SOLVING TOMORROW'S DESIGN CHALLENGES REQUIRES NEW TOOLS FOR LARGE WORLD DECISION-MAKING

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ABSTRACT

Engineering design research has largely focused on normative models of decision analysis based on small world causal frames where uncertainty can be resolved as probabilities or probability distributions. However, today we need to design solutions for our built environment that are sustainable, just, and able to adapt. Because of the scale and complexity of our world, designs that address sustainability, justice, and adaptability are dominated by unresolvable uncertainty. This requires large world frames and new engineering design frameworks and tools that provide a much broader and nuanced understanding of the impact of our engineering decisions. In this paper we propose that these tools will need to link quantitative and qualitative data and engineering judgment using narrative decision-making processes. To support this, we provide two examples where engineering decision-making is based in part on narrative processes. We then identify five research areas that require additional research to support large-world frames including (1) how can we create microcosms that enable transition between large- and small-world frames and (2) how engineers develop conviction to act using the narratives they create.

Keywords: Sustainability, Decision making, Uncertainty, Narrative, Large world frames

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Cite this article: Ferguson, S., Drobac, K., Bryden, K. M. (2023) 'Solving Tomorrow's Design Challenges Requires New Tools for Large World Decision-Making', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.320

1 INTRODUCTION

The world is reaching a critical moment. It was announced at the recent COP27 meeting that CO_2 emissions have reached record levels and preventing rising global temperatures is unlikely. Managing the built environment will require that we control carbon emissions, identify strategies for resilience, and adapt to a changing world (Baisas, 2022; UNFCCC, 2022). While it is easy to assign blame for the problems we face, we must look forward. Finding solutions for our built environment that are sustainable, just, and able to adapt to a changing environment and technologies will be challenging. This challenge falls to engineering designers who work in an entangled world where systems have complex and irreducible coupling, system performance is impacted by human behaviour, and time and resource constraints prevent uncertainties from being resolved.

Yet, much of the decision analysis and support tools developed by researchers—particularly for decision scenarios involving selection—are based on normative models that require small world causal frames. When modelling a decision in a small world frame, uncertainties are represented in the "form of probabilities or probability distributions" using "available experimental data, but in many cases … the experienced judgement of experts" (National Research Council, 2001). By representing uncertainties using probabilistic distributions, alternatives in a decision can be ranked—using a single numerical value such as expected utility—and vast design spaces can be explored using computational tools.

However, in looking forward, the problems that confront us as we manage the built environment will require decision-making tools that enable better decisions when engineers work in large world casual frames. Large world frames cannot be converted into mathematical "puzzles" like their small world counterparts (Kay and King, 2020). Rather, in large world frames we find that defining the set of outcomes is inherently difficult and assigning (meaningful) probabilities to these outcomes becomes effectively impossible. Modelling these decisions with a small world causal frame would require the quantification of things that the engineer does not (and likely cannot) know.

Further, we posit that decision analysis alone does not help the engineer reach a state of action. Human engineers, unlike their computer counterparts, use models for exploring different causal frames (Cukier *et al.*, 2021). Even if they create a small world frame and conduct decision analysis, they know that this frame is not comprehensive. So that they can find sufficient motivation to act, they extend their normative decision-making analysis to include—albeit on an ad hoc and informal basis—what is often referred as engineering judgment. Yet, the role of judgment—and even the rationale that engineers provide for their design decisions—has not been adequately studied.

In this paper, we describe that new perspectives and frameworks for modelling and supporting engineering design decision-making are needed. More complete explanations are needed about how engineers synthesize and judiciously weigh available information in drawing conclusions. Such insights will facilitate and inform the development of new engineering decision-making frameworks and tools that must be developed **now.**

We support our claim for the need of new perspectives and frameworks by presenting preliminary findings from a "simple" engineering selection problem and a significantly larger decision scenario that has more consequential outcomes. We present the simple engineering selection problem as evidence that engineering judgment is central to decision-making even in cases where a small world causal frame can be mathematically formulated. The larger decision scenario is presented to illustrate how small world microcosm creation, interpretation, and judgement come together in reaching (or not reaching) a state of action. In both, the decision-maker challenges the small world frame or finds it unsatisfactory.

