General Examinations - Primary Area - Day 3

Jack Reid

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For Day 3, please build on all that you have written and considered for the first 2 days. Please write the first draft of a text with graphics for a specific writing context. Select a writing scenario of your choice and share what you select. A writing scenario may include opportunities such as a traditional journal paper; a short, high-profile article in a widely circulated publication like Science; an editorial in the New York times; an article in a tech-centered periodical such as Technology Review; a proposal to NASA; a white paper for the next Earth Science Decadal Survey, etc. Please consider these and other writing scenarios and choose one you want to work on. Once you select your scenario, write the first draft of a text with graphics that presents the opportunities and future vision for EVDT. Craft an argument, select an audience, invite the audience to take some action in response to your text.

Chosen Writing Scenario: The following paper draft is perhaps not what was envisioned when you wrote the above prompt. While it certainly makes use of the work of the prior two days, it is not centered on EVDT itself (it only appears in the final couple of sections), but instead is a sort of manifesto for why EVDT should exist. I'm not sure what venue this would fit in. The primary audience that I would like to reach is systems engineers, but I think that the style and length of this make it a hard fit in such venues. Nonetheless, I have listed some options below.

1. Systems Engineering - Review Paper (10-15 pages): Judging by their description of Review Papers, this would require significant changes made to the below to focus more on a systematic literature survey, but this could be done will preserving the same message. Such a rewrite could be modeled upon [1].
2. Systems Engineering - Editorial (1-2 pages): This would be a better thematic fit than the Review Paper category, but obviously this paper as written is significantly too long. Perhaps due to my own deficiences as a writer, I am unable to conceive of a way to cut this down to the required length, but I left it here in case you see a path.
3. INCOSE's Insight Magazine (???): This might be a decent fit, though it isn't clear how open they are to unsolicited articles. Their general length is still shorter than this paper (3-6) pages, but longer than the editorial articles in the actual scholarly journals.
4. A planning journal - ??? (???): I am not familiar with the landscape of planning journals, having only read a selection of articles curated by others. I would want to talk with someone more experienced, such as Prof. Sarah Williams, in order to situate this piece. Such a venue may also require significant changes.
5. Science - Perspectives (<1000 words): Similar to the Systems Engineering editorials.

Learning from the Past and Moving Forward

A Case for a Systems Engineering Approach to Sustainable Development

1 Introduction

The field of systems engineering has a long and troubled history with urban planning and development. Numerous urban planning failures, both large and small, of the mid-and-late 20th century were under the management of systems engineers, often from the aerospace industry, or those seeking to emulate their methods. In the decades since, however, both the systems engineering and the world have changed significantly. Systems engineering has moved away from its strict prescreptive design orientation and its desire to suppress uncontrolled phenomena. The world has come to recognize the interconnectedness of its peoples and systems, both natural and human-made. We have seen the rise of sustainable development, with its three components of economic development, social development and environmental protection. There is a need for methodologies that can help us navigate these complex systems and make plans for the future that benefit us all. The question is, can a new, perhaps more humble systems engineering be of use in this endeavor? This paper argues that it can. To get there, it explain what we mean by systems engineering, recount the history of its meddling in development, and why things may be different this time around. We will end by providing an example of how we are actively pursuing this and invite others to join with us or to pursue their own projects in this vein.

2 What is systems engineering?

Systems Engineering: An interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal [2].

Systems engineering, perhaps due to its inherently interdisciplinary nature coupled with its roots in several different fields (aerospace engineering, civil engineering, mechanical engineering, etc.), has had numerous definitions proposed over the course of the past century. Some of these have been by individual authors, such as Maier and Rechtin's "*A multidisciplinary engineering discipline in which decisions and designs are based on their effect on the system as a whole*" [3], and some by international standards organizations, such as the international standards organization (ISO)/International Electrotechnical Commission (IEC)/Institute of Electrical and Electronics Engineers (IEEE) definition "*Interdisciplinary approach governing the total technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life*" [4] . For the purposes of this discusion, the specific definition is not overly important, as we do not seek to create a foundational work of systems engineering, but rather to understand its relations to other fields.

It is worth noting International Council on Systems Engineering (INCOSE) affiliated Systems Engineering Body of Knowledge (SEBoK) definition, however: "Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal" [2]. Something missing from this definition is that systems engineering refers to a specific intellectual tradition that arose out of mechanical, civil, electrical, and aerospace engineering fields in the early-to-mid 20th century. It thus tends to draw from an engineering mindset and relies upon engineering techniques, rather than those of urban planning, architecture, or program management, all of which also could be considered to fall into the SEBoK definition. This is important because the nature of systems engineering is that it is inherently abstracted from its subject matter to a certain degree. The tools of systems engineering were developed in order to design hydroelectric dams, rockets, global communications systems, and much more. In this way it is similar to control theory, in that is is not deeply tied to the specific thing being designed or controlled, only to an abstract understanding of its mechanics and relationships. This means that systems engineers, like some physicists, can have a tendancy to see any problem, any situation as tractable with a systems engineering perspective.

3 A troubled history with planning & development

3.1 Technocratic planning in general

We should start by noting that this section is not intended to consider all of the arguments for and against planning in general (for that see Klosterman [5]), but instead to focus in on the narrower question of whether *technocratic planning*, particularly in an international context, can be helpful and ethical.

By "technocracy" we mean the basic idea that "the human problem of urban design has a unique solution, which an expert can discover and execute. Deciding such technical matters by politics and bargaining would lead to the wrong solution" [6]. It is typical for a believer of this idea to quickly put themselves in the role of the "expert [who] can discover and execute." That said, they quickly find themselves beset by complexity and gapes in the data that frustrate their efforts. For such aspirants "legibility [is] a central problem," one that must be solved prior to addressing urban design itself. To this end, "exceptionally, complex, illegible, and local social practices" must be turned into "a standard grid whereby it [can] be centrally recorded and monitored." This, of course, requires immense simplification. These "state simplications... have the character of maps. That is, they are designed to summarize precisely those aspects of a complex world that are of immediate interest to the mapmaker and to ignore the rest. To complain that a map lacks nuance and detail makes no sense unless it omits information necessary to its function." And the interest of these would-be-technocrats tends to be their "unique solution." Taken together, there are five specific characteristics of these simplifications [6]:

1. They are interested and utilitarian, aimed at a particular end.
2. They are nearly always written, as opposed to visual or verbal.
3. They are typically static and thus, perpetually out-of-date to at least some extent. "The cadastral map is very much like a still photograph of the current in a river."
4. They are typically aggregate facts, not individual ones.
5. They are standardized, so as to enable comparison and longitudinal analysis.

