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Engagement with Urban Soils Part I: Applying Maya Soil Connectivity Practices to Intergenerational Planning for Urban Sustainability

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Abstract: Urban soil security depends on the means and social practices that enable multiple generations to maintain and improve soil resources. Soils are pivotal to urban sustainability yet seem absent from international planning advisories for sustainable urban development. Subsuming soils under broad and unspecific categories (ecosystem, environment, land, etc.) leaves soil interests indeterminate and largely ignored in urban planning. The absence of soils in sustainable urban planning advice permits planning guidelines that cause increasing land-use conversions which seal soils. Urban patterns of sealed and distanced soils, preventing access to and direct enjoyment of soil benefits, generate disengagement from soils. Despite fierce land-use competition, urban areas offer the greatest potential for soil connectivity exactly because people concentrate there. Based on previous work we accept that everyday opportunities to encounter and directly engage with soils in Pre-Columbian lowland Maya urban life rendered soil connectivity commonplace. Here, we review how the two original routes towards soil connectivity, knowledge exchange and producer–consumer relationships, reinforced and supported regular soil engagement in Maya urban practice. We frame our interpretation of Maya cultural values and urban practices in terms of leading insights from environmental psychology on pro-environmental behaviour and stakeholder attitudes and the principles of building resilience. This allows us to recognise that Maya urban soil connectivity functions thanks to the structural involvement of the largest societal stakeholder group, while imparting soil knowledge is entangled in shared socio-cultural activities rather than a task for a minority of soil specialists. The emerging Maya model for a socially engaged soil-aware urban society combines bottom-up practices and top-down social–ecological cultural values to increase resilience, to diminish reliance on long-distance supply chains, and to maintain productive human–environment relationships over the long term. As such it becomes a primary task for urban planning advice and guidelines to enable and support a widely shared and enduring culture of soil care. Urban sustainable development may only be successful if underpinned by a broadly carried increase in soil knowledge and awareness of intergenerational soil dependency.

Keywords: soil connectivity; urban soils; urban planning; applied archaeology; Pre-Columbian Maya; Maya urbanism; environmental psychology; urban sustainable development; New Urban Agenda

Citation: Vis, B.N.; Evans, D.L.; Graham, E. Engagement with Urban Soils Part I: Applying Maya Soil Connectivity Practices to Intergenerational Planning for Urban Sustainability. *Land* **2023**, *12*, 892. https://doi.org/10.3390/land12040892

Academic Editor: Evangelia Golia

Received: 3 March 2023
Revised: 27 March 2023
Accepted: 28 March 2023
Published: 15 April 2023

1. Introduction and Aims

Despite their recognition as a fundamental common global resource [1,2], soils are conspicuously absent from urban planning guidelines and advisories. Achieving soil security through sustainable development depends on installing the means and social practices that enable multiple generations to maintain and improve soil resources [3,4]. Present-day trends favouring high-density urban land cover result in a lack of positive role models of urban societies and spatial patterns that display broad soil awareness. Failure to recognise that sustainable urban life depends on maintaining the essential ecological functions of soils in urban environments leads to an impoverished position and treatment of soils in urban planning policy and resultant urban design approaches. To counter the misrepresentation and side-lining of soils and soil management in policy recommendations that support sustainable urban development goals, we seek to offer perspective by exploring the position of soil knowledge and societal stakeholders in an urban tradition acutely aware of its soil dependency. For that, we build on Evans et al.'s [5] synthesis of physical and spatial evidence of pragmatic soil management behaviour and strategies in Pre-Columbian lowland Maya agro-urban landscapes. Evans et al. consider how this archaeological evidence substantiates the notion of *soil connectivity* as conceptualised by McBratney et al. as one of five dimensions that are critical for achieving soil security [3] ([5], p. 2):

- *capability* (the functions a soil can be expected to perform)
- *condition* (the current state of the soil, often discussed in terms of soil quality)
- *capital* (the soil's stock of physical and biological resources)
- *codification* (the need for public policy and regulation in soil management)
- *connectivity* (soil–society relations)

Evans et al. [5] show spatial and practical consistencies relating to soil management in recurrent Maya agro-urban landscapes across the diverse environments of the karstic tropical lowlands over the long term, indicating that their model of urban life thrived on productive soil–society relationships. Of particular relevance is the identification of a pivotal third route for stimulating soil connectivity: everyday opportunities to encounter and directly engage with soils in urban life. Regular soil engagement complements the two soil connectivity routes originally proposed by McBratney et al. [3]: knowledge exchange and producer–consumer relationships. We posit that there are deficiencies in knowledge exchange and producer–consumer relationships, and how these two routes invoke and delimit specific societal stakeholder groups whilst permitting urban soils as an intergenerational resource to be overlooked and poorly articulated in urban planning guidelines and aspirations. Meanwhile, Evans et al.'s [5] third route urges urban planners and designers to be proactive in installing the means and facilitating social practices that rehabilitate and maintain urban soil resources in the long term. This raises the question of how Maya soil knowledge and knowledge exchange distributed the stakes of urban soil dependency to generate urban environments that bring about priority of societal engagement with soils.

Building on Evans et al.'s [5] thesis, our present purpose is thus to go beyond empirical evidence for soil management practices using archaeological interpretations of Maya culture and urban society to explore the position of soil knowledge in Maya society and the societal stakeholders this implies. By assembling complementary insights into how soil connectivity was supported and realised in lowland Maya urbanism, we will be able to conjoin Evans et al.'s [5] third route with evidence for McBratney et al.'s [3] original two. This allows us to reconstruct a comprehensive foundation of a Maya model for urban soil connectivity. Based on the Maya model, we then assert the specific tasks for urban planning with the objective of stimulating urban soil connectivity. These urban planning tasks also imply a revision of McBratney et al.'s [3] implicit rudimentary division of societal stakeholder categories towards a wide awareness and participation of urban inhabitants in soil engagement and the promotion of a culture of urban soil care.

2. Absence of Urban Soils in the New Urban Agenda

The expansion of urban land cover and the agricultural practices used to meet the demand of growing urban populations are largely responsible for the alarming state of global land degradation [1,2,6–8]. To tackle the loss of land and soils due to urban growth, urban planning practice has become vested in the compact city paradigm, where high residential density with mixed land uses requires less per capita infrastructure in contrast to transport-reliant urban sprawls [9]. Remaining areas of open or underused space within urban built environments are filled in and maximised to further concentrate the population. The expectation is that concentration leaves more space for agriculture and ecosystemic functioning out of the city, externalising soils which are thus assumed to be protected [10]. Urbanisation expanding over land is treated exclusively as an obstruction to achieving urban sustainability. The compact city model thus becomes a shortcut to, and a simplification of, a sustainable approach to urban development. Various urban planning policy advisories and guidelines shape this model by permitting urban soil sealing as long as this is compensated by unsealing soils elsewhere ([4,11] cite Swiss and French examples). As a result, urban planning and design concerns with urban sustainability subsume knowledge of and engagement with soils.

