Rethinking 'Sustainable Infrastructure': Natural Processes, Context, Value and Balance

Sara Adhitya, Tom Dolan, Nick Tyler, University College London

Who Should Read This White Paper?

This paper is of interest to all stakeholders involved in infrastructure design and development, concerned by the sustainability of current approaches and in search of new perspectives which may inform their own practice. These include professionals from all relevant disciplines – from engineering, urban planning, governance and environmental science – as well as concerned members of the general public.

Key Messages from the White Paper

1. **Natural Processes**: The importance of natural processes to sustainable infrastructure and their potential to deliver infrastructure outcomes rather than just be inputs to infrastructure. Infrastructure is dependent on, and enabled by, the role natural processes play as 'source' and 'sink' for infrastructure inputs and outputs. Infrastructure planners, investors and operators must be aware of this dependence when making infrastructure decisions
2. **Spatio-temporal Context**: The need to incorporate multiple simultaneous timescales and the flexible nature of human perception of time so that the planning, design and operation of the local context takes into account its spatio-temporal characteristics
3. **Balance**: The importance of balance in sustainable infrastructure and the need for a systemic perspective including the elements of natural processes such as air, water and sunlight (see 1)
4. **Value vs Growth**: The role infrastructure can play in supporting growth in Value, rather than just the economy and sustainability

Abstract

In light of the current sustainability crisis, this white paper addresses concerns that current perceptions of infrastructure are limited, and could in fact be standing in the way of the achievement of 'sustainability'. It re-examines infrastructure as comprising both large-scale systems (railways, bridges, communications networks and health systems etc.), and supportive elements. In particular, it proposes that natural processes are in effect an underlying layer of 'infrastructure' and over-looking these core elements, undermines the sustainability of infrastructure and the societies it supports. Thus this white paper attempts to redefine the meaning of 'sustainable infrastructure' to include these natural processes. This white paper also looks at sustainability as a temporal condition and proposes that infrastructure design must address more than the life term of the infrastructure itself, and also consider the spatio-temporal context into which the infrastructure will be introduced. It also raises the importance of balance between these different elements of an infrastructure system and the values behind economic growth and 'sustainable development' in general. We thus propose expanding the definition of infrastructure to a more holistic one, which includes natural processes, the spatio-temporal context in which infrastructure are situated, their relationship to each other as elements of a connected system and the values driving their development. The overall aim of this paper is to prompt discussion, help conceptualise and pose important questions regarding our current perception of ‘sustainable infrastructure’.

Key words

Sustainability, Infrastructure systems, natural processes, balance, value

Connections to Other ICIF White Papers

TBC

Where Can I Find Out More?

For more information please contact Dr Sara Adhitya (s.adhitya@ucl.ac.uk), Dr Tom Dolan(thomas.dolan@ucl.ac.uk) or Professor Nick Tyler (n.tyler@ucl.ac.uk)

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1 Introduction

This paper was born from the concern that current perceptions of infrastructure are limited, and could in fact be standing in the way of the achievement of 'sustainability', defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Harlem, B.G. et.al., 1987). Infrastructure is defined as "that which lies underneath and supports a structure" (OED, 1989). Infrastructure debate is frequently focused on large systems such as railways, bridges, communications networks and health systems and the 'sustainable' development of these larger infrastructure elements. This can cause the sustainability of the natural processes underlying infrastructure: sunlight, air, water, wind, earth, minerals and heat to be overlooked; and it is the effective stewardship of thesese elements which is vital to address the current sustainability crisis.
Furthermore, the term 'sustainability' is inherently a temporal condition, yet the concept of time relative to infrastructure is often thought of only in terms of the life term of the infrastructure itself. However, environmental sustainability requires a much longer time frame than that which we give our infrastructure, therefore approaches to infrastructure investment must factor in this temporal perception. We thus propose expanding the definition of infrastructure to a more holistic one, which includes natural processes, the spatio-temporal context in which they are situated, their relationship to each other as elements of a connected system and the values that give infrastructure development a purpose.

