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Framing flexibility: Theorising and data mining to develop a useful definition of flexibility and related concepts

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ARTICLE INFO

Article history:

Available online 17 June 2011

ABSTRACT

Flexibility is a term used in various fields with widely differing interpretations. Moreover, several related concepts, such as *adaptability*, exist that have an overlap in meaning or are simply used synonymously. This article presents a framing of flexibility, and three concepts with which it bears a close family resemblance, for the use in the context of infrastructure constellations. The definitions proposed in this frame draw inspiration from existing literature, though they are not based upon a classical literature review. Rather, a usable set of definitions is proposed for the intended context. The definitions all have the same structure to better appreciate how the concepts are related and how they differ. To verify whether the definitions correspond to their practical use, a data-mining exercise is performed on over 11,000 scientific articles that use the concepts of flexibility. After the corpus of articles is identified that is close to the intended field of application (infrastructure constellations), a co-occurrence analysis is carried out in order to clarify the differences between the concepts and to give nuance to the meaning conveyed in the definitions.

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1. Introduction

The concept of flexibility applies very much to itself. The word is used in various contexts with varying meanings, conveniently meeting diverse needs. Moreover, there are many that have a similar ring to them and are used in similar contexts. But, convenience can lead to confusion.

In this article, the discussion of the concept will be restricted to its use in relation with infrastructure systems. The realisation that infrastructures are typically in place for decades or more, while demands and circumstances can change on much smaller timescales, makes the idea of a flexible infrastructure attractive. That there are many possible futures confronts society with large, and deep, uncertainties, and if infrastructures could be so flexible to accommodate those unforeseen changes in demand, function, or availability of resources, this would be highly beneficial.

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In this manner, flexibility and related concepts have been proposed as ways to deal with the uncertainties that the future holds. Just to give some examples from different viewpoints: Allen and Torrens [1] suggest, in