Although the presence and functioning of soil is crucial to achieving many of the goals set out in the New Urban Agenda's vision [12], soil remains a silent partner. Silent, because soil is not directly addressed at any point. The first article (13a), however, immediately acknowledges that cities as places of inhabitation depend on "the social and ecological function of land". In NUA's implementation plan, the dependence of cities on land is progressed through commitments to promote and support the sustainable management and use of natural resources and land in spatial frameworks and urban planning. The agenda includes a commitment to avoid exceeding the regenerative capacity of the global ecosystem that supports cities (art. 51, 69–71, 76, 98). That air and water do not suffer similar subsumption by larger environmental categories demonstrates a lacking imperative ascribed to urban soil dependency. Failure to comprehend urban soils' integral ecological position is symptomatic of a general trend acknowledged in soil science: " . . . the public at large tends to be oblivious to the extreme complexity of soils and, in fact, to soils themselves. Unlike in the case of water and air, whose [sic] pollution tends to be readily noticeable even by non-experts, most people are entirely unaware of the processes that occur in soils and of the essential benefits human populations derive from them" [13] (p. 23). Understanding the contribution of material use and decay to soils also remains underdeveloped. In terms of circular economies, consigning end-use materials to landfill reflects general incognisance concerning soil. NUA emphasises strategies of waste minimisation and recycling to manage hazardous effects of waste (art. 74, 76), overlooking the potential for waste to contribute to the essential role of material decay in soil formation [14]. Since NUA generally acknowledges cities' reliance on the ecosystem, while underlining compactness, density, infill, and planned extensions, the proximal position of soils in urban environments remains ambiguous.

When soils in urban planning are considered as merely relevant 'out there' at a distance and their social–ecological benefits stay invisible and inaccessible to inhabitants, societal awareness of, and relations to, urban soils are likely to remain minimal. Peleman et al. [4] trace discourse on soil in architectural design and urban planning to the 1980s, and find that public initiatives to increase interest, awareness, and care for soils since then have had little effect. Urban design disciplines have recently started engaging with soil as a multidimensional tangible and mutable material and the soil matrix as ecological foundation [4]. Since people concentrate in urban areas, these offer the greatest potential for the highest intensity of soil–society relationships, i.e., McBratney et al.'s [3] soil connectivity. Paradoxically, urban areas are also subjected to the most complex and intense pressures on land, which threaten soil security [5]. Meanwhile the rate of urban expansion tends to outpace the rate of urban population growth [15], exemplified by Mexico [16,17].

Typical development and expansion of urban land cover involves land-use conversions that increase paved and built space. The consequence is soil sealing, habitat fragmentation, and reduced access to the local stock of soils, while deficient management of waste and decay lead to contamination and marginal soil quality. The resultant patterns prevent direct enjoyment of soil benefits, causing disengagement from soils (we readily acknowledge recent trends increasing urban agriculture, spearheaded perhaps by the exceptional contemporary response to economic stress in Havana, see [18]). The obvious risk of disengagement from soil is that opportunities for the proactive and mutually (environmental–societal) beneficial management of soil resources are missed. These risks are especially acute in areas of the global south where rapid urbanisation of the population is projected for several decades [2,15,19–21].

The land-use paradox forms an obstacle and complication for including productive soil relations in urban development strategies. Multi-stakeholder entanglements in competing land-use priorities and inconcrete sustainable development policy guidance obscure urban planning's task and potential to promote soil connectivity. Only a dramatic uptake in soil knowledge and awareness of intergenerational soil dependency among urban stakeholders could leverage a paradigmatic attitude shift across agents of urban development to help safeguard and improve urban soil resources.

3. Stakeholders, Knowledge Exchange, and Environmental Attitudes

3.1. Focus on Soil Connectivity

Soil connectivity is pivotal to achieving soil security, because societal soil dependency and thus soil–society relations directly impact all other dimensions, particularly in urban environments [5,22]. Evans et al. [5] reassess archaeological evidence to demonstrate that lowland Maya urbanism displays patterning congruent with urban spatial frameworks that support the sustainable management and use of urban soils (cf. NUA art. 51 [12]). Physical archaeological evidence of urban built environment patterns, landscape modifications, as well as traces of practices that would have helped to preserve, enhance, and contribute to soil quality and quantity, show the outcomes of practical responses required to sustain urban populations. We recognise that the exact way in which these practical responses were implemented are suggestive of socio-cultural lifestyle values and preferences. Maya soil practices demonstrate societal leverage and engagement in urban soil management, which is indicative of mechanisms of knowledge exchange and distinctive attitudes to producer–consumer relationships.

Even if physical and chemical soil scientific knowledge in Maya society were limited, the intergenerational inheritance of soil management practices demonstrates that urban populations recognised the benefits gained from engaging with urban soils. From this we can infer that a commonplace understanding of general operating principles pertaining to soil connectivity is essential to how society acknowledges and values the idea that urban environments shape connections to soils. Archaeological knowledge on Maya urban society can thus be used both to assess how current urban environments compromise the potential for urban soil connectivity (see [2]; Part II) and to consider in detail how societal knowledge, cultural norms, and environmental attitudes reinforce urban soil connectivity. Therefore, we will now consider what archaeological evidence suggests about Maya societal awareness and knowledge of soils and the environmental attitude of urban stakeholders towards participating in soil management. We frame this exploration of archaeological interpretations in terms of pro-environmental attitudes as investigated by environmental psychology and the roles in promoting soil connectivity ascribed to the societal stakeholder categories implied by McBratney et al. [3]. In addition, we use the lens of soil connectivity to connect Maya practices and urban development to the seven principles of building resilience in social–ecological systems [23–25]. This cross-disciplinary effort will help to relate insights derived from Maya urban society to the dynamics of urban life as addressed by urban planning today.

3.2. Contemporary Societal Stakeholders and Knowledge about Soils

Viewing soil connectivity in the broader context of sustainable development and environmental care highlights the lacuna between the growing publicity on the necessity of soils (e.g., [1,6], and the lagging individual and societal preparedness or motivation to act accordingly [26]). This lacuna demands we tackle the question: what motivates an individual or community to deliberately encounter and pro-actively engage with their soil resources? The general logic applies that effectuating public participation in pro-environmental behaviour minimally requires broadly carried and publicly accessible knowledge and awareness. Even with an ample societal knowledge base and awareness of the global challenges of sustainable (urban) development in addressing the climate emergency, protecting biodiversity, poverty, health, or food security, there are a multitude of complex factors that influence whether people will be motivated to act [27].