The purpose of this White Paper is to prompt discussion of, and raise important questions regarding current perceptions of 'sustainable infrastructure'. Four main discussion statements (see Table 1) referring to the themes of: the natural processes underlying all infrastructure systems; the spatio-temporal context of those natural processes and infrastructure; the concept of balance in infrastructure systems; and the values behind economic growth and ‘sustainable development’ are used for this purpose. Thus, the White Paper is divided into four sections, in each of which a discussion statement is posed and briefly elaborated on. Each section concludes by identifying questions to frame the future debate and research agendas with which infrastructure stakeholders and, more broadly, society need to engage with in order to provide infrastructure better suited to the complex dynamics of the Socio-Ecological-System (SES) (Walker et al., 2004) of which infrastructure (a built system) (Hollnagel, 2014) is a part (see white paper Infrastructure Resilience: a multi-disciplinary perspective).

Table 1 Discussion Statements

A	Infrastructure, like all human activity, depends on natural processes. These natural processes supply inputs to infrastructure and can be disrupted as a result of outputs (foreseen and unforeseen) from infrastructure. Additionally, it is possible for natural processes to provide ‘infrastructure-like’ outcomes. However, the importance of natural processes in the provision of resilient infrastructure is often overlooked or undervalued during infrastructure planning.
B	The local context into which infrastructure is introduced is shaped by natural processes, which are both temporal and spatial in nature. Acknowledgement of such issues should be central to infrastructure planning and ‘one-size fits all’ solutions recognised as inappropriate on this basis.
C	Sustainability requires a system-wide view and should incorporate the concept of 'balance' based on an awareness of the importance of the fundamental natural processes (sunlight, air, water, etc.). As the basis of many ancient practices

	addressing both human and environmental health, the achievement of 'balance', can be a useful point of learning for sustainable infrastructure planning.
D	Sustainability as stated is driven by the need for economic growth: Is economic growth a suitable objective, or should we be prioritising social and environmental sustainability even if economic growth is zero (or even negative)? Maybe promoting Value rather than growth would be a better objective.

2 Discussion Statement A: Natural Processes

Statement: Infrastructure, like all human activity, depends on natural processes. These natural processes supply inputs to infrastructure and can be disrupted as a result of outputs (foreseen and unforeseen) from infrastructure. Additionally, it is possible for natural processes to provide 'infrastructure-like' outcomes. However, the importance of natural processes in the provision of resilient infrastructure is often overlooked or undervalued during infrastructure planning.

Elaboration: The carbon cycle, the water cycle, rotation of the earth and countless other natural processes enable the viability of human societies. Climate change, is one such example of the potential impacts on human societies when these natural processes are disrupted and their ability to enable the societal structures which depend on their stability is altered. Similarly, infrastructure enables desired outcomes (including economic growth) for the benefit of human societies and like natural processes the benefits generated are most keenly noticed in their absence i.e when infrastructure fails.

All infrastructures are to some extent dependent on, and enabled by, the role natural processes play as ‘source’ and ‘sink’ for infrastructure inputs and outputs. It is for this reason that Edwards refers to ‘*nature as the infrastructure on which all human-built infrastructures ultimately depend’* (Edwards, 2002).

Recognition that infrastructure is tightly bound with natural processes is of critical importance if we are to provide cost-effective, sustainable and resilient infrastructures in the future and successfully adapt our current infrastructure. It is, therefore, useful to conceptualise infrastructure levels as shown in Figure 1. Natural processes (level 1) are the critical enabler of man-made infrastructure processes (level 2) and outputs from infrastructure have the potential to impact on natural processes (level 1). Level 3 services are in turn enabled by level 2 and therefore, indirectly depend on, and could not function without, level 1 natural processes.

Based on Figure 1, it is clear that infrastructure planners must explicitly consider natural processes (level 1) when selecting the type of infrastructure (level 2) they plan to provide and when making decisions on where to locate infrastructure. Similarly, infrastructure planners must consider the type of services (level 3) they want to enable when making infrastructure (level 2) decisions.

Figure 1 also raises an important question about whether desired infrastructure outcomes must necessarily be provided by man-made processes. The Royal Society, in the context of defensive infrastructure options to improve resilience, examined Engineered, Hybrid and Ecosystem-based options for infrastructure and concluded that all have a role to play when planning for resilient societies (Royal Society, 2014). Similarly, a growing body of work on

Green Infrastructure (for example GLA, 2014) recent interest in Natural accounting, and Article 7 of the Water Framework Directive legislating for catchment management in favour of investment in new treatment infrastructures for drinking water supply (Dolan et.al, 2014), all demonstrate that in certain circumstances natural processes can do more than act as inputs to infrastructure.