We use these findings to advance our argument that decision-making in engineering design is a narrative creation process that combines quantitative analysis and engineering judgement. We suggest that Conviction Narrative Theory (Fenton-O'Creevy and Tuckett, 2021; Tuckett and Nikolic, 2017) provides a framework for studying how narratives develop and engineers reach a state of action, particularly in decision scenarios that require large world frames where uncertainties cannot be mathematically modelled—that is, the uncertainties cannot be resolved (Kay and King, 2020). Gaining a better understanding of how engineers make sense of large world frames will give us insight into the decision-making process used by engineers who are faced with engineering design problems that must be considered using large world causal frames. This understanding is also necessary if design researchers are to create decision-support tools that support *larger, messier decisions by moving beyond our reliance on traditional, normative decision-making analysis tools derived for use in small world causal frames.*

https://doi.org/10.1017/pds.2023.320 Published online by Cambridge University Press

2 CONSTRASTING SMALL WORLD AND LARGE WORLD FRAMES IN ENGINEERING DECISION-MAKING

Moving the design process forward requires that engineers make many decisions—decisions that mature the concept (Miller *et al.*, 2018; Simon, 1996; Yukish *et al.*, 2015), define the concept's lifecycle (Hazelrigg, 2012), and commit resources in ways that cannot easily be reversed or corrected (Bertsimas and Mišić, 2017; Dieter and Schmidt, 2013). While the goal of design (and decision-making) is changing an existing situation into one that is more preferred, the outcomes—and ramifications—of our decisions are realized after we make them. Dealing with risk and uncertainty, therefore, becomes an inescapable element of moving the design process forward. As the public good is impacted by design, tools that help engineers optimize their decision outcomes receive significant attention.

Toward ensuring mathematical consistency in decision analysis, design researchers have argued for using normative expected utility calculations for modelling risk and uncertainty so that decisions have a "defensible analysis" (Abbas, 2018) or so that decisions can be reduced to "an equivalent deterministic optimization" (Hazelrigg, 2012). Beginning with Bernoulli's work in the 1700s, normative models of decision analysis are built on axioms established by studying decision scenarios with a finite set of outcomes and objective probabilities (Bernoulli, 1954; Von Neumann and Morgenstern, 2004). Savage, in 1954, extended the applicability of these axioms toward a wider range of decision scenarios by introducing subjective probabilities (Savage, 1954). Using Savage's subjective probabilities, decision-makers—engineering designers in our context—could now create a 'small world' model with a constrained outcome space. Binmore (Binmore, 2007) summarizes Savage's distinction between a small world and a large world by characterizing a small world as one where it is "feasible always to look before you leap." That is, small world frames require explicit causal models that relate possible paths of action and expected outcomes. Conversely, in a large world "there are some bridges that you cannot cross before you come to them."

In developing his theory on small worlds and subjective probabilities, Savage argues that it may be possible to create microcosms where large worlds are partitioned into tiny events. For some engineering design decisions, such as those that occur during the detailed design phase, we believe that partitioning this way may be an appropriate approach. However, as engineers tackle the fundamental problems faced by society, they face entangled worlds that require sustainable, adaptable, and just solutions. Creating microcosms for such design decisions may pose significant challenges, as engineering serves as the bridge between science and realization and requires explicit decision-making frameworks and tools. As stated by Hardy Cross, managing the natural world to improve human life requires that engineers not only "make important decisions about the mere mechanical outline of structures and machines, but they are also confronted with the problems of human reactions to environment and are constantly involved in problems of law, economics and sociology." (Cross, 1952)