In twenty-first century global society, smallholder farmers are the largest stakeholder group with an awareness and understanding of soils, and soils' capacity for agricultural production [28]. Processes of urban migration and global urban encroachment continue to threaten the existence of smallholder farmer populations, despite the fact that present-day urban life and development are deemed unsustainable [2]. The progressive sealing of soils and fragmented access to soils in urban environments are the greatest impediments to nurturing and harnessing soil connectivity. Awareness of, and engagement with, urban soils are low among all stakeholder groups, including only 2% of soil scientists [28]. For urban populations, soils predominantly remain hidden or even hold negative connotations (cf. [29]) on dirt as matter out of place). Since one rarely encounters soils in urban environments, one is barely prompted to think about their presence. As McBratney et al. [3] posit, the motivation to engage or connect with the goal of soil security is partly contingent on one's knowledge about soil. Based on current global policy advice, such as NUA, we can appreciate that we are still stuck at this first hurdle of generating awareness and distributing knowledge.

McBratney et al. [3] (p. 208) make a number of suggestions for enhancing soil connectivity through knowledge exchange. One proposition posits an ethic that "the person who is responsible for the soil in any given piece of land [should have] the right knowledge and resources to manage the soil according to its capability". They develop this position by specifying that acquiring the "right knowledge", relies, in part, upon the land manager having access to "those with soil science knowledge [i.e.,] work-ready soil science graduates [who can] communicate [this knowledge] sufficiently to the broader community" [3] (p. 209). The implication of this standpoint is that society can be divided into at least three societal stakeholder categories. These categories are based on a qualitative (knowledge) difference borne out in the directness of economic dependency on soil resources of societal groups. Ordered from small to large groups, we recognise: (1) trained soil specialists; (2) those who manage or use soils, e.g., farmers, rangers, and gardeners; (3) and 'all others', i.e., the general public as end-users who consume and rely on soil products.

To some extent, McBratney et al. [3] acknowledge this tripartite division of society in their assessment of the social support for advancing soil security. They claim that only those who *know* about soil security issues will feel compelled to lobby for soil-protective measures and active soil maintenance. Meanwhile, the general dependency of society on soil products is deemed much less likely to be a motivator. This could be explained by the relative directness of the economic soil dependency per stakeholder category. The existence of trained soil scientists, and those who actively manage, use, or cultivate soils, depends directly on the stock, capability, and condition of soils. Despite the fact that the number of end-users of soil products by far outstrips the other two groups combined, thus exposing the weight represented by this particular stakeholder dependency as paramount, the indirect relation to soils conceals end-users' fundamental economic soil dependency, especially in cities. This means that the general public is much less likely to become aware of their vulnerability to soil insecurity or choose to lobby for or engage with soils.

Some argue that enhancing connectivity between soil and society at large, in terms of general awareness and engagement rather than motivated by dependency, is an imperative goal for building soil security. Morgan et al. [30] suggest that 90% of the general public should have an awareness and understanding of soil security by 2030. To realise this, they detail a number of objectives, including to "engage 0.1% of the population to nurture and connect their values with securing soil" [30] (p. 461). The ways and ease by which this nurturing of a connection with soil can manifest will ultimately be heavily dependent on the individual. Its success on a grander scale arguably relies on how habitual behaviour, collective action, and a sense of shared benefits foster community engagement. The current model offered by soil scientists puts a heavy burden on highly select groups to act as educational catalysts, assuming both a quick dispersal of knowledge and rapid escalation to action and behavioural change.

As the evidence presented by Evans et al. [5] demonstrates, tropical lowland Maya urban life employed a range of coordinated strategies and individual actions to care for, enhance, and contribute to the quality and quantity of urban soils. Meanwhile, the spatial configuration of their urban environments suggests a majority of people would have enjoyed direct benefits from the availability, proximity, and accessibility of urban soils. While this is not direct evidence for soil–society engagement motivated by urgent dependency, the evidence shows that habitual interactions with soils would have been inevitable in Maya urban life. Considering that spatial configurations of land use and urban form stimulated the inevitability of soil engagement, how was such documented lowland Maya urban design reinforced by Maya societal knowledge about soil, and how does Maya urban life invoke soil connectivity stakeholders?

3.3. Knowledge about Soils in Maya Society

The state of material preservation and the often coarse or fragmentary nature of concrete archaeological evidence make it difficult to retrieve communal knowledge and individual motivations unambiguously. Iconography and epigraphy can afford us a view of Maya knowledge sharing systems. The interpretation of Maya iconography, which can depict large varieties of flora and fauna, relies heavily on correlations to modern ethnography (e.g., [31]). Meanwhile, only four Maya *codices* (folding books) have survived conquest and colonisation. It appears an unlikely coincidence that all, but in particular the *Madrid Codex*, contain almanacs and depict cycles of seasonal events and ceremonies, including activities such as planting, sowing, or harvesting crops [32,33]. In Mayan languages, words for soil, some soil distinctions, and especially a rich idiom of soil properties and descriptors have been recorded [33,34]. Furthermore, it is argued that the use of the ergative case in Mayan languages is indicative of the significance and active role of non-human agents, spiritual connections to ancestors, and the animism of environmental elements (see [35,36]).

Our knowledge of narratives and myths that may have been part of Pre-Columbian Maya knowledge sharing systems is highly speculative. Records of such stories were created in the early colonial period. The most notable record of Maya mythology is the *Popol Wuj*, a document from the highland K'iche Maya people that is known from an 18th century copy of an original likely from the 1550s. Since this represents "the cosmological vision and political history of a specific group" [37] (p. 237), extrapolating its contents to apply to all Maya peoples, languages, regions, and periods is contentious. Mythical narratives from all societies will have been derived from long-term practical knowledge of human–environment relations. In many societies across the globe, we find references to animism and holistic worldviews that contrast with globalised gain-oriented socio-economic values. Knowledge exchange occurs through repeated socio-cultural experiences of sharing such narratives through ceremonies, celebrations, and everyday rituals, which internalises useful and culturally specific understandings of our lifeways and its cyclical rhythms.

Wells and Mihok [33] recount a highland Maya version of the creation myth in which gods fashion human bodies, first of soil, then of cornmeal, produced by manipulating soils. "Maya ideas of creation, growth, and reproduction (physical and social) as attested in the Popol Vuh [Wuj] and the Madrid Codex interlink the creation of humans with the creation of the earth and with the underlying belief that humans are made from maize" [33] (p. 319). The importance of subsistence through maize cultivation is reinforced by the Mesoamerican concept of the four-sided world as a maize field [31] (p. 461). References to cyclical practices of sowing, planting, and harvesting connect creation and other narratives to sustenance through cultivation. The remarkably accurate Maya calendar system, with its combination of linear (absolute) and cyclical time reckoning, is considered one of the great knowledge feats of Maya society. The utility of the calendar's time cycles—the *haab*, similar to Gregorian months, and the *tzolkin*, a complicated kind of "week" count—aided in synchronising seasonal changes with cultivation practices. Milbrath [38] (pp. 94–96) argues that the 260-day calendar cycle has its roots in the maize cultivation cycle.