Level	**Description**	**Elements**
1	Natural processes	Sunlight, air, water, wind, drainage, soil, minerals, heat
	Input Source / Output Sink	
2	Man-made infrastructure processes (inputs conversion into services/desired outcomes)	Power supply, telecoms, drinking water, sewage, transport, heating.....*other*
	Enabler	
3	Services enabled by infrastructure processes	Education, healthcare, business (services and industry), safety and security, recreation, tourism

Figure 1. Three levels of Infrastructure

This line of argument can be extended to demonstrate that in any situation where we want to use infrastructure to deliver desired outcomes, it is important that infrastructure planners are aware not only of the importance of natural processes as enablers of man-made infrastructure

(Figure 1), but also that infrastructure solutions can be sourced from anywhere on the continuum shown in Figure 2, including the direct use of natural processes as 'infrastructure-like'.

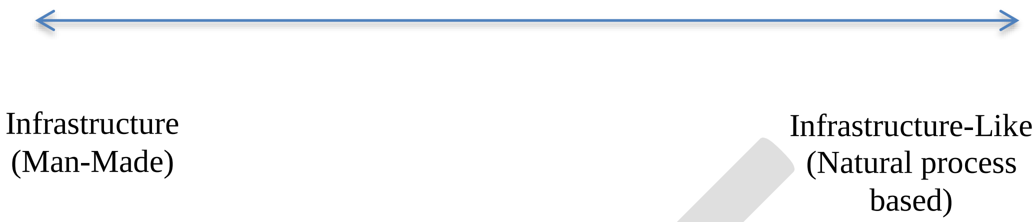

Figure 2. A Continuum of Possible Infrastructure Options

Possible examples of 'infrastructure-like' use of natural processes include buffer strips to minimise diffuse pollution run-off in agriculture and natural formations (e.g Chesil Beach), mangrove swamps and reed beds being used as flood defences. However, despite these examples, the potential for 'infrastructure-like' use of natural processes is currently undervalued and underappreciated.

Questions arising from Elaboration of this Statement:

1. What language should we use to communicate the significance of natural processes to infrastructure provision?
2. What role should the concept of natural processes providing 'infrastructure-like' outcomes play in infrastructure planning processes?
3. What other examples of infrastructure-like use of natural processes can be identified?

3 Discussion Statement B: Spatio-temporal Context

Statement: The local context into which infrastructure is introduced is shaped by natural processes, which are both temporal and spatial in nature. Acknowledgement of such issues should be central to infrastructure planning and 'one-size fits all' solutions recognised as inappropriate on this basis.

Elaboration: Explicitly including the concept of time when considering infrastructure is imperative to the concept of sustainability. Infrastructure operates over multiple time scales – even the same infrastructure might endure for centuries yet might change in nanoseconds. People handle this simultaneity of different time scales easily enough – we can appreciate an old bridge both for its history and heritage as well as for the way it feels to the touch or sounds in the wind. Yet, infrastructure planners, designers and operators rarely seem to consider this in their approach to infrastructure. Infrastructure evolves with respect to both man-made and natural processes – including climate change, use and material degradation – and we need to design for this evolution. When we build infrastructure today, we also need to design for the future, not only in terms of our view about how long it should last in its present form, but also how it will evolve, wither and die. How can it proceed through its entire life course and remain of benefit to society throughout, and how can we design it from the outset with re-use and recycling, in mind to keep these options open into the future? Currently we see this rather opportunistically: the non-use of a railway line that was not destroyed has become the High Line in New York; in London, Islington's Georgian houses morphed into apartments, then factories, then back to houses as use and need changed over the centuries.

The natural environment, when it encounters man-made infrastructure, also responds in a temporal way – organisms inhabit infrastructure, becoming in some cases partial contributors to its degradation. In some cases, infrastructure becomes eroded because of natural chemical reactions caused by human interventions: the erosion of steel reinforcing rods in bridges due to application of salts to prevent ice formation in winter being just one example. In other cases, natural processes are at work over time, such as the wind vortices around tall buildings and the effects of reflection of solar radiation. These spatio-temporal interactions arise over different periods of time. Some interactions are negative whereas some are positive, and in order to improve ‘sustainability’, we can encourage positive interactions as well as minimising or eliminating negative ones.