These individuals are what Easterly calls "Planners," to be distinguished by "Searchers," those who seek for bottom-up solution to specific, addressable needs [7]. The Planners, meanwhile, fashion themselves into benevolent dictators (though they would eskew being called as such) focused on implementing their general solution [8]. Beyond outright failure, such endeavours have not infrequently caused immense social harms, including famines, cultural destruction, and environmental collapse. Furthermore, such technocratic planning is bound up in the history of colonialism and, while formal colonialism has ended, its impacts continue and certain mindsets are still embedded within such planning efforts [9].

James Scott argued that four elements were necessary to precipitate the most tragic of these social engineering disasters [6]:

1. The "administrative ordering of nature and society." This includes items like cadastral maps, surnames, census records, and a standardized legal system. As Theodore Porter put it, "Society must be remade before it can be the object of quantification." [10]
2. A "high-modernist ideology," which Scott defines as a "strong," "muscle-bound" "self-confidence about scientific and technical progress, the expansion of production, the growing satisfaction of uman needs, the master of nature... and the rational design of social order commensurate with the scientific understanding of natural laws."
3. An authoritarian state that is both "willing and able" to wield power to inact the high-modernist ideology.
4. A vulnerable civil society that "lacks the capacity to resist" the plans of that authoritarian state.

In essence what is "truly dangerous to us and our environment... is the *combination* of the universalist pretensions of epistemic knowledge and authoritarian social engineering" [6]. Such a combination often takes the form of undue focus being places on specific metrics, with little interest in underlying causes and dynamics. "Many studies involve ranking places on one or more criteria, and allocating policy benefits accordingly. At its crudest this applied geography merely provides a list of winner and losers with no understanding of why the differences occur" [11].

With regard to the second element a key aspect is that, as Scott notes, high-modernist ideology is not scientific practice exactly. Rather, it is a "faith that borrowed from the legitmacy of sciency and technology." In fact, it was more an aesthetic prediliction than anything scientific. Furthermore, the underlying ideas were, in fact, quite sympathetic. "Doctors and public-health engineers who did possess new knowledge that could save millions of lives were often thwarted by popular prejudices and entrenched political interests" [6]. The dangers were when an authoritarian state adopted the aesthetic veilings of such ideas to justify actions, such as how Social Darwinism used evolutionary theory to justify its horrid actions. In this way "the classism and racism of elites are mathwashed, neutralized by technological mystification and data-based hocus-pocus." [12] This ideology could also be considered a "dangerous form of magical thinking [that] often accompanies new technological developments, a curious assurance that a revolution in our tools inevitably wipes the slate of the past clean" [12] (something that we are currently seeing repeated with discussions about Big Data and machine learning [13]).

The details lost in the necessary simplifications that the technocrat must make often turn out to not be so neglibible after all. In the USSR, "a set of informal practices lying outside of the formal command economy - and often outside Soviet law as well - [arose] to circumvent some of the colossal waste and inefficiencies built into the system. Collectivized agriculture, in other words, never quite operated according to the hierarchical grid of production plans and procurements." [6] The technocratic leaders were often aware of this but so committed to their ideology that they had no alternative but to maintain a sort of pretense, which anthropologist Alexi Yurchak called 'hypernormalization' [14], that served to compound problems until the Soviet Union eventually collapsed. Such a phenomena is particularly visible in strictly planned capital cities that have, "as the inevitable accompaniment of [their] official structures, given rise to another, far more 'disorderly' and complex city *that makes the official city work* - that is virtually a condition of its existence" [6].

Even the 'successful' development projects often came at a high cost and raised the question of "successful for whom?" After all "Haussmann's Paris was, *for those who are not expelled*, a far healthier city" (emphasis mine) [6].

So, with all of this said, do we think that the field of planning, particularly expert-and-technology-informed planning, still has a positive role to play in society? We propose three arguments in favor of such an idea, none of which are wholly satisfactory, but together may amount to something credible.

First, we may attempt to avoid fulfilling the conditions proposed by Scott above. We may, for instance, refuse to do work in areas with authoritarian governments, though this would certainly neglect many in dire need. We may also reject the high modernist ideology in our planning. This is certainly easier, as I have been doing exactly that, but it should not be taken as trivial either. In many ways such an ideology is the default of the technologist, and it requires active self-reflection to avoid falling into that trap.

And the unfortunate matter is, even if we assume that Scott is correct in that his conditions are the necessary and sufficient conditions, what are they conditions for? "The *most tragic* episodes of state-initiated engineering" (emphasis mine) [6]. The egregiously racist influence that Robert Moses had the design of New York City [15] happened in at least somewhat democratic society, not an authoritarian one. While it did not directly lead to mass famine and death, it is hardly something that we would want to replicate. We daresay that we want to do more than avoid the most tragic outcomes and instead want to do active good. We must therefore look beyond merely avoiding Scott's conditions.

Second, we may argue that planning has simply "come a long way from focusing on single page map and a timescale of 20-30 years" [16]. It is certainly true that many of the tools have changed over the past few decades. Systems engineering, for instance, is a substantionally different field than it was in the middle of the 20th century, as is discussed later in this piece. Sachs meanwhile proposes that prescreptive economics should be modeled on clinical medicine and should not seek to attribute all negative outcomes to the same cause nor to prescribe the same solution to all problems, but instead to "make a differential diagnosis for the economic case at hand." He lays out several different conditions of poverty, for example, and proposes different solutions to each. Foreign aid is effective at treating the "poverty trap" condition (wherein "the country is too poor to make the basic investments it needs to escape from extreme material deprivation and get on the ladder of economic growth"), but less so for other conditions [17]. In this way, he seeks to distance himself from the high modernist ideology, with its affinity for singular, simple solutions, while still doubling down on the technocratic approach in general.

It should be noted, however, that Sachs has been a senior advisor to numerous states and the United Nations (UN) dating back to the mid 1980s and thus has had ample time to demonstrate his ideas. Nonetheless, many of the critiques referred to already are addressing this time period and some, such as Easterly [7], were specifically aimed at Sach's efforts, with some arguing that many of his projects have left people worse off than before [18].

We do think that many of the methodological and technological changes over the past several decades are meaningful, but it also seems undeniable that these changes seem insufficient to ensure good outcomes. So we must look elsewhere for means of shoring up the deficiencies.