For these larger—messier—design decisions, engineers are faced with decisions that involve complex and irreducible coupling between systems where system performance is inherently impacted by human behaviour. We contend that models created around a small world frame for these design scenarios are inappropriate. Koen suggests that such decision scenarios are faced frequently, requiring that engineering designers imagine possible futures while working in poorly understood situations with limited resources (Koen, 2003). Here, decision analysis—our main quantitative tool—gets us only so far. Reaching a state of action requires that we combine quantitative analysis with engineering judgement. This notion is supported by Cross, who further states that engineers "know that analyses, whether mathematical or by models, experiments and experience are all merely evidence bearing upon their problem, to be judiciously weighed in drawing conclusions." (Cross, 1952)

Binmore notes that Savage acknowledged treating all decision scenarios as small worlds was 'ridiculous' and 'preposterous' (Binmore, 2007). Yet, the limitations of modelling design decisions using a small world frame have not been explored or challenged. Researchers have explored the use of heuristics in design (Fillingim et al., 2020) as a means of balancing time and/or resource constraints against the optimality of the outcome. It is also noted that designers are often not consciously aware they are engaging heuristics when making decisions. Researchers have also analysed eight hundred and forty-six pages of technical engineering design reports so that they could identify the design rationale—defined as the explicit documentation of the reasons a decision is made—in product and system design (Mirabito and Goucher-Lambert, 2022). However, this characterization of design rationale is limited to textual phrases used in a written report and may lack the nuance about the

https://doi.org/10.1017/pds.2023.320 Published online by Cambridge University Press

complete set of the information that was available at the time, and how that information was managed so that a state of action could be reached.

Recent scholarship in psychology (Beach, 2009, 2010) and economics (Chong and Tuckett, 2015; Kay and King, 2020; Tuckett and Nikolic, 2017) offer descriptive frameworks for modelling human decision-making, even in decision scenarios where the uncertainties cannot be resolved. These scholars argue that narratives are integral to the disciplined process of systematically envisioning and assessing possible futures and the pathways toward realizing them. Our research into the decision-making journey has been strongly influenced by Tuckett's research and his development of Conviction Narrative Theory. We have previously described how normative models of decision analysis could be incorporated within the narrative creation and assessment process (Bryden and Ferguson, 2021). This combination of narrative creation, normative decision analysis, and engineering judgement is depicted in Figure 1, and is our first effort toward highlighting the significance of engineering judgment in decision-making. We have also described, using interview data, how three engineers envisioned possible futures in a decision scenario by creating and assessing narrative fragments (Ferguson and Bryden, 2022).

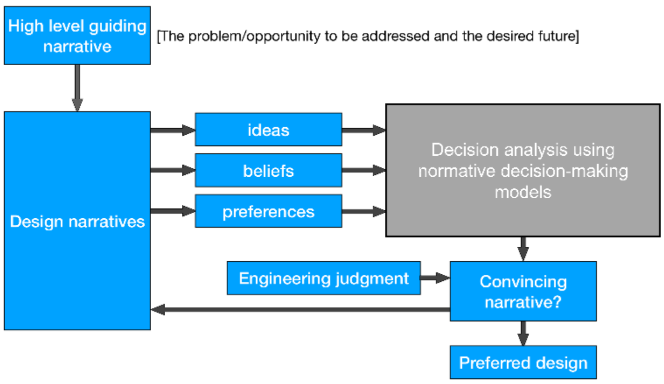

Figure 1. We previously proposed a decision-making framework where narrative creation, quantitative decision analysis, and engineering judgement combine. (Bryden and Ferguson, 2021)

In this paper, we focus our exploration of decision-making by considering how respondents challenge small world causal frames or look for reasons that they find it unsatisfactory. We present decision scenarios in two different examples and describe how the decision makers converts the decision into a larger world where they do not have the information needed to "look before they leap". We hypothesize that this behaviour is typical of many engineering design decisions, where quantitative decision analysis—if used—becomes only a part of the envisioning process used when considering possible futures. We then discuss the ramifications of our findings in the context of designing complex engineered systems and meeting the challenges facing society.