In addition to thinking about the simultaneous multiple scales of time, we also need to think about the fact that the human construction of time as represented by clocks is actually artificial. Although our wide utilisation of clocks can be attributed to the development of infrastructure itself (e.g.. the practical measuring of rail journeys), our body clock runs on a different time frame: following the initial experiments of Michel Siffre in the 1960s (Siffre (1963), the human diurnal cycle has been shown to average between 24.2 and 25.5 hours rather than the 24 hours we have given each day. In addition to this physiological difference, there is also our perceptual difference of time. Hammond refers to a study where people routinely miscalculated the time at which events in the past occurred, fairly consistently and their errors were sometimes in the order of decades (Hammond, 2013). We similarly routinely underestimate the duration of events in the future, yet we can detect microscopic fluctuations in time in the present, such as the subtleties of rhythmic change in music. This issue reveals itself in our daily use of infrastructure, such as when waiting for a bus. Here, our perception of waiting time is often exaggerated (up to 2 or 3 times longer than clock time) and influences our attitude towards this piece of infrastructure: many people are reluctant to use public transport due to this perception of time, instead choosing more polluting and energy-hungry modes of transport. The perception of time is clearly instrumental to human behaviour and thus must be considered in the design of our infrastructure in order to encourage more sustainable relationships.

Questions arising from Elaboration of this Statement:

1. How can we incorporate the perception of time in the design of our urban infrastructure?
2. How do we understand the relationship between the spatio-temporal environment and infrastructure in these terms?
3. How do we bring spatio-temporal environment needs into the policy and design objectives of urban planning?
4. How do we monitor the situation at the local level in order to obtain a city-wide assessment of the spatio-temporal environmental health?
5. Is a city-wide assessment of spatio-temporal inputs and impacts useful, or should everything happen at the local level?

4 Discussion Statement C: Balance

Statement: Sustainability requires a system-wide view and should incorporate the concept of 'balance' based on awareness of the importance of natural processes identified in A (and in particular sunlight, air and water). As the basis of many ancient practices addressing both human and environmental health, including Ayurveda and Traditional Chinese Medicine, the achievement of 'balance', can be a useful point of learning for sustainable infrastructure planning.

Elaboration: 'Balance' can be viewed as a necessary condition of sustainable infrastructure systems. It refers to a 'stability or steadiness due to the equilibrium prevailing between all the forces of any system' (OED, 1989). By maintaining balance within a given system, the system, as well as each of its individual elements, can continue to function at an acceptable level. After all, the sustainability of the system is both an emergent property of, and a requirement for, the sustainability of each system element.

Balance is a concept which has been applied to the health of the human body for thousands of years, where health is not merely the absence of disease. The approaches of traditional health systems such as Indian Ayurveda and Traditional Chinese Medicine are both fundamentally based on balance, or harmony. Ayurveda views the human body as a system of five universal elements found in the macrocosmic environment – air, fire, water, earth and space. Each body is considered to have its own ideal constitution of elements, which should ideally be in balance. Health is obtained by maintaining this balance and illness results from an imbalance. Traditional Chinese Medicine also views the healthy body as a microcosm of the external environment, but this time in terms of two types of energy – yin and yang – which describe opposite characteristics of the same phenomenon. Again, health is an outcome of maintaining this balance and healing is aimed at restoring it. A body out of balance is not in a position to heal with any superficial treatment, whereas a robust and resilient body can rejuvenate and protect itself. Thus the process of healing aims to restore balance to the underlying bodily system – not just the area under illness – in order for it to be able to heal itself and resist further illness in the long term.

Because the body and the environment are interdependent, we require healthy external environments to enable individual health and the health of our societies. For most living creatures – plants, animals and people - natural processes such as sunlight, air and water identified as 'first-level' infrastructure elements (see Table 1), can be seen as the building blocks of survival and sustainability. However, in the design of our infrastructure systems, we are clearly affecting the balance of these processes i.e. we use them as input sources and output sinks for our infrastructure (see **Error! Reference source not found.**), without considering the consequences. As a result the climate is changing, in many parts of the world air is increasingly polluted, and water is often undrinkable without treatment. Rather, an imbalance of these natural processes can be seen to have evolved through our own imbalanced infrastructure systems. Yet as balance is an important concept underpinning health and ultimately sustainability, maintaining the balance of the core natural processes of sunlight, air and water can therefore be seen as essential to achieving sustainability. Thus we propose the application of the notion of ‘balance’ to the design of future infrastructure systems, in order to create more robust, resilient and ‘healthy’ environments.