The third argument we may make that planning still has a positive role to play involves collaborative and participatory forms of planning. After all even one of the proponents of high modernist ideology recognized that "rational, hierarchical, closed-door decision strategies" had negative consequences and that "more democratic process might produces worse results, but it would respond to the increasing sense of alienation among the nation's urban population" [19]. This avenue is not without its flaws, unfortunately. By providing tools for more participation, we are not necessarily changing anything fundamental. "Participation is not power; its reform is not radical" [20]. Even if participation is quite extensive and includes actual political power, "democracies rarely end up expropriating and redistributing capital" [21]. Thus even "inclusive planning practices cannot 'shift the effects of (post)colonial structures and relations of power on indigenous nations without a fundamental recognition of rights'" [9].

Not only is participation evidently insufficient on its own, but some argue that neoliberalism in factor prefers to use participation as a means of underming resistance rather than resort to violence, though this has the risk of providing a structure for coalition building and radicalization [22]. This can occur even unintentionally, as "an inappropriate leve lof participation may disempower individuals... and it also can distract groups from a desired outcome" [23]. In fact, increased community involvement can result in more restrictive, unambitious goals that are not in the interests of certain minorities [24]. A key aspect of participatory planning is that mere participation does not magically eliminate power hierarchies. Such pre-existing hiearchies can wield their power in planning discussions in three primary ways: "by promoting formal decisions, setting the agenda, and influencing the broader ideogical context of the debate" ([25] as paraphrased by [26]). Similarly, merely connecting individuals and enabling the sharing of information does not necessarily promote engaged political deliberation [27].

Despite this, there is evidence that, with proper creation of the structures of participation or in the wholesale rejection of the state-led participatory structures, that planning can be used to promote equity and development. Goodspeed points out several examples of how participatory and even insurgent scenario-based planning helped address injustices such as racism in urban development [26].

To resolve this confusion, Arnstein proposes an eight-step "ladder of civic participation" [28] [ADD FIGURE AND DISCUSSION] Bekkers and Moody provide some examples of visualization and geographic information system (GIS) use that made the citizenry feel manipulated [29].

This suggests that, while technology-based collaborative or participatory planning efforts are unlikely to effect radical change, they can, *if done well*, still affect positive change. Gordon and Manosevitch, building upon Gastil, argue that two components are needed to have truly participative planning: an 'analytic process' for sharing and analyzing information and a 'social process' for providing for deliberative discussion [27].

In line with some of Easterly's arguments, Virginia Eubanks proposees two gut check questions to ensure that a planning tool avoids harmful consequences [12]:

1. Does the tool increase the self-determination and agency of the poor?
2. Would the tool be tolerated if it was targeted at non-poor people?

Jonathan Furner, meanwhile, proposes three strategies for developing such tools ([30] as paraphrased by [31]):

1. Admission on the part of designers that bias in classification schemes exists, and indeed is an inevitable result of the ways in which they are currently structured.
2. Recognition that adherence to a policy of neutrality will contribute little to eradiction of that bias and indeed can only extend its life.
3. Construction, collection, and analysis of narrative expressions of the feelings, thoughts, and beliefs of classification-scheme users who identify with particularly racially-defined populations.

So, while we argue that a combination of new methodologies and technologies, collaborative and participatory design, and a general intellectual humility are sufficient to avoid the harmful outcomes of the past (and present), Eubank's and Furner's points are worth keeping in mind as we continue.

3.2 Systems engineering in particular

So how does systems engineering relate to this discussion of technocratic planning? Well, systems engineering constituted one of the primary fields that technocrats drew upon, particularly in the 1950s-1970s. US Vice President Herbert Humphrey said in 1968 that "The techniques that are going to put a man on the Moon are going to be exactly the techniques that we are going to need to clean up our cities" [19]. In the same year, the RAND Corporation established a multi-year attempt to bring systems analysis and engineering to urban planning. Around the same time the American Institute of Aeronautics and Astronautics (AIAA) hosted meetings on urban technologies to bring aerospace expertise to bare on the urban crises of the time [19]. It was a heady time, with engineers themselves feeling "that, having reached the moon, they could now turn their energies to solving the problem of growing violence in cities along with other urban "crises" [32]. These applications were justified by several different rationale, chief among them were [19]:

- Computer simulations and related techniques were simply advances on the statistical models already widely used by the urban planning profession.

- The rise of cybernetics, with its cross-disciplinary control analogies, promised to unify disparate fields within urban planning and analysis, resulting in a unified understanding of cities.
- The use of these military innovations would transform urban planning and decision-making into scientific endeavors.

Almost immediately, however, such grand ideas met with difficulties. While recounting the full history of this trajectory is beyond the scope of this work, one can get a sense of it in quotations from urban planners of the time and since:

> The systems engineers bring some expertise and substantial pretensions to the problems of the city. Their prinicpal system expertise seems to be relative to complex organizations that are mission oriented. There is in any case a good deal of difference between the mission of reaching the moon, and the mission of surival and welfare for soceity and the city. The systems engineer can in general deal best with subsystems and specific tasks, and he therefore suboptimizes. This is a charitable description. [33]

“Trying to solve ‘earthly problems,’ especially urban problems through aerospace innovations had shown that ‘transporting the astronauts from terra firma to land on the lunar sphere, travel hither and yon over its surface, and then back home to Houston’ was a comparatively simple task. [19]”

This perception continues to the present day. Figure 1 situates systems engineering and analysis among other intellectual schools of urban planning. It is positioned on the far left of the figure, indicating that the field ”look[s] to the confirmation and reproduction of existing relationships of power in society. Expressing predominantly technical concerns, they proclaim a carefully nurtured stance of political nuetrality. In reality, they address their work to those who are in power and see their primary mission as serving the state” [32]. Marcuse, meanwhile, refers to systems engineering as primary concerned with efficiency and highly deferential to existing relations of power [20]. It is natural that the more authoritarian-minded decision-makers would thus find systems engineering of interest. It was not only in dictatorships that systems engineering found a planning home, however. Many of the examples cited above where within the United States. In keeping with Scott’s theory of social engineering disasters, the democractic nature of the US kept these applications from becoming large scale tragedies, but this does not mean they were successes by any means either.