3 HUMAN SUBJECT STUDY OF A "SIMPLE" ENGINEERING DESIGN DECISION

As a starting place for examining how engineers make decisions, and to start gathering evidence so that we can test our hypothesis, we conducted an IRB-approved experiment involving 171 NC State engineering students. Respondents were presented with a binary-choice selection scenario that reflects a small world frame that is adapted from (Herrmann, 2015). This decision scenario requires that respondents choose between using an LED or a traditional flash lamp as the light source in a medical device. The students recruited in this study were at various levels of engineering education. The pre-engineering students were recruited from a College of Engineering introductory class that spans all engineering majors. The remainder of our respondents were recruited from various courses in the Mechanical and Aerospace Engineering department at NC State.

We framed the decision scenario by providing respondents with a text-based description of the problem and a decision tree, shown in Figure 2, where the payoffs and associated probabilities are

https://doi.org/10.1017/pds.2023.320 Published online by Cambridge University Press

quantified. Under Savage's definition, this is a decision scenario where enough information is provided so that respondents could "look before they leap"—respondents could perform probabilistic calculations and identify the outcome with the smallest expected cost. Respondents were also asked to provide a written rationale for their decision. Our expectation was that respondents would describe their assessment strategy, giving us insight into how mathematical analysis and engineering judgement were used in arriving at their choice. We chose this simple decision scenario because we wanted to test if our respondents would extend the small world causal frame by finding elements of it unsatisfactory. By getting text-based descriptions of their rationale, we would collect data that could be assessed to help explain what additional factors they were considering or where judgment was being used.

Suppose you are designing a medical diagnostic device and are considering an LED instead of a traditional Flash lamp for the light source. The LED will cost less, however you are unsure if it will provide adequate light intensity over the lifetime of the device. If you choose the LED, you will conduct lifecycle testing to determine the expected degradation and if the performance will be adequate. If the testing shows that the power decreases too much too soon, then you will have to redesign the device to use the Flash lamp.

Assume all the development costs are mapped in the decision tree below. Based on published data about LED performance, you believe that the probability that the LED performance will be adequate is 75%.

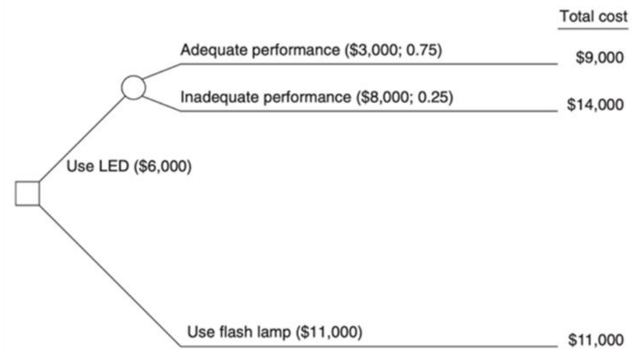

Figure 2. Binary choice question given to respondents in a "simple" engineering design decision.

Respondents who treat this problem as having a closed set of information, and who use this information to calculate an expected cost, would determine that the LED light source is the optimal choice. The result of our experiment, however, was that 98 of the 171 respondents (57.3%) selected the LED. Choice results segmented by student educational level are presented in Table 1.

Table 1. Choice data across education levels

Respondent educational level	# in cohort	LED	flash lamp
Pre-engineering students	61	32	29
Sophomore and junior students	66	36	30
Senior and graduate students	44	30	14
Totals:	171	98	73

We also coded the respondent's written responses that were provided as their decision rationale. The codes presented in this paper were generated inductively by a single coder. NVivo was used for linking identified text fragments of the written responses to codes as they were being generated (QSR International Pty Ltd., 2018). After all responses were coded, the coder grouped codes into one of four characterization categories: probabilistic reasoning, cost, outcomes, and external factors.

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Of the 171 respondents, 73 (42.6%) provided decision rationale that was coded to the use of probabilistic reasoning. Of these respondents, 55 chose the LED while 18 chose the flash lamp. Utility or expected value calculations were coded in 16 of the 73 responses, of which 15 selected the LED light source. The remaining 59 responses mentioned the odds of the LED being successfully developed, often using statements that described whether these odds were sufficient to move forward.