Questions arising from Elaboration of this Statement:

1. What is the meaning of a ‘healthy’ infrastructure system?
2. How can the notion of ‘balance’ be applied to the planning of our infrastructure systems, particularly in regards to supporting a balance of natural processes?
3. How can we design more ‘balanced’ infrastructure systems at various system levels and scales.
4. How can the achievement of ‘balance’ in the functioning of our infrastructure systems contribute to more resilient infrastructure, sustainable natural systems and wellbeing?
5. How can more balanced natural systems help contribute to more sustainable infrastructure, and vice versa?

5 Discussion Statement D: Value vs. Growth

Statement: Sustainability as stated is driven by the need for economic growth: however we should ask if economic growth is actually a suitable objective, or if we should be prioritising social and environmental sustainability even if economic growth is zero (or even negative). Promoting Value rather than growth is arguably a better objective.

Elaboration: If we allow the objective of achieving economic growth to become the primary driver of infrastructure decision making, we are unlikely to make infrastructure investments that give rise to a sustainable long-term infrastructure. Sustainability criteria cannot be retrospectively applied to decisions that have already been made. Infrastructure investments that are less destructive/resource intensive than they would have been had a sustainability filter not been applied to pre-made decisions are not sustainable, they are merely less unsustainable.

Making economic growth a requirement for investment presupposes that such growth is a good thing. Growth has a tendency to exacerbate the inequality in society – the rich become richer and the poor become poorer – unless measures are taken to curb inequity. A simple example might be the price of housing – as house prices increase, so the cheaper housing becomes unaffordable to more people. The 'growth' is illusory because it is only if a house owner leaves the market altogether that they actually realise the benefits of the price increase. For those finding it difficult to enter the market, the increase in price makes the difficulty increasingly impossible. Salaries have to increase in order for the house owners to be able to continue to afford ownership, which then puts up the prices of other commodities, including those for people who are not yet in the housing market. Thus the lives of poorer people become worse, rendering this society unsustainable.

It is not always the case that infrastructure planning is based on suitable objectives. Too often it is driven by the desire to meet lower-level aims such as 'build a metro', or 'increase capacity' rather than a clear understanding of what society needs and thus how infrastructure might be able to contribute to achieving these societal aims (desired outcomes). Much of this is due to the fact that we do not educate planners or designers to identify the problem that is there – we prefer to train them to respond to the demand that 'something is done'. This is just bad decision-making practice. By setting those desired outcomes as the driver for every decision in the planning and design process, we can determine what factors would lead to successful achievement and what would led to limitations or even failure to achieve them. The actions – the implementation of the decision – are then those that maximise the success factors and minimise the limitations. If this approach is taken, the perceived uniqueness of the importance of the economic case for the infrastructure reduces in importance in the face of more important factors. The economics/finances become facilitators of achieving the outcome, rather than the outcome itself. This change of emphasis makes it easier to conceptualise holistic actions that seek to address whole problems, rather than just those that happen to meet appropriate – and arguably arbitrary – financial or economic criteria.

To bring these two themes together – the sustainability of society through infrastructure and the relative benefits of one potential scheme over another – it is useful to consider the concept of Value: comparing the relative Value of the two schemes would be a useful way to support a sustainable decision.

The concept of Value Engineering was introduced by Larry Miles in the 1950s to record the benefits of evaluating the value of products, considering their functionality rather than their price (Miles, 1989). Functionality is seen as the set of functions that the product could provide. For Miles, Value is the ratio of functionality to cost. Functionality suggests something about the extent to which the functions actually work: does the function satisfy the need? However, the concept can be brought into the social domain by considering that 'functionality' can be determined by people – in the sense that for something to function it must successfully achieve a reasonable proportion of the aspirations people had for it. So there is a sense in which value of a product or project is an account of how satisfied people are with its functionality.