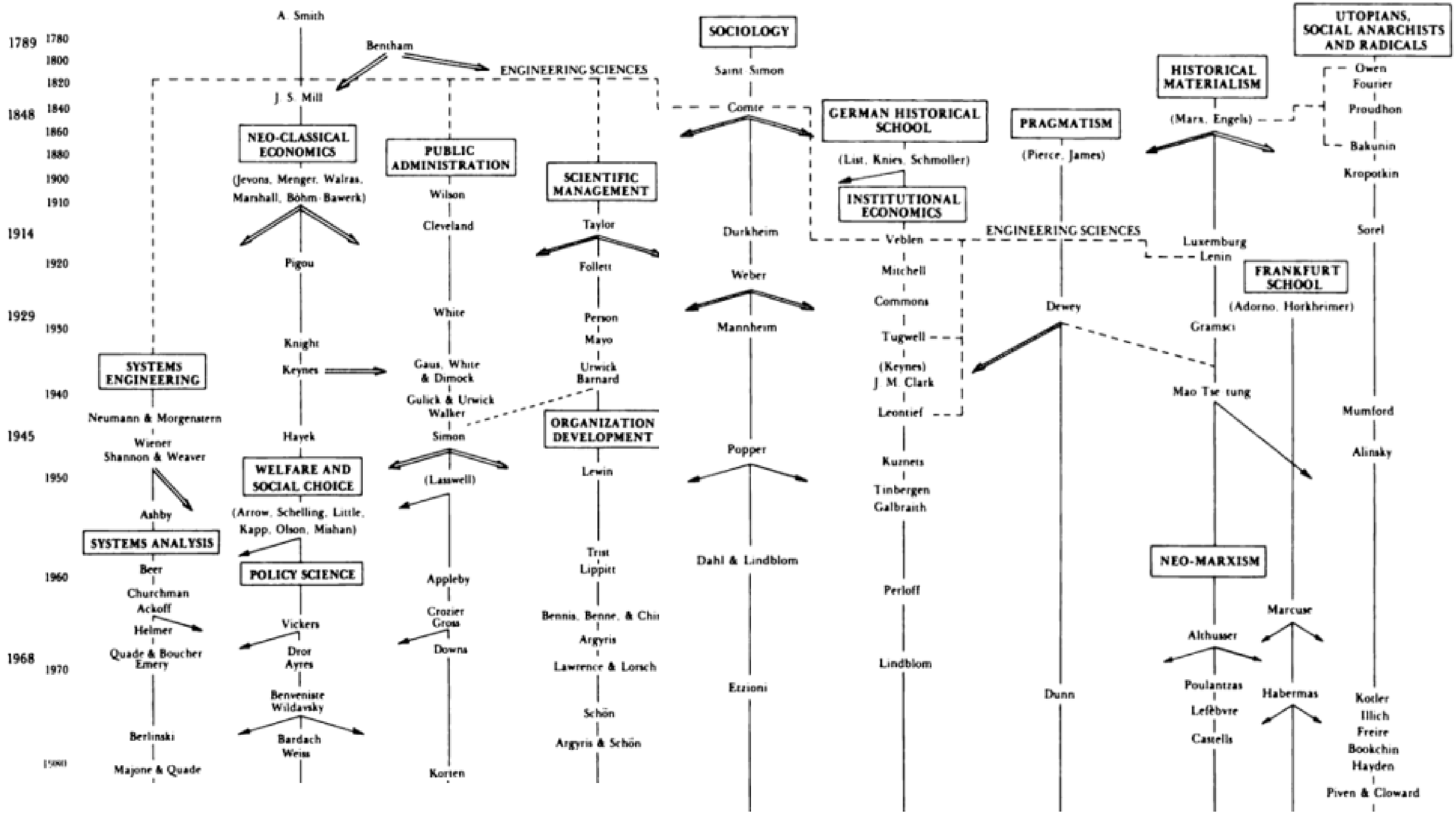

Figure 1: Timeline of intellectual influences on American planning theory. From [32]

This leads us to asking why systems engineering did not achieve all that it was promised to. An examination of the literature reveals certain common factors [19, 32, 12, 6, 34, 35]:

- These new techniques, heavily dependent on quantification, suffered from a lack of relevant data, particularly on social wellbeing.
- There was a lack of prior goal setting by decision makers. Technical experts were driven by a desire to use the tools available to them rather than to actually address the specific needs of the community. This resulted in proposed alternatives being unconnected to community goals and thus irrelevant.
- Systems engineers tended to have a sense of certainty about the virtues of designing a society from the ground up and an ignorance of history that blinded them to the lessons learned by previous technocratic and utopian planning endeavors.
- Technocratic systems and defense analysts displaced professional urban planners and others with detailed subject knowledge, rather than seeking to cooperate and learn from them. Some urban planners went so far as to complain that "their work had been hijacked by refugees from aerospace."
- Similarly, engineers tended to ignore and denigrate local practices and local expertise, perhaps because to recognize these as reasonable, to learn from and negotiate with them, would have undermined the institutional powr and status of the technical expert.
- Having been raised on the cultural norms of the military and private industry, development applications of systems engineering were marked by significant secrecy, undermining their legitmacy in the eyes of the public.
- While proponents of social applications of systems engineering argued that it would transform urban planning and decision-making into scientific endeavors, such an espousal tended to be more of an aesthetic argument, grounded in the high modernist ideology rather than fact.
- The Law of requisite variety from the field of cybernetics says that the variety (the number of elements or states) of the control device must be at least equal to that of the disturbances [36]. Any development plan is going to fall far short of the variety expressed by human society and the natural environment. Planning efforts must then make reliance on the natural homeostasis behavior of such systems and of more flexible, ad hoc measures not specified in the plan in order to make up the difference in variety. System engineering tools of the time did not have the capacity to make use of such flexible measures.
- Systems engineering frameworks of the period held that complex controversies could be remedied by simply getting the correct information to the correct place in an efficient manner. They failed to recognize that even if complete and 'correct' information is available to all stakeholders, significant or even irresolvable disputes may remain.

All of these causes led to the gradual rejection and retreat of systems engineering in development planning. As early as 1973, planning scholars were (perhaps preemptively) eulogizing the death of large-scale models and other tools of the systems engineer [37]. The intervening decades have seen the fields of systems engineering and development planning grow largely independently of one another. The next section will discuss whether the current states of these fields and of the world are sufficiently different to envision a more positive role for systems engineering in the field of development.

4 Prospects for change / What Systems Engineering has to offer

Since the 1970s, urban planning professionalshas evolved and adopted computational models on their own terms. Interactive Decision Support System (DSS) abounds [38, 39]. The use of GIS has become the norm [40, 41, 42]., including more participatory variants [23]. Numerous quantative economic and social indeces have been developed [43, 44, 45, 46, 47] . Mathematical tools such as cellular automata have become popular [48, 49]. Digital models underly the popular subdiscipline of scenario planning [26, 50]. Interdisciplinary, integrated models have even started to re-emerge [51, 52, 53]. Arguably urban planning has adopted many of the tools and methodologies of systems engineering.