Lucero and Cruz [35] link what they describe as a Maya cosmocentric worldview (CWV) to a holistic concept of the urban environment that revolves around diversity in environmental responses and a central appreciation of urban–rural interdependence (cf. Du Plessis' [39] conceptualisation of social–ecological systems). Recognition of environmental interdependence speaks from thousands of years of adaptive Maya farming practices which did not (permanently) deforest the landscape, possibly reflecting the absence of grazing animals in the subsistence base. In most lowland Maya environments, the forest itself formed a primary resource, essential for sustaining life and ecosystemic functioning (compare: [40] with [41]; iconographic and ethnographic evidence provided by Taube [31]). On a socio-cultural level, the longevity of careful management of Maya dependency on forest resources and its resilience against disturbances [41] matches our assessment that urban soils were regarded and treated as an intergenerational resource.

Diversity and distributed participation in soil management practices certainly emerges across a large sample of lowland Maya cities, demonstrating that the urban Maya were often intensively engaged in soil management to support a level of cultivation [5]. While in some cases self-sufficiency might have been possible, these soil management practices also occur in cases where it was not achievable, such as at Chunchucmil (Mexico) [42,43]. In the case of Xuenkal (Mexico), residential groups are organised around karst sinkholes (*rejolladas*) that enhance opportunities for cultivation thanks to soil accumulation and moisture retention [44]. In the medium-sized city of Aventura (Belize), households are deliberately placed on slightly elevated locations with shallower topsoils, proximally associated with pocket *bajos* (small-scale karst depressions) [45]. The spatial organisation of Maya cities thus clearly prioritised close connections and proximity to urban soil resources, maximising opportunities for access.

Preference for maintaining diversity as a pattern of resilience further bears out in the Maya subsistence base. The urban Maya practised polyculture with a strong orientation towards plant-based cultivation as opposed to a model characterised by the human–grazing animal complex, which causes deforestation to allow grass to grow for herbivores [46]. The evidence suggests that this polyculture supported high species diversity and a multitude of cultivation techniques and small-scale patch separations in horticulture, agriculture, and agroforestry. This took place in different types of locations distributed over the urban landscape: (in) fields (*milpas*), home gardens (*solares*), and managed forests [5,35,41,47–50]. Experience sharing, knowledge exchange, and (occasional) collective action as a community based on a cosmocentric worldview, appear to have built an urban Maya society in which soil engagement and enhancement became habitual over many generations.

Reports on colonial-era Maya describing practices for managing soil fertility and moisture show that habits of urban soil engagement were passed down and adapted over generations. Notable are the many agrarian rituals which were performed to seek divine permission for disrupting the biophysical environment with activities such as planting, harvesting, 'feeding' (associated with clearing), and 'curing' (associated with restoring) land, and particularly for invoking sufficient rain and bountiful harvests. Wells and Mihok [33] infer this as representative for how soils are intertwined with cosmology. From the urban archaeological record, we know that lowland Maya urban environments featured many locations that were constructed to engage in ceremonies and rituals at several scales: shrines are identified in domestic spheres, at neighbourhood centres or community ceremonial building groups, and in large central civic-ceremonial districts in cities dating to different archaeological periods (Figure 1) (e.g., [51–56] ([56] pp. 72–73))".

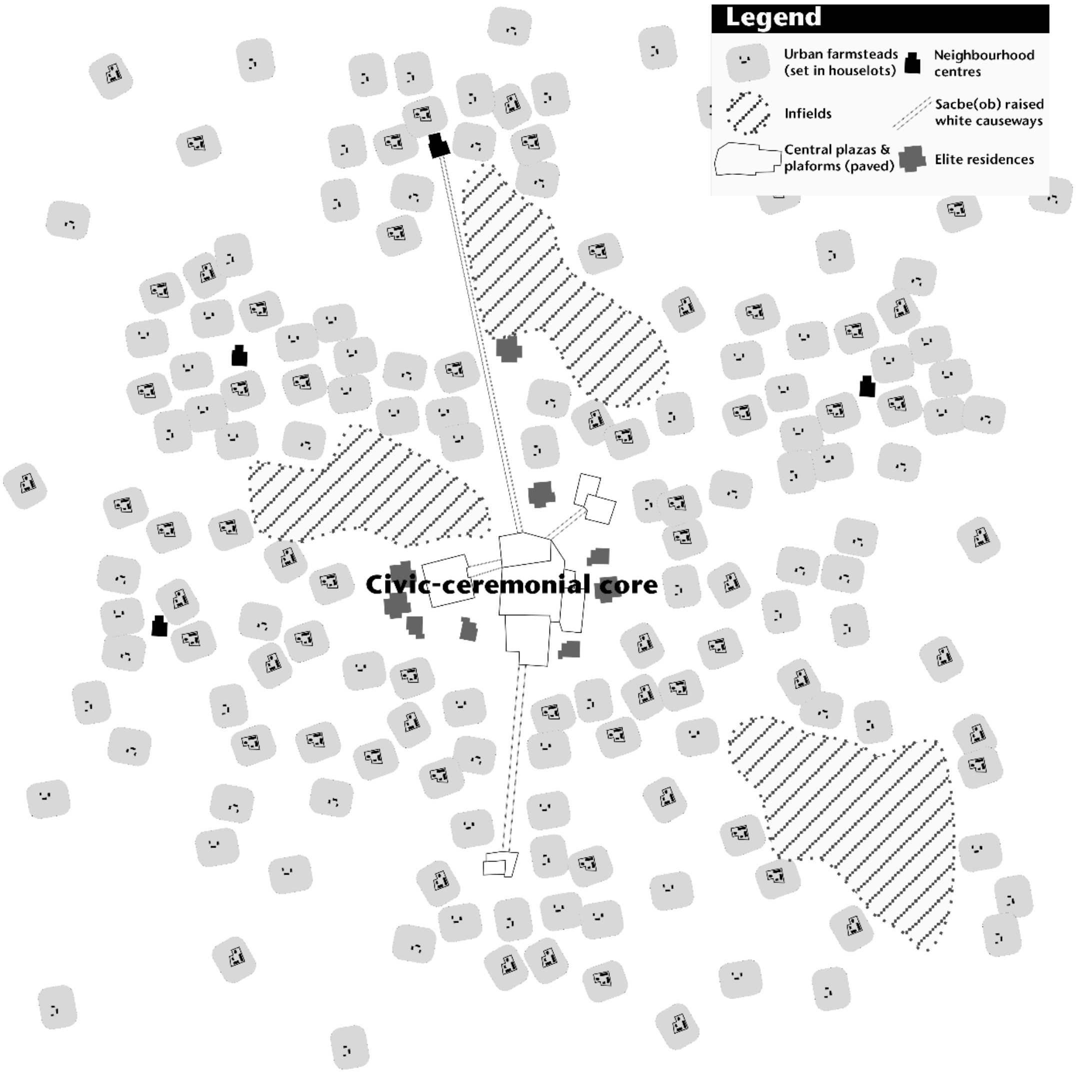

Figure 1. Idealised abstracted map of the general spatial plan of principal elements making up lowland Maya urban settlements (from [5] (p. 5)).