Functionality can be seen to be satisfaction compared with a more general use of resources (i.e. not just financial cost). So, what is meant by 'satisfaction'? Tyler suggests that if someone aspires to do something, then the extent to which they manage to achieve it is a mark of the extent to which they have satisfied their aim (Tyler, 2015). So *Satisfaction* can be considered to be the measurement of *Achievement* compared with the originating *Aspiration*. Perhaps *Satisfaction* is *Achievement* compared with the *Aspiration* involved in trying to increase sustainability. We can now consider *Value* to be *Achievement*, compared with *Aspiration*, given the required *Use of Resources* and can represent this shift in a series of relationships, starting with Larry Miles's original equations:

$$Functionality = \sum_{i=1}^{n} function \qquad (1)$$

$$Value = \frac{Functionality}{Cost} \qquad (2)$$

To be acceptable, *Functionality* should signify the satisfactory result of the various functions so we can widen the concept of 'cost' to include resources in general, including financial, human, environmental etc. So:

$$Value = \frac{Satisfaction}{Use\ of\ Resources} \qquad (3)$$

However, the definition of *Satisfaction* for these purposes is actually the extent to which the *Activities* manage to achieve the *Aspirations* which are driving the initial wish to improve the state of wellbeing. So:

$$Satisfaction = \frac{Achievement}{Aspiration} \tag{4}$$

Rearranging the Value equation then gives a relationship between Value, Achievement, Aspirations and the Use of Resources, to give an 'enhanced' view of Value:

$$Value = \frac{Achievement}{Aspiration \times Use\ of\ Resources} \tag{5}$$

This sequence suggests a rethinking of engineering, planning and design, from the 'hard' 'nuts and bolts' product-based approach (which drove the original concept of Value Engineering) view of functions in Equations (1) and (2), towards a softer view, which requires in addition the understanding of the psychology, anthropology and culture that jointly define context for the generation of those aspirations and the sense of wellbeing as exemplified in Equations (3), (4) and (5). The sequence shows the shift in emphasis from function to aspiration and achievement – and we can see this as a useful driver for sustainability. It then follows that we should aim for an increase in functionality in our infrastructure, in order to create a greater Value in terms of achievement of aspirations, rather than simply aim to increase economic growth.

Questions arising from Elaboration of this Statement:

1. How do we establish the *Functionality* of infrastructure and calculate its *Value* in terms of social as well as technical outcomes?
2. How do we construct a suitable multicriteria appraisal tool that can provide consistent assessments of holistic views of the problem?

3. How do we respond to the inevitable issue of how to pay for a project, and how this compares with other projects in terms of priority – currently done mainly by economic factors, but now should be done by a more sustainable environmental approach?

6 Conclusions

From the elaboration of the discussion statements (**Error! Reference source not found.**), four cross-cutting themes emerge (**Error! Reference source not found.**):

Table 2. Cross-cutting themes

Natural Processes: The importance of natural processes to sustainable infrastructure and their potential to deliver infrastructure outcomes rather than just be inputs to infrastructure
Spatio-temporal Context: The need to incorporate multiple simultaneous timescales and the flexible nature of human perception of time so that the planning design and operation of the local context takes into account its spatio-temporal characteristics
Balance: The importance of balance in sustainable infrastructure and the need for a systemic perspective including the elements of natural processes such as air, water and sunlight (see Figure 1)
Value vs. Growth: The role infrastructure can play in supporting growth in Value, rather than just the economy and sustainability

We can view these four themes as important factors of sustainable infrastructure that should be considered in their design. We suggest that in order to achieve sustainability, it is necessary to expand our perception of infrastructure to include the first layer of infrastructure as natural processes. Furthermore, we emphasise the need to consider the balance of these elements, over time and with respect to their individual contexts. Finally, we call for a reassessment of our search for economic growth with respect to a more holistic and value-based engineering.

It is clearly no longer sufficient to respond to any perceived need for infrastructure with solutions we have used previously and therefore assume are the ‘obvious’ solution (i.e. we need to challenge assumptions when planning infrastructure, for example is building additional roads capacity always the most appropriate response to congestion?). Before any infrastructure decision is taken, the root cause of the perceived need and its context need to be understood, as do the outcomes society desires from any solution to the perceived problem. This White Paper intends to raise these needs.

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