At the same time, systems engineering has changed. The belief that systems, even human systems, can be made simple, rational, and controllable has been largely outmoded within the field. Instead, in the guise of theories of complex systems and chaos, they have adopted Jane Jacob's view that "intricate minglings of different uses are not a form of chaos. On the contrary they represent a complex and highly developed form of order." [54]. Complex systems, emergence, systems-of-systems, and complex adaptive systems have all become popular fields of study within systems engineering [55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65], with numerous frameworks being proposed for how to classify and handle such systems [66, 67, 68, 69, 70, 71]. Faced with such systems, engineers have had to recognize their own inability to definitively predict the future and have turned to probabalistic methods that instead "manage" complexity over longer time scales, such as epoch-era analysis [72, 73] (which in many ways resembles the aforementioned urban planning method called scenario planning).

Parallel to this, systems engineers have moved away from singlemindedly implementing the directives of an individual client to identifying, mapping, and analyzing the stakeholders in a system and their connections to one another in order to inform the design of the system. This stakeholder analyses involves both qualitative and quantitative tools, such as the Stakeholder Requirements Definition Process [74], Stakeholder Value Network Analysis [75], and qualitative interviews of representatives from different stakeholder groups (something that would have been anathema to the earlier era of systems engineering. In order to translate these complicated networks of stakeholders into designs, systems engineers have developed methods for handling multi-stakeholder negotiation and [76, 77, 78] tradespace visualization and exploration [76, 77, 79, 80, 81], , the latter of which demonstrates an increased willingness to appreciate the psychology and experience of ther user. The historic preference of the impersonal and 'objective' versus the personal and 'subjective' is by no means unique to systems engineering. It can also be found in economics, jurisprudence, education theory, political science, and even moral philosophy [82]. The development of stakeholder analysis has helped to bridge the gap between these two and thus rectify this traditional deficiency. In fact, the use of stakeholder analysis in contemporary systems engineering is, in a way, a step away from the worldview that sees "human beings as unknowable black boxes and machines as transparent," a viewpoint that "surrenders any attempt at empathy and forecloses the possibility of ethical development" and is a tacit "admission that we have abandoned a social commitment to try and understand each other" [12].

All of this suggests that the fields of systems engineering and urban planning are perhaps more close to each other than ever before, even showing some elements of convergent evolution (see the use of the term complex adaptive system in both fields [83]). Much benefit could be gained through more direct dialogue and collaboration with one another. Why then, do we not see that occuring? After all, several of the critical comments made about systems engineering cited above were from recent years. Part of this is likely historical memory. While decades have elapsed, we are still within a single professional lifetime of some of the excesses of systems engineering. But some concerns can be found much temporally closer. While urban planning is a deeply historical field, systems engineering is not. What histories do exist tend to focus on the engineered technical systems, such as the Apollo program [84], rather than the planning dalliances of the 50s-70s. This is has not gone unnoticed: "One cannot know about the history of media stereotyping or the nuances of structural oppression in any formal, scholarly way through the traditional engineering curriculum of the large research universities from which technology companies hire across the United States. Ethics course are rare" [31]. This can lead to each new generation of engineers using new tools that are attempts to resolve the mistakes of the past, but while maintaining the same tabula rasa mindset that led their forebearers astray. Can one begrudge the urban planner their skepticism when one of the highest profile contemporary applications of systems engineering to planning is the 'urban digital twin' or 'smart city' [85, 86, 87, 88, 89] that seems to be a repitions of the belief that "complex controversies can be solved by getting correct information where it needs to go as efficiently as possible," that "political conflict arises primarily from a lack of information," and that "if we just gather lack the facts, systems engineers assume, the correct answers to intractable policy problems like homelessness will be simple, uncontroversial, and widely shared" [12].

So how can we make use of the opportunity for constructive collaboration and avoid falling prey to the same pitfalls as before? The next section will lay out a multipronged approach.

5 Moving forward

1. Explicitly grapple with the historical ethical shortcomings of the systems engineering field and related technocratic approaches to societal development.
2. Seek collaborations outside of the engineering disciplines and even outside of technical experts.
3. Select an application domain that can benefit greatly from both systems engineering and urban planning, preferably a relative novel domain.

The first is necessary, as mentioned in earlier sections, to avoid new generations of systems engineers being educated in ignorance of past mistakes. This grappling should take place in classes (either designated ethics courses or as integrated components of other engineering courses), within research groups, and in the scholarly literature. Topics can include the urban planning perspectives of systems engineering, such as Robinson [33], Friedmann [32], and Marcuse [20]; it can include critical histories of systems engineering, such as Light [19]; and specific case studies, such as the Navajo perspective on the lunar burial of Eugene Shoemaker [90] or Nostikasari's account of how underlying assumptions in a transportation model can perpetuate inequality [91]. In general, systems engineers should take a firm stance of antiracism and anticolonialism and engage in the related fields of literature.

The second approach is an extension of norms already embedded within systems engineering. From its beginnings, systems engineers have depended upon multidisciplinary teams of engineers. After all, systems engineers are largely would unnecessarily for projects that can be accomplished by a single individual. Teamwork, communication, and collaboration are thus fundamental to the field. Over time, the boundaries of these collaborations expanded to include multiple organizational stakeholders in a single project, including multiple clients, government agencies, and non-client beneficiaries. What we are now proposing is to expand this still further, by including both technical experts such as environmental scientists, ecosystem services economists, and anthropologists; and nontechnical members of the communities in which our systems operate. We are arguing for a participatory systems engineering, taking a page from the fields of GIS and planning that have been building participatory frameworks and tools for the past couple decades [92, 93, 23, 94, 95]. Systems engineering already has many of the tools for this, in the form of multi-stakeholder negotiation methods and tradespace exploration tools. These can be readily adapted to to incorporate community perspectives and be used as part of existing collaborative scenario planning processes.

The third approach is appropriate not only because it allows for plenty of research opportunities, but it avoids one field (systems engineering or urban planning) from being dominated by the other due to historical entrenchment. Urban planner Scott Campbell recognized a similar need within his own field:

> The danger of translation is that one language will dominate the debate and thus define the terms of the solution. It is essential to exert equal effort to translate in each direction, to prevent one linguistic culture from dominating the other... Another lesson from the neocolonial inguistic experience is that it is crucial for each social group to express itself in its own language before any translation. The challenge for planners is to write the best translations among the languages of the economic, the ecological, and the social views, and to avoid a quasi-colonial dominance by the economic *ingua franca*, by creating equal two-way translations... Translation can thus be a powerful planner's skill, and interdisciplinary planning education already provides some multiculturalism [96].

The question then, is what domain would be fruitful for this endeavor. Campbell suggests that "the idea of sustainability lends itself nicely to the meeting on common ground of competing value systems." We tend to agree with him.