We stress that ritual behaviour is generally unified with practical utility. Mayan languages do not express abstract concepts of 'religion' [57] or, asserted by Lucero and Cruz [35], 'nature'. Cultural rituals usefully strengthen the connections between people, while the same rituals can inform and structure human–environment interactions. In Maya agro-urban landscapes, civic-ceremonial sites enabled large scale cultural experience-sharing, whereas everyday life locations, such as water sources or constructed mounds, are inferred to have offered frequent opportunities to engage meaningfully with human–environment interdependence through mundane ritual behaviour [35,42,45].

Besides accurate time reckoning, direct (archaeological) evidence for Maya environmental planning policies is absent. In spite of this, the effects of social practices and rituals that reinforced respect and care for environment–society interdependence by imparting and sharing environmental knowledge and broadening participation might be likened to environmental planning policies, such as those pursued through soil *codification*. Wells and Mihok [33] (p. 315) assert: "The variety and complexity of agricultural systems demonstrate that the ancient Maya held a deep understanding of soils and their properties, management, and care." Without a greater variety of Pre-Columbian Maya books to assess how knowledge (or policy) may have been documented and imparted, we might assume that knowledge in Maya urban society would probably have functioned like traditional ecological knowledge (TEK) in some of today's non-globalised rural societies. That is, based on inheriting cultural values, generational experience, and repeated participation in ritual behaviours supported by narratives that internalised utilitarian cultural practices (see [58] (pp. 71–75)). The contrast with western future-oriented urban planning is deceptive, since today's adaptive planning goals, participatory governance, and planning processes put down foundations that would permit integration of alternative indigenous knowledges.

In fact, the combined reviews from Wells and Mihok [33], Lucero and Cruz [35], and Evans et al. [5] permit us to link Maya societal practices to several of the seven principles for building resilience in social–ecological systems (such as urban landscapes) [23–25]. Through the lens of soil connectivity, there is ample evidence for maintaining diversity that, through its distribution and frequency in the urban environment, in many cases incorporates redundancy (principle 1). The integration of soils and their relative proximity and accessibility (often already within the residential unit of the urban farmstead), shows a concern for managing connectivity (principle 2) (cf. [59] on water management). Spatial distribution, and rituals marking and reinforcing knowledge about agrarian and environmental cycles and interdependence, promoted at least colloquial and communal learning. Judging by the variety of soil management techniques in, for example, terracing and soil enrichment and accumulation, it is likely that experimentation was encouraged [5,49,60–63] (principles 5 and 6).

Regionally varying evidence from environmental modelling indicates that Classic Maya urban society (250–900CE) experienced limitations that prevented the effective management of slow feedback and longer periods of deviating environmental conditions (principle 3). Notwithstanding regional variability, the inability to manage slow feedbacks especially pertains to waning resilience in the context of environmental change from persistent droughts and land degradation when agricultural carrying capacity in urban landscapes is maximised (e.g., [40,64–68], cf. [41]). Acting on enhanced scientific knowledge resulting from long periods of detailed monitoring and documentation of environmental fluctuations and change over time, could bring current urban society an advantage. In this respect, the famed rapid and successive declines of several major dynastic Maya city-states in the central lowlands over the 9–10th centuries CE may show the part played by path dependence (cf. multivariate models for the Maya collapse: [69]). Path dependence of Classic Maya urban governance and socio-cultural functioning restricted flexibility and adaptation in mechanisms for knowledge exchange, learning, and participation (see [70], cf. [59] on mythology against over-exploitation).

North and east of the major agro-urban landscapes that occupied the central lowlands, urban centres demonstrate greater continuity. In some places we can document an influx of population to urban centres in coastal or lacustrine regions (e.g., at Lamanai (Belize) [71] and Motul de San José (Guatemala) [72], also see [73]). From the perspective of societal adaptation, the collapse of dynastic rule drastically changed the settlement dynamics in which central lowland cities ceased functioning as urban centres leading to population dispersal, some of which potentially benefitted the growth of urban centres elsewhere (cf. [35]). The next phase for Maya civilisation was characterised by increasing political complexity, shared rulership, decentralisation of cultural value systems, coastal trade, and commercialisation [74,75]. These societal changes could arguably be positioned as signs of principle 7 (polycentric governance systems) and an increase in principle 4 (complex adaptive systems thinking), even though for a significant period political power in Postclassic Maya society (1000–1500 CE) concentrated in a single city where ruling lineages assembled [56].

3.4. Stakeholder Groups in Maya Urban Soil Connectivity

Maya knowledge and practices exemplify crucial benefits of a social–ecological, mutually inclusive and interdependent approach to urban systems. Maya cosmology stands as a pertinent alternative to the prevalent mechanistic and reductionist growth- and gain-oriented worldview from which today's most dominant and unsustainable social–ecological systems emerged (see [39], cf. [35] (p. 2)).

The evidence from Aventura provides a quantitative dimension to the interconnectedness of nature and culture in a Maya urban environment on the basis of the many pocket *bajos* of varying sizes located within and around the settlement core. Grauer [45] (p. 84) reports: "Of the 162 mounds [ruins of architectural construction] mapped at Aventura, 20 percent are located within 20 m of a pocket *bajo*. Every pocket *bajo* mapped at Aventura has between 1 and 3 mounds within 5 m of its edge. However, at least 50 percent of the perimeter of every pocket *bajo* mapped at Aventura has no construction within 50 m. They were neither entirely within the city nor outside of it". Grauer continues to argue that despite undeniable means and technical ability for large-scale construction, the inhabitants left the shape of the pocket *bajos* intact, at most occasionally modifying and interacting with their edges (see Figure 2). In addition, material evidence shows that the spaces between residential buildings and the pocket *bajos* were also used as the site for ancestor veneration (rituals that play an important role in identity formation and social group creation [53]), signalling the importance of human–environment interdependence in this spatial connection [45]. Pocket *bajos* have been demonstrated to be a vital part of the urban fabric at the ancient Maya cities of Tikal and Yaxnohcah as well [76].