Interestingly, 19 respondents—16 of which chose the LED—provided decision rationale that went beyond the information provided in the problem. The text in these responses was coded, and these codes were binned in the external factor characterization category. Seventy other respondents mentioned external factors in their response but did not provide text that, when coded, was mapped to probabilistic reasoning. The choice between LED and flash lamp were evenly split for these 70 respondents.

In total, 89 of the 171 respondents (52%) provided some discussion of external factors that went beyond the information provided in the problem statement. The coder coded 47 text elements that related to:

- Perceptions of a performance advantage (12 coded elements for the LED, 4 for the flash lamp)
- Efficiency, sustainability, and lifespan of the LED (11 coded elements)
- Quality, technology level, compatibility, and modern nature of the LED (5 coded elements)
- Reliability (14 coded elements) and lifespan (1 coded element) of the flash lamp

The coder also coded 67 text elements that related to rationale describing:

- How development of the LED could be extended toward future designs (32 coded elements)
- Regulatory testing related to the fact that this is a medical device (16 coded elements)
- Concerns about development, testing, and redesign times (8 coded elements)
- Concerns about uncounted costs (4 coded elements)
- Safety and efficiency of each technology (1 coded element)
- Concerns about the impact of the choice on the firm's engineering reputation (1 coded element)

The presence of coded elements in the decision rationale related to such external factors provides evidence—albeit on a limited scale—that engineering decision-making under uncertainty combines quantitative analysis and engineering judgement. Many respondents, across all levels of education, provided no quantitative justification and relied predominately on qualitative reasoning—that is, they exercised their engineering judgement. Here, their judgement tells them that the small world frame posed in the problem statement is not comprehensive enough. They do not view this decision as a homework problem that requires only a mathematical assessment (even though the problem prompt is derived from a textbook). Yet, at the same time, the external factors described in their rationale are decision elements for which it is unlikely that the respondents can define the outcome space or assign (meaningful) probability distributions. That is, given their state of knowledge, and the time and resources available to them for making the decision, the uncertainties created by these external factors are unresolved. This resembles the decision-making challenges faced by economists as described by (Kay and King, 2020), who question the value of using normative decision analysis models in the broad sense when unresolvable (radical) uncertainties are present.

Tuckett and his colleagues find that this type of narrative-based decision-making, in which a qualitative model in the form of an extended narrative is used to incorporate judgement into the decision process, is used extensively in business investment decisions. This data, combined with our previous and informal observations with engineers and ad hoc reflections on engineering design projects, support the hypothesis that this type of decision-making process is also the norm in engineering. That is, engineers may create a small world for part of their analysis, but that information alone is not enough for action. A larger world must first be constructed. However, this perspective of the decision-making process in engineering design has not been studied. We argue that such studies must be completed, as we also see this same type of decision-making used in difficult, complex scenarios when action is needed on problems that fundamentally influence the public good.

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4 THE CHALLENGE OF LARGE WORLD DECISION-MAKING WHEN UNRESOLVABLE UNCERTAINES ARE PRESENT

In August 2018 Nathaniel Rich in a New York Times article, "Losing Earth: The Decade We Almost Stopped Climate Change," describes the debate and indecision about climate change during a 10-year period from 1979 to 1989 leading up to the first major political climate change conference in November 1989 Noordwicijk, The Netherlands (Rich, 2018). Seen through one lens, this is straight forward story in which special interests worked to block the establishment of a binding international agreement on greenhouse gas emissions. However, in Rich's reporting a more nuanced picture emerges in which various individuals struggled to achieve the motivation to act. That is, the world's response to climate change in the 1980s was a decision-making process based in unresolvable uncertainty. Given the unresolved uncertainty around the impacts and costs of climate change, two potential courses of action emerge—(1) even if there are unknowns we must act now, the risk of disaster is too high and we will not be able to take effective action in the future, and (2) the costs imposed by the needed changes are too high and the models are too uncertain to justify these costs.