Sustainability first enters engineering literature in the 1970s and its frequency rises in a exponential fashion over the course of the subsequent decades [1]. Computational models have been closely linked to the pursuit of sustainability and with its definition, stemming from the World3 system dynamics model underlying the Club of Rome's *The Limits to Growth* report in 1972 [97]. This rise is mirrored by a similar rise in other domains (such as architecture) and in the popular consciousness. For example, the Leadership in Energy and Environmental Design (LEED) certification program was founded in 1994 and has since become commonplace around the world. More recently, the term *sustainable development* has become dominate. It is often defined as the integration of three separate, previously separate fields: economic development, social development and environmental protection [98]. These fields are alternately described as "as interdependent and mutually reinforcing pillars" [98, 17], and as 'conflicting' [96], as seen in Figure 2. Sustainable development is now a powerful enough of a framework and a pressing enough of an issue that the UN followed up their 2000-2015 Millenium Development Goals (MDGs) [99] with the 2015-2030 Sustainable Development Goals (SDGs) [100] in order to coordinate development action globally.

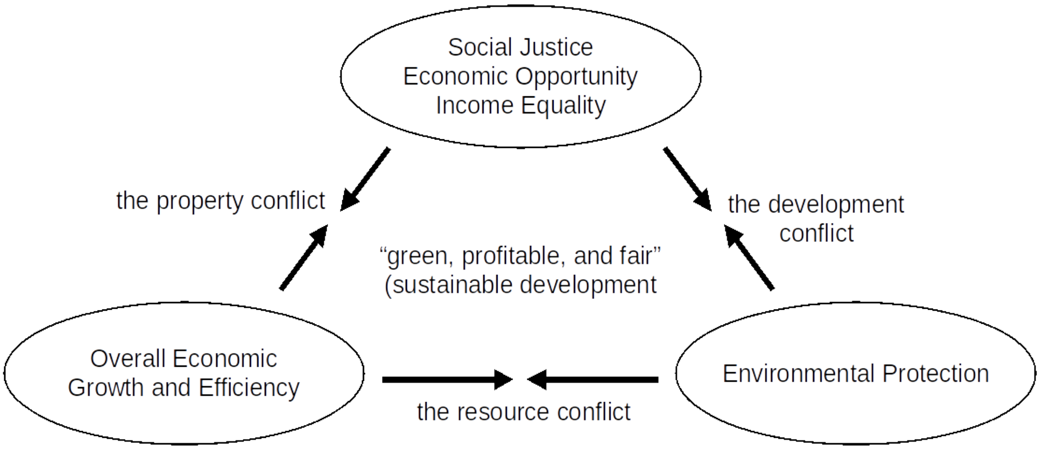

Figure 2: The triangle of conflicting goals of sustainable development. Adapted from [96]

The rise of sustainable development, with its interconnected systems, has also been paralled by the (rightfully) expanded number of stakeholders involved in decision-making processes and a increased recognition of linkages across differing geographic scales [101]. This increase in complexity is something that systems engineering is well posed to address, while still being well within the purview of urban and regional planning. Economist Jeffrey Sachs argues that ”sustainable development is also a science of complex systems,” and that two specific tools are important for implementing the UN SDGs: backcasting and technology road-mapping [17], two tools that systems engineering is well equipped to provide.

6 Putting it in practice

The Space Enabled Research Group strives to implement all three approaches because we believe that systems engineering has the potential to offer significant value to planning and development, but also that it has the potential for great harm. This can be seen in our mission statement: “Advancing justice in Earth's complex systems using desigs enabled by space.”

We put Approach 1 into practice making works by such scholar as Ibram Kendi [102] part of our core curriculum and by hosting events such as our regular Tech & Justice Research Community Meetings and our Indigenous & Anticolonial Views of Human Activity in Space panels.

To Pursue Approach 2, we engage in multidiscplinary collaboration both within the group and outside it. Researchers within the group come from backgrounds in systems engineering, design, aerospace engineering, geospatial analysis, machine learning, community organizing, art, and more.

For Approach 3, most of our sustainable development work is organized within the Environment, Vulerability, Decision-Making, Technology (EVDT) modeling framework shown in Figure 3. These four components seek to encapsulate the major interacting aspects of sustainable development. As Sachs put it, ”Sustainable Development involves not just one but four complex interacting systems. It deals with a global economy...; it focuses on social interactions...; it analyzes the changes in complex Earth systems...; and it studies the problems of governance” [17]. Sachs neglects the importance of technological systems in there list (though he addresses it elsewhere), but we have included it as technology is both one of the primary means by which we monitor changes in the other systems and also one of the mechanisms by which we influence them. This is essentially a combination of the established fields of sociotechnical systems [103, 104, 105] and socio-environmental systems [106].

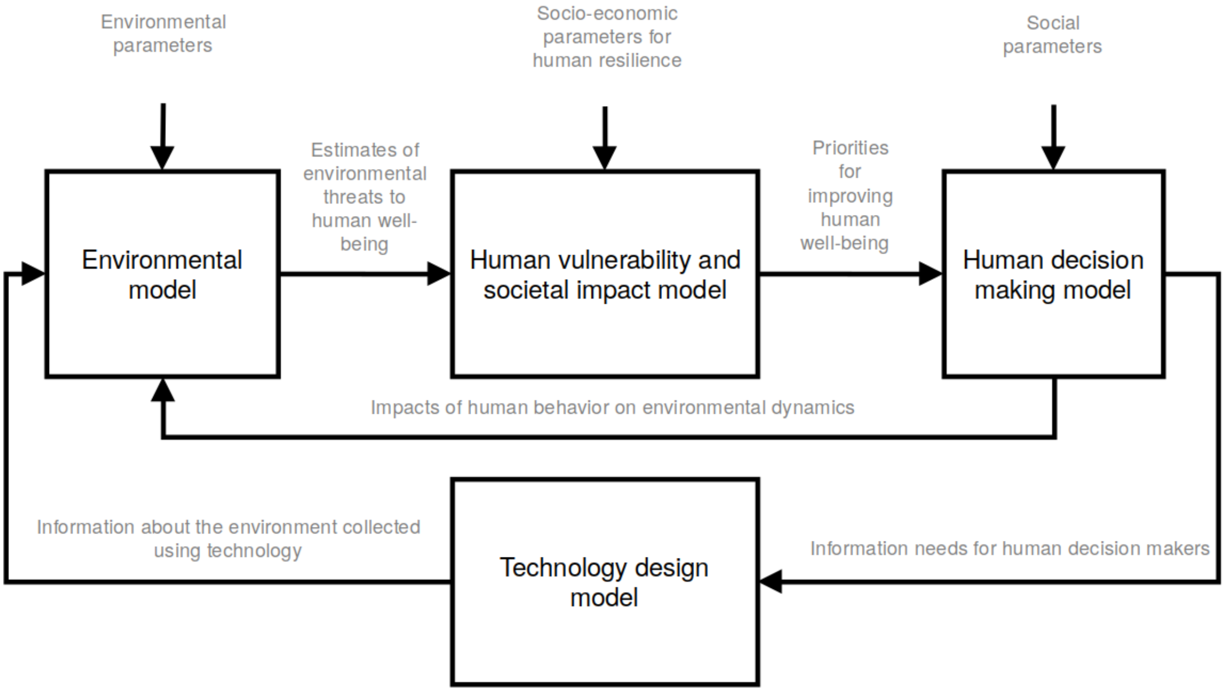

Figure 3: Baseline version of the Environment - Vulnerability - Decision - Technology Model (Generic Case)