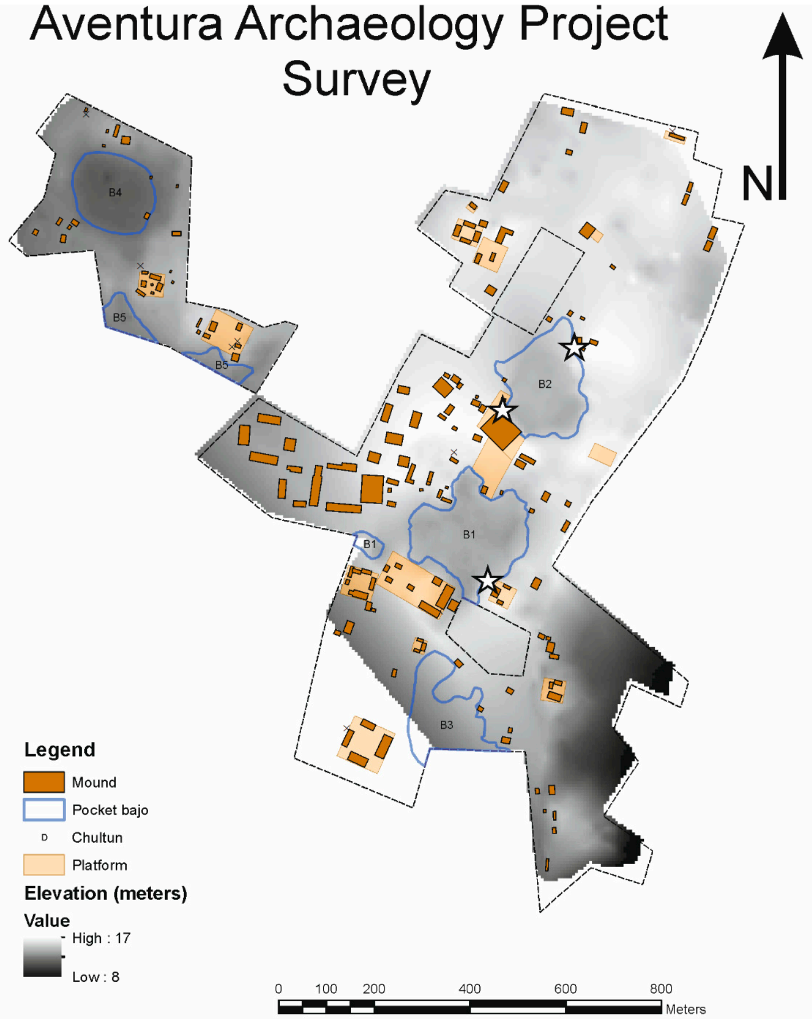

Figure 2. Map of the central core of Aventura (Belize) showing the close-knit relationship between significant building groups and integrated pocket *bajos* containing soil resources, always keeping some of their edges clear from built development. Stars indicate excavation locations (source: [45] (p: 83) reprinted with permission from Kacey C. Grauer).

Through the lens of TEK, urban Maya soil connectivity practices represent a completely natural proclivity encapsulated in the broad cultural knowledge and appreciation of human–environment interdependence seen in other non-globalised rural societies (see [28,77]). The most immediate evidence demonstrates a strong correlation between soil engagement and cultivation. Furthermore, urban Maya care for soils will have contributed to managing soil condition, capital, and capability, causing a range of general ecosystemic benefits. Compared to urban populations today, Maya society must at least have been equally dependent on soil-derived productivity. Yet, thanks to a deep appreciation of various dimensions of human–environment interdependence broadly carried through social practices, a large proportion of Maya urban inhabitants was intensely involved in soil management, resulting in large numbers of knowledgeable users and consumers. The benefits of intergenerational environmental knowledge exchange through social practice are apparent in the persistence of indigenous botanic, farming, and agroforestry knowledge (e.g., [35,41,77–79]). The difference in Maya life stance and expectations arises from an alternative conceptualisation of urban life.

Among the lowland Maya there is a broad community of soil users who are both producers and consumers, which supplants the implicit extreme division of societal stakeholder groups into soil specialists and unknowingly benefitting inhabitants. When a majority proportion of the population (Roman et al.'s [67] model assumes 70% for Classic Maya cities) is involved in cultivation practices, it stands to reason to expect that productive cycles, including working the land, will have had a determinant stake in Maya cultural communication and socio-cultural reproduction (cf. sociological *habitus*). Moreover, Maya reliance on plant-based resources for food and materials, and a commensurate absence of grazing animals, implies that a greater proportion of land, including forests, will have been available to accommodate cultivation activities or environmental management, thus elevating opportunities for direct soil–society engagement (cf. [5,80,81]). Soil–society relations are further maintained by the configuration and morphology of the urban environment that preserves and encourages the presence of urban soils through material inheritance of spatial designs and situated personal biographies (see [82] (pp. 77–89)). Therefore, Maya evidence suggests that a different attitude to urban life, one which is based on practical engagement with the environment, can effectively mitigate the contemporary rift between knowledgeable soil scientists, economically driven practitioners (especially farmers), and the soil-ignorant consuming public.

Conversely, the emphasis on knowledge exchange via soil specialists and specific producers otherwise detached from urban populations (cf. [3,30]) risks further disengaging the urbanising public from soils. Such disengagement can lend urban development strategies to further reduce urban soils as a proximal resource silent permission. Moreover, using policy to allocate and enforce the responsibility for soil maintenance to land owners or users, or seeking ways in which soil scientists can educate a large enough proportion of the population, seem permissive of maintaining the minimal and reductive existing societal relations to soil. Policy and education-led approaches are also likely to depend on repeated, and potentially costly activities, which makes such strategies vulnerable. Similarly, the small section of the urban population that is better informed about soil science but increasingly disenfranchised from soil engagement opportunities is unlikely to evangelise their views and press for changes to spatial planning that could enhance overall soil connectivity. In contrast to Maya urban society, limited and specialised proposals, as those suggested by McBratney et al. [3] and Morgan et al. [30], ultimately risk perpetuating the current societal stakeholder division because they largely exist within the same paradigm of thought that causes the current threat to sustainability [39].

3.5. Where Are Urban Soils in Environmental Attitudes?

Contemporary factors that may currently motivate or discourage societal or individual concern for soils have not been extensively reviewed by soil scientists (although see [83] for a preliminary assessment of the concerns raised by selected industry sectors). However, insights may be afforded by consulting the broader literature on people's attitudes towards environmental care. For example, Gifford and Sussman [84] identify a range of factors that can influence individuals' concerns for the environment, including age, gender, socio-economic status, religion and politics, personality and values, education, and environmental knowledge. They acknowledge that differences exist in the level of environmental concern among urban and rural dwellers, but none of the groups show a substantially greater commitment to preserving environmental resources.

The progressive loss of direct contact with natural environments and wildlife in everyday life has become referred to as the so-called 'extinction of experience', leading to disaffection and negative attitudes and behaviours towards the natural environment ([85]: referencing the memoir of Robert M. Pyle for the term). Conservation societies suggest that bringing children in contact with nature through education at early ages results in positive environmental attitudes [86,87]. A body of evidence compiled over several decades demonstrates that outdoor recreation positively correlates with environmental concern (e.g., [88–90]), but variation in these studies suggests that the motivation to participate in a specific outdoor activity, the frequency, and the duration (from a young age) likely plays a more decisive role in establishing a pro-environmental attitude [91]. Meanwhile, the sense of a connectedness with nature and a duty of care towards the natural environment are recognised motivators among household gardeners. Although urban and suburban gardens represent largely untapped resources for pro-environmental behaviour, survey-based research shows there is great willingness to enact improvements and to contribute to the environment through gardening by encouraging learning and engagement [92,93].

