outreach campaigns, and changed technical designs. Broadly speaking, I suggest the relationships discovered here are concrete ways in which development practitioners and engineers may begin to directly incorporate cultural considerations of empirically proven relevance into sanitation infrastructure design and construction.

These findings suggest local measurements could be used in combination with the relationships discovered here in order to determine how to better select sanitation technologies that suit local culture. While national measurements of culture cannot be assumed to represent any single community, recent meta-analysis has suggested Hofstede's tool may also be applicable to the analysis of individuals and groups[35] such as communities. Readers are referred to Taras et al.[35] for an analysis of and references to these studies. Caution is urged against the indiscriminate use of the equation: the limitations of Hofstede's framework (discussed previously) also apply to work derived from it. In addition, national values are certainly not the only

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consideration in selecting appropriate technology, and it is easy to imagine situations in which the ultimate local preferences would not match local cultural leanings (for example, due to financial limitations, technical issues, or previous experience with a particular technology).

Ultimately, the surprising significance of the relationships observed in this study lead to the conclusion that future research is urgently needed to understand other ways in which infrastructure technology and culture are interrelated. As shown in this research, the implications of these interactions are global and significant. For example, due to the availability of data I was only able to consider onsite versus sewered sanitation technologies. A study that could consider a higher resolution of technology types might be able, for example, to determine the relative cultural fit of various onsite technologies rather than grouping them all together. An additional variable that could not be considered here is a robust measure of the international development efforts undertaken in each nation between 1990 and 2010. Similarly, these strong results suggest that additional studies investigating these relationships for other types of infrastructure are also urgently needed, such as the author's ongoing work considering drinking water coverage and Hofstede's dimensions.

■ ASSOCIATED CONTENT

Supporting Information

Change in sanitation coverage metrics and Hofstede's cultural dimensions. The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.5b01039.

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Notes

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