This set of four models with the particular linkages shown in Figure 3 are not the only form that EVDT can take, merely the most general arrangement. Some applications may involve replacing a model with a human-in-the-loop (e.g. having the user themself substitute for the decision-making model) or omitting a model altogether. For other applications, it may make sense to conceptually break a model into two or more components. In the Vida project, which is the multi-context COVID-19 application of EVDT, it was considered worthwhile to seprate the social impact model into two components, one focusing on public health (the obvious priority when dealing with COVID-19) and one focusing on non-health metrics (such as income, employment, etc.). Such a separation can be useful if either significantly different modeling methodologies are going to be used or if the linkages with the other EVDT components are different from one another. Further discussion of some other possible arrangements of the EVDT components can be seen in Section **??**.

One way to determine the optimal arrangment of EVDT components is to consider what questions the user or researcher is seeking to answer with this application of EVDT. For instance, the default EVDT arrangement shown in Figure 3 was motivated primarily by the following four questions:

1. What is happening in the natural environment?
2. How will humans be impacted by what is happening in the natural environment?
3. What decisions are humans making in response to environmental factors and why?
4. What technology system can be designed to provide high quality information that supports human decision making?

Alternate questions may result in a different configuration or set of components. The point of EVDT is not to insist upon a particular set of linkages and feedbacks, but rather to encourage a consideration of such linkages between domains in general, and to consider them through a systems engineering perspective. Of course answering the structuring questions, and even phrasing them in the first place, requires the use of collaborations. The EVDT framework and its associated projects are characterized by extensive collaborations, both inside the US and internationally, including earth scientists, ecosystem services economists, DSS designers, public health researchers, and more. In each local application context, we collaborate with a team of government officials, academic researchers, and local community organizations. We make stakeholder-analysis-informed systems architecture a core part of the collaborative development process, including qualitative interviews and ongoing meetings with a diverse set of stakeholders. We also seek to understand the history of the area both environmentally and socially, in order to understand the existing systems that we are intervening in, rather than assuming that each location is a sustainable development tabula rasa. The Space Enabled philosophy of research (and thus of EVDT) involves a level of participation and collaboration that goes beyond stakeholder analysis. We actively work with partners who are embedded in the application context and seek to enable them to take charge of their own situation. By paring complex Socio-environmental-technical System (SETS) theory with such collaborative planning theory, we can thereby avoid many of the traditional problems of systems engineering [26].

7 Future opportunities

Sustainable development is a pressing need for our world, one that we need our best minds and methods to fulfill. Systems engineering, particularly the new, humbler systems engineering, is well posed to contribute, provided it can maintain that humility. Opportunities for such contributions abound, as nations around the world pursue the SDGs and they increasingly recognize the interconnectedness of our human, technological, and environmental systems.

Furthermore, EVDT is not intended to be an exclusive project of Space Enabled. We actively invite involvement from other systems engineers and those from other disciplines. As mentioned earlier, we already have collaborators from across the world. At the moment, it is still in its initial stages. While we have several different application projects at the moment and multiple prototype DSSs have been made, in none of the ongoing projects has it reached an operational stage that has been actively used by collaborators or community members (though we are getting closer to this). One or more operational applications are necessary to demonstrate viability to the relevant audiences. Once this is accomplished, the next step will be to consolidate and standardize the underlying code, so as to facilitate furture improvements, as well as the reuse of materials for future contexts. The open source code repositories, already available online [107, 108, 109], will be used as a basis for building a community of practice, where individuals can contribute in a variety of ways, as shown in Figure 4.

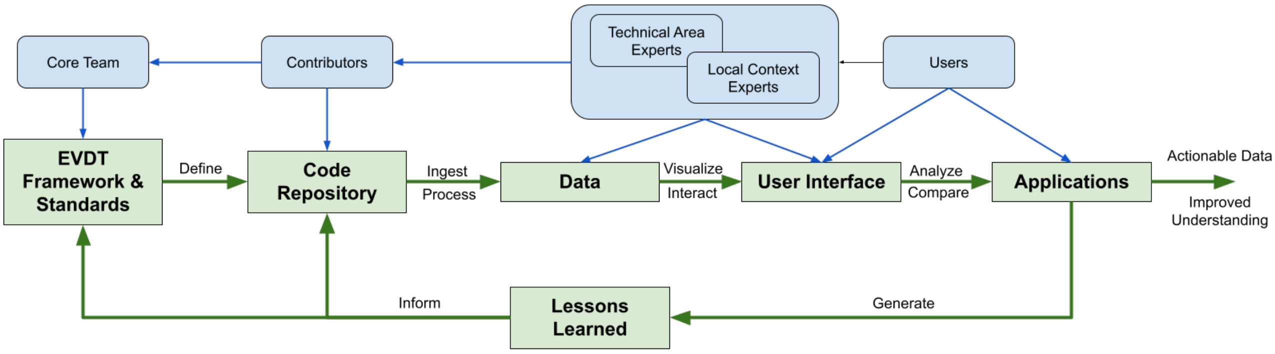

Figure 4: The EVDT development pipeline. Note that the different community groups, shown in blue, are not necessarily discrete and one individual could simultaneously participate in multiple.

As the number of applications increase and the code is refined, the various models used in the applications may themselves be the first members of an openly accessible library of models. Potential user groups could adapt and reuse EVDT components in other applications, without having to start from scratch. Initially this would likely still require significant code expertise, but it is entirely possible for functionality to be created to allow for ‘plug-and-play.’ A user may be able to, in browser or on desktop, select a geographic area of interest (e.g. the Sóc Trăng Province of Vietnam), select an environmental model (e.g. coastal forest health), a societal impact model (e.g. cyclone vulnerability), a decision-making model (land use conversion and conservation policy), and a technology model (satellite versus in-situ monitoring), all without writing a line of code (though perhaps being required to import new datasets themselves). Such functionality, along with the recruitment pipeline shown in Figure 4, help to expand participation in all aspects of EVDT.

We are cognizant that making EVDT truly participatory is easier said than done, but we do believe it is a worthy goal. In addition to model interoperability standardization, the code moderators will need to specify accessibility norms as well, so as to ensure usability by individuals with a wide range of backgrounds. Existing prototypes have made some steps in this direction, by having multiple language options available. Thus far, this has been accomplished by existing language knowledge of code moderators as well as the occasional volunteer translator, but some more targeted efforts may be required in the future to specifically recruit translators for targeted languages.

Language is not the only accessibility barrier, however. Terminology, presentation, and interactiveness can also be differentiately accessible to different individuals, depending factors such as educational or cultural background. That said, these difficulties can be addressed via some of the same methods that are already core to the EVDT methodology: namely partnerships with local collaborators; stakeholder analysis; and iterative, participative design.

Another consideration in the future of EVDT are the types of applications that it will be used for. Some potential applications include:

1. To inform sustainable development policies.
2. To educate on the connections between the different EVDT domains.
3. To facilitate the exploration and evaluation of sensing technology architectures for particular applications.
4. To facilitate scientific research on ecosystem services and/or the impacts of human behavior on the environment.
5. To provide a basis for studies of the effectiveness of different DSS attributes (visualization techniques, workshop formats, etc.).

These applications are varying levels of interest and importance to different stakeholders, and some could potentially be viewed as competing for development resources and focus. In some cases they may rely upon different configurations of the EVDT components, as shown in Figure 5. For instance Item 3 requires a functional model of the relationships between different remote observation design parameters and performance parameters, along with a means of visualizing and exploring the tradespace. A user who is predominantly interested in Item 1 may find this functionality irrelevant or outright distracting.

On the other hand, some applications are more complementary. While the Item 1 is likely to be a government official or community member while the Item 5 user is likely to be an academic researcher, the findings from an 5 would result in the design of EVDT being improved, so as better serve the needs of the Item 1 user.

Ideally, EVDT would be open to all these applications and more. In practice, care must be taken so that interests of one user group do not unintentionally dominate those of others or, worse, that the interests of the developers do not send them on a path counter to the interests of the users. This will thus require ongoing discussion and consideration with the EVDT community.

8 Conclusion

Opportunities for systems engineers to get involved in sustainable development abound. The urban planning field is more receptive to systems engineering now than it has been in decades. Interest is high from those in need of multidiscplinary modeling and ways to manage complex systems. This paper has made that case, along with the warnings of what could behalf an overly enthusiastic and naive engineer. We hope that this paper helps situate the reader in the history of their field and gives them pointers towards moving ahead towards a more sustainable future.

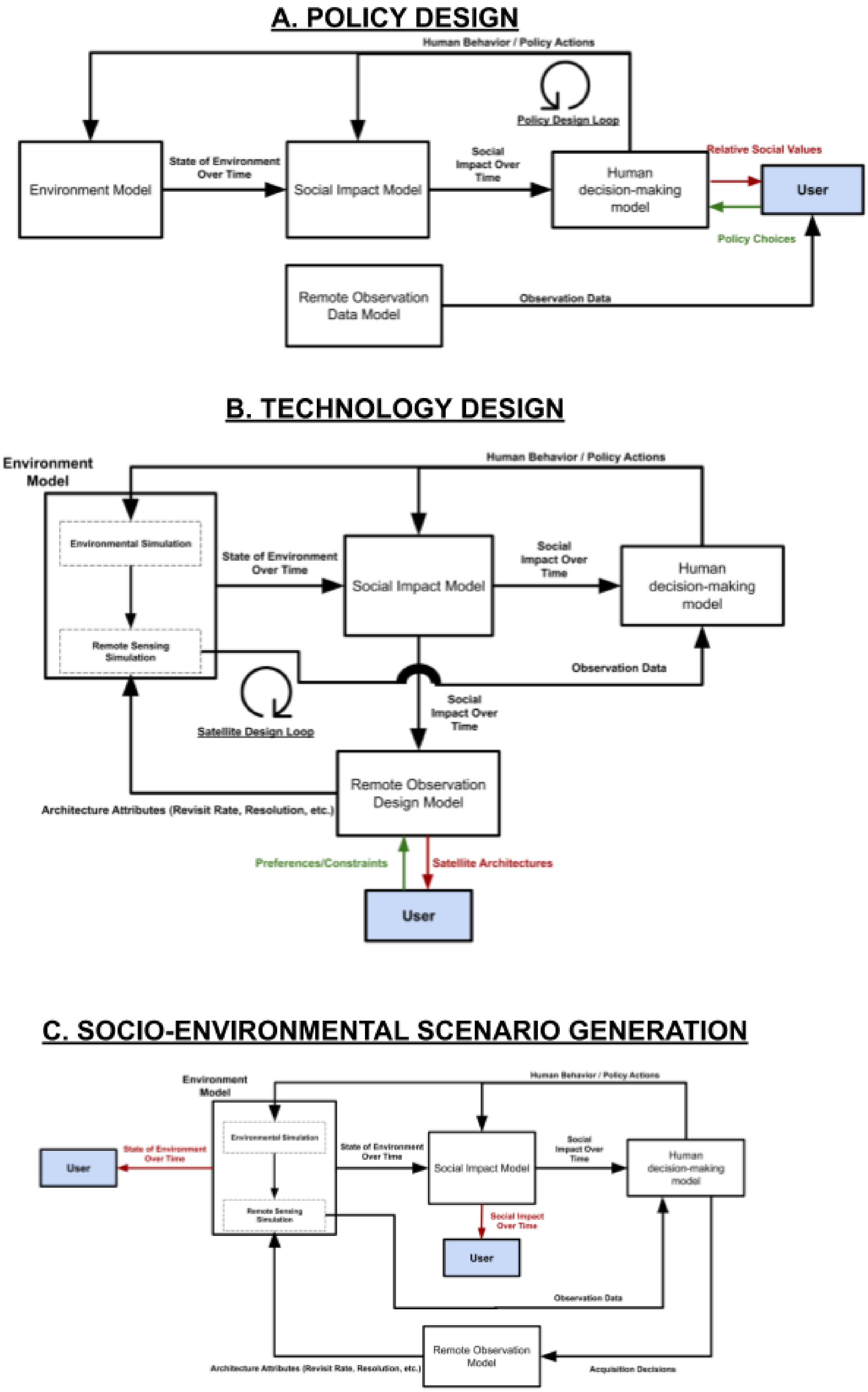

Figure 5: Three example EVDT research configurations.

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