It is paramount in the evidence of Maya urban spatial morphologies [5] that the distribution, diversity, and frequency of proximal accessible urban soils played a significant role in building soil awareness through offering constant opportunity for soil engagement in everyday life. In this light, it is particularly concerning that the land-use pressures from increasing population densities in urban environments will reduce the number of private green or garden spaces to which urbanites have access [28] (see a UK policy briefing [94]). Private urban green spaces offer prime opportunities to start environmental engagement safely and frequently from an early age. Furthermore, when urban and suburban gardens are being permitted to be gradually phased out, there will be no spatial resources and urban lifestyle values left to tap into in order to nurture pro-environmental behaviours.

Across environmental psychology studies of human–nature connectedness, the emerging consensus suggests that more direct, intentional, and conscious interaction with nature (e.g., regularly visiting natural environments rather than living in an engineered green environment) makes pro-environmental behaviour more likely [95,96]. Gifford and Sussman [84] observe that individuals who engage or have direct experience with the outdoors tend to correlate with an increased concern for the environment. While environmental psychology studies often focus on flora and fauna, we posit that concern for soils is a logical extension of environmental care. Moreover, Soga and Gaston [96] reason that spatial dynamics heavily shape opportunities for human–nature interactions due to availability and ease of access, while Martin et al. [95] suggest that interventions that increase contact and connection to nature may be necessary to improve planetary health. These suggestions are particularly pertinent to the potential of building resilience in urban environments, since the drastic alternative configurations for urban life in lowland Maya urbanism at the very least supported the principles of diversity, connectivity, learning, and participation (see [23,24,97,98]).

Siebe et al. [28] observe that urban dwellers avoid soils. Soil avoidance in urban contexts shifts the public perception of soil utility from being life-sustaining to signifying infrastructure (cf. [4]), waste deposition, and even an occasional health hazard or nuisance. The value of urban soil areas is determined by the socio-economic potential of their spatial location in the urban system rather than ecological functioning. Until soils are considered to be indispensable social–ecological resources in urban environments, positive attitudes towards soils are unlikely to strengthen. A pro-environmental attitude regarding soil security relies on how we employ soil–society interdependence to promote soil connectivity that shapes opportunities to engage with, maintain, and enhance soil quality. Currently, the immediate need for the availability and accessibility of soils in urban life is bypassed by a reliance upon mediated services provided through globally connected social interaction and global supply systems that are locally integrated at the urban landscape scale. Distortion of soil–society interdependence is especially apparent with regard to the direct sustenance of the population, which is provided through global food networks. Yet, soil–society interdependence is no less pertinent regarding climate change, water security, waste and material life cycles, and air quality. Increasing encounters and contact with soils, that is to say, fostering a direct experience of soils, requires as a minimum the availability and physical accessibility of soils in urban environments and their proximity (absolute distance) to residential human populations. The principle of distance decay stands to diminish the appreciation of social–ecological soil benefits, while the vulnerability of the chain supplying soil benefits increases with distance. Creating suitable opportunities for direct experience of soils will be critical for stimulating a community-wide shift in cultural attitudes.

3.6. Conditions That Promote Direct Engagement with Urban Soils

By identifying a desire for connectedness with nature, a perceived duty of care towards the natural environment, and a willingness to improve local and global environmental conditions, environmental psychology discourse presents us with excellent starting points for leveraging (urban planning) policy interventions through soil codification (we tackle concrete translations into starting points for planning policy in Part II). However, we surmise that in current societies across the globe, holistic worldviews are trailing more exploitative norms and expectations. Unlike Pre-Columbian Maya society, environmental attitudes, cultural values shared in rituals, and quotidian social practices and knowledge exchange engage little with human–environment interdependencies. Multiple lines of evidence reveal not just soil management practices in Maya society, but cultural knowledge communication that generated a heightened awareness of, and involvement in, what soils did for them. Maya cultural knowledge was translated into valuing and safeguarding the presence of urban soils in everyday lived experience.

The evidence on societal values shows that it would be simplistic to dedicate the importance of the use value of soils in Maya culture to the directness of their soil dependency. Reliance on what healthy urban soils are capable of providing was not absolute. The evidence does suggest that high levels of participative engagement were not solely consumer-based, but existed simultaneously as producers, processors, and consumers of food. Nonetheless, it is plausible that the populations of most lowland Maya urban landscapes partially depended on maintaining urban soil quality for sustenance (cf. [43,99]). Local production complemented their longer distance and international relations in the Mesoamerican culture area that existed in a similar fashion to today's technologically enhanced globalisation (e.g., [100–102]). The implication for us is that the urban Maya displayed a balancing act of better realising their direct dependency on urban soils with benefits enjoyed from a global trade and exchange system. At the city level, a long-distance supply system did not replace the valuable utility of a healthy and productive social–ecological urban environment. Urban Maya populations would have felt compelled to participate in environmental care in order to successfully enable urban life, likely without complete reliance on productive human–environmental relations such as local cultivation at all times.

Recurrent ritual behaviours and cultural communication would have structured the seasonal rhythms of Maya urban life and reminded and encouraged urban populations to participate in practices benefitting soil management. This may not be direct evidence specifying the communal stock of environmental or soil knowledge available in Maya urban society, nor is it unequivocal evidence of intentional engagement to deliver environmental care. In fact, the constitution of the Maya worldview may have prevented Maya individuals from recognising their cultural practices in such terms [35]. Similar to gaining environmental benefits from everyday cultural behaviour, the urban Maya may not have fully realised some of the negative environmental effects of incremental urbanisation processes and slow feedback and variables (i.e., building resilience principle 3). The path dependence of urban governance and ritual knowledge exchange may occasionally have limited Maya adaptability and resilience at a single site scale, i.e., as isolated urban sustainability rather than societal survival (cf. [103]). The central lowland Classic Maya collapse [35,67,69] demonstrates the determinant role of governance and social dynamics in limiting the adaptability of a particular kind of urban centre. The lowland Maya model for everyday urban life situated in urban built environments that accommodate diverse strategies for supporting largely plant-based subsistence continued elsewhere and was replicated in Postclassic urban centres until colonisation. The principles of resilience demonstrated in lowland Maya urban life stress the inevitability and constant necessity for social–cultural values and practices to maintain a pro-environmental attitude.

We recognise that generating a broadly carried and enduring positive attitude towards the maintenance of local urban soils per se remains a difficult objective. We should be watchful that ecologically optimal urban soil quality is not an 'ecosystem service' in its own right. Instead, soils are implicated in the performance or delivery of most social–ecological benefits that are often discussed and presented as ecosystem services [104,105]. Therefore, it may well be that soil management for soils' sake remains an objective best reserved for specialists and those who are especially engaged in achieving specific soil properties and capabilities. However, lowland Maya urban life indicates that heightened soil awareness and engagement with an enhanced level of soil knowledge is achievable as part of an overall environmental attitude shift towards holistic human–environment relations.