In the center of this discussion is the primary decision maker/advisor, John Sununu, White House Chief of Staff under President George H. W. Bush. It is John Sununu in 1989 who advises President George H. W. Bush on climate change and who ultimately persuades the United States, Japan, the Soviet Union, and the United Kingdom to oppose the establishment of a binding international agreement on greenhouse gas emissions. Having a Ph.D. from M.I.T. in mechanical engineering, John Sununu is confronted with evidence comprised primarily of climate change models. He is skeptical. His skepticism is based on his experience with earlier models and predictions. These include

> "… Paul Ehrlich's 'The Population Bomb' which prophesied that hundreds of millions of people would starve to death if the world took no action to curb population growth; the Club of Rome, an organization of European scientists, heads of state and economists, which similarly warned that the world would run out of natural resources; and as recently as the mid-'70s, the hypothesis of some of the nation's most celebrated scientists – including Carl Sagan, Stephen Schneider and Ichtiaque Rasool—that a new ice age was dawning, thanks to man-made aerosols."

Framing this as a narrative decision-making process, we see that the question became—*are the models of future outcomes sufficiently accurate to merit changing our current behaviour and bearing the cost of large-scale economic change?*

Nathaniel Rich writes that to resolve this question in his mind, in part, "He [John Sununu] had taken it upon himself to study more deeply the greenhouse effect; he would have a rudimentary, one-dimensional general circulation model installed on his personal desktop computer." This appears to be an attempt to find sufficient motivation to act, one-way or another. Confronted with his internal narrative of skepticism regarding scientific modelling results, seemingly unresolvable uncertainties, and political realities, John Sununu advises the United States to oppose freezing greenhouse gas emissions and the Noordwicijk Climate Conference ends with a without a clear commitment to act. *The fundamental question resulting in this outcome is: In the face of unresolvable uncertainty do the models provide a sufficiently convincing narrative to act?*

John Sununu's actions with respect to climate change, and his decisions discussed here, remain controversial. We are not seeking to join this controversy or justify his decision. Rather, we seek evidence and examples of how engineers make decisions. We are also arguing that this process needs to be better understood to ensure that we make better decisions, particularly in light of the challenges we as a society face today and the impact of decisions that engineers can make.

5 RAMIFICATIONS FOR ENGINEERING DESIGN OF SUSTAINABLE, ADAPTIVE, AND JUST PRODUCTS/SYSTEMS

The results of our preliminary studies demonstrate the need to learn more about how engineers use narratives during the design process, the impact of unresolvable uncertainties, and how narratives help us manage these uncertainties so that we can reach a state of action readiness and make a design decision.

Today, we as engineers and designers are confronted by the challenge of designing engineered products that support a sustainable, resilient, and just world. In addition to climate change, we face issues of pollution, water scarcity (Unfried *et al.*, 2022), energy security (Axon and Darton, 2021), and the threat of new diseases (Excler *et al.*, 2021; Ristaino *et al.*, 2021). The challenge is that:

- The products and systems we are designing exist in a larger ecosystem where sustainability, resilience, and justice cannot be reduced to a simple number or set of goals (e.g., reduced or zero carbon emissions, recycled materials, or renewable energy) within a design requirements document.
- While each of these goals is an excellent start, creating a product or system to meet a set of goals without considering its place within the larger ecosystem of infrastructure, consumer and societal needs, and built systems simply shifts the impact elsewhere or creates new (unintended) impacts.
- This larger ecosystem is not well defined and is difficult to determine the overall impact and to assign the impact to a particular product.
- The linkages between products/systems and today's decisions and their full outcome are often difficult to discern and harder to model.

As we shift the emphasis of design from a single product/system to one that considers function and impact within a larger societal ecosystem, we must also change our perspective of design from a small world frame (in which the outcomes and their probabilities are known—or largely known) to a large world frame in which unresolvable uncertainty dominates the decision-making process. *That is, truly confronting the challenge of designing for a sustainable, resilient, and just world requires extending our perspective of engineering design decision-making and moving beyond our reliance on traditional decision-making tools derived for use in a small world frame.*

However, making design decisions for products and systems in the presence of unresolvable uncertainty is a messy process. We, somewhat unsurprisingly, have a limited understanding of this process. Our counterparts in economics, psychology, and business are struggling with the same challenges. That said, as in the case of the student decision-making efforts discussed here, engineers routinely make decisions with incomplete information (unresolved uncertainty) using a narrative process that embeds engineering judgment. This narrative process allows us to take that which is known and combine it with limited, incomplete, and uncertain information where we construct a qualitative understanding of outcomes and goals. Information is weighed as to its relevance, trustworthiness, and then is assembled—like how we solve mysteries—to build a coherent and well thought out narrative in support of our eventual decision. From a research perspective, this decision-making process is largely hidden and unexplored. However, in an increasingly entangled world that requires a much broader and nuanced understanding of the impact of our engineering decisions, we must develop clear understandings of the narrative decision-making process for large world problems. And we must develop new engineering design tools based on these understandings. This needed research includes:

- Achieving good design outcomes to the larger problems facing the world requires that we better understand the decision space and our process for making these decisions. Models—as developed, used, and then explained to others by experts—are the primary tool that we use for understanding the linkage between our actions and future outcomes. Yet, the linkage between models, expert interpretation, and narrative construction is not well understood.
- Further complicating matters, models come in various forms. While significant attention has been turned toward creating, validating, and presenting quantitative models, we also use qualitative models that are based on data we interact with and are used to define our expectations of future outcomes. Understanding the process of building, choosing data sources, and testing these qualitative models is not understood and yet is a part of any complex engineering project.
- In addition, engineering is not a process of decision-making without review and accountability. Full participation in the process of building a shared narrative requires the ability to understand, test, and question the critical data that shape and change the narrative and explain this process. That is, engineering judgment must be clear and open to review.
- In most cases the modeling process is not open, transparent, or participatory, and as a result, its effectiveness as a tool for building a shared understanding of the action required is limited.

https://doi.org/10.1017/pds.2023.320 Published online by Cambridge University Press

6 CONCLUSIONS

Engineers have successfully developed products and systems for the built environment that change the way we live. The documented and linear process of engineering is established by creating models appropriate for a small world frame. By decomposing a large world into a series of small worlds—or in Savage's words, microcosms—we can make sense of complexity, the output relationships of our models can be measured with accuracy, and risks can be calculated. Normative models of decision analysis help us think wisely by navigating these risks in a mathematically consistent manner.

Yet, as engineers tackle the large problems faced by society, small world frames are insufficient. Complexity is a key feature, the performance of our products/systems require an understanding of both physics and human behaviour within an entangled and complex system. Within this large world frame, obtaining meaningful measures of outcomes becomes more challenging, and the information we must process is often in conflict. Further, the aggregation of our small world models may mislead us. In short, uncertainty reigns. Frameworks and engineering design tools suitable for large world decision-making, where quantitative analysis and engineering judgement combine, are needed.

We present two examples where humans challenged the small world frame or found it unsatisfactory. In our first example, decision-makers described how they supplemented quantitative data provided to them with external information—guided by experience—and used their engineering judgement to make a decision. Our second example illustrates how engineering judgement played a role in developing a narrative that combined scepticism of scientific modelling results, unresolvable uncertainties, and the inability to create a convincing argument that would result in a new course of action.

These examples serve as a call for further research into decision-making for large world frames.

- We must answer pressing questions about when it is appropriate to create microcosms that allow us to transition between large and small world frames and how this can be done.
- We need additional evidence describing how engineers develop conviction in the narratives they create, particularly when faced with uncertainties that cannot be resolved given the time and resources available.
- We need to better understand the linkage between models, expert interpretation, and narrative construction.
- We need clearer insight into the process of engineers choose data sources and construct and test qualitative models.
- We need to develop frameworks that enable decision and model transparency and documentation when confronted with large world frames.

These are the questions that we, as engineering design researchers, must answer if we are to create products within today's increasingly entangled world. Our answers will help develop new engineering design decision-making frameworks that enable the creation of solutions for our built environment that are sustainable, just, and able to adapt.

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