Since urban soils form an essential and often pivoting variable in achieving urban sustainability, the relative absence or silent subservience of soil quality and soil security from urban policies is unacceptable. We advocate for an explicit role and reference to soils in educating on and addressing environmental concerns such as climate change, food, water, energy security, waste processing, and material life cycles. Generating general public demand to forefront the need for land surfaces where urban soils can be maintained and accessed will put additional pressure on local land-use competition. Urban planning advice and guidelines have a crucial role to play in nurturing a culture of valuing soil care that supports and encourages public demand for soils, making them a visible, tangible, and productive part of urban life.

Importantly, public demand for urban soils will stimulate questions about the mode and method of urban development strategies that structure how urban expansion and intensification take place. Rethinking spatial configurations for sustainable urban life should consider the multidimensional and multifunctional social–ecological benefits of maintaining urban soils and enabling everyday engagements with soil. Such a paradigm shift puts the spatial dynamic and integration of intermittent soil sealing on the front line, problematising the exact characteristics and material properties of fragmentation and connectivity and highlighting their effects on ecosystemic functioning. We will have to address the paradox that in urban environments instances of soil sealing or the absence of soils are virtually inevitable to mediate opportunities for soil connectivity (see Part II). Therefore, spatial and urban planning guidelines must consider how soil connectivity is shaped by land-use configurations and urban design. Ultimately, a broad contingent of society can only enact their stake in urban soil security if they are provided with accessible resources, a combination of soil and urban design, to do so.

4. Conclusions

We have applied the socio-cultural interpretation of archaeological evidence of long-term lowland Maya urban society to the urban planning challenge of nurturing and enhancing a contemporary culture that values the role played by urban soils in beneficial human–environment relations. We built on previous syntheses of urban archaeological evidence that identify that Maya spatial design integrates the availability, proximity, and accessibility of urban soils, and that presents a variety of social practices and strategies that contributed to soil quality and the protection of urban soils. Accepting that soil connectivity was commonplace in Maya urban practice, here we focused on exploring how everyday opportunities to encounter and directly engage with soils were reinforced and supported by knowledge exchange, stakeholder roles, and the socio-spatial conditions of the urban environment. As such, we have greatly expanded the archaeological evidence-base with a socio-cultural specification for McBratney et al.'s [3] original two routes for stimulating soil connectivity: knowledge exchange and producer–consumer relationships. Throughout we framed our interpretation of Maya cultural values and urban practices in terms of leading insights from environmental psychology on pro-environmental behaviour and stakeholder attitudes and the principles of building resilience. This allowed us to hone in on key principles for valuing urban soils and reinforcing soil connectivity.

It is promising that we can match the notion and approach of social–ecological urban systems to the sensitivity of human–environment interdependency in Maya urban practice and cosmology. We recognise that Maya participation in everyday ritual behaviour cannot be separated from practical knowledge on human–environment interdependence. We identify that soil connectivity in Maya society is especially embodied by the largest stakeholder group of producers–consumers. Soil knowledge exchange is entangled with actively sharing cultural values, rather than dependent on a small minority of soil specialists to impart and mobilise beneficial soil–society relations. Urban Maya polyculture, with strong orientation towards plant-based cultivation (vs. grazing and beasts of burden), likely afforded them an advantage in balancing dependency on local productivity from healthy urban soils with enjoying the benefits from a long-distance exchange system. Despite great uncertainty over the existence of Maya urban planning policies governing the development of spaces for everyday life, we acknowledge the evidence for bottom-up mechanisms contributing greatly to most contemporary principles for building resilience. Combining bottom-up practices and top-down social–ecological cultural values communicating seasonal rhythms enabled Maya soil connectivity to diminish vulnerability to reliance on long-distance supply chains and to maintain productive human–environment relationships over the long term.

Thus, the emerging Maya model for a socially engaged, soil-aware urban society draws out that the key task for urban planning advice and guidelines is to enable and support a widely shared and enduring culture of soil care. Making a culture of soil care a primary task in urban planning acknowledges that urban sustainable development objectives may strive to meet a range of environmental threshold and resiliency conditions, but ultimately may only be successful in maintaining this over generations through popular motivation and support construed from an awareness of soil dependency. As such, the Maya model stresses the necessity of shared values and intergenerational participation of broad societal stakeholder groups in Peleman et al.'s [4] (p. 11) assessment that "sustainability cannot simply be an item that we tick off our list of ecological tasks at a given moment in order to meet current standards, and that subsequently vanishes back into bureaucratic oblivion. Sustainability requires a continuous and long-term engagement."

Our next step must be to consider exactly how urban planning policy can attain the motivation and mobilisation of a broad stakeholder group to become entangled in productive soil–society relations (see Part II). Therefore, urban planning advice and guidelines cannot afford to avoid explicit attention to soil presence, quality, and dependency within social–ecological urban systems. Explicit attention to soils in policies serving entire urban populations will, on the one hand, support soil specialists and those tasked with achieving specific soil properties and capabilities in the technical management of soils and, on the other hand, formulate guidelines that effectively stimulate general soil connectivity. Formulating such guidelines will require planning tools and information that reveal and analyse the current condition and situation of urban soils in urban environments so as to identify targets for unlocking the potential for urban soil connectivity.

Author Contributions: Conceptualization, B.N.V., D.L.E. and E.G.; Methodology, B.N.V. and D.L.E.; Investigation, B.N.V. and D.L.E.; Writing—original draft, B.N.V. and D.L.E.; Writing—review & editing, B.N.V., D.L.E. and E.G.; Visualization, B.N.V. and D.L.E.; Project administration, B.N.V.; Funding acquisition, B.N.V., D.L.E. and E.G. All authors have read and agreed to the published version of the manuscript.

Funding: The paper was initiated as part of the project Pre-Columbian Tropical Urban Life: Placing the Past in Designs for Sustainable Urban Futures (TruLife), funded by an Arts & Humanities Research Council (AHRC; UK) grant to Benjamin Vis (PI) and Christian Isendahl (CoI) (AH/N006240/1), the steering committee of which included Elizabeth Graham and Karsten Lambers. The onward development of this paper has been supported by funding from project No. 20-02725Y awarded by the GACR—Czech Science Foundation awarded to Monika Baumanova (PI) and Benjamin Vis (CoI) and funding from the European Union (Project: 101063202—REMIND—HORIZON-MSCA-2021-PF) to Benjamin Vis. Daniel Evans was in part supported by funding from a 'NERC Cross-disciplinary research for Discovery Science' project (NE/X018326/1), as well as an 75th Anniversary Research Fellowship awarded by Cranfield University.

Data Availability Statement: No new data were created or analysed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors thank Christian Isendahl for his valuable feedback on previous versions of this work. The authors thank Kacey C. Grauer for her permission to reproduce a figure.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare that the work described here has not been published previously, it is not under consideration for publication elsewhere, and that it is approved by all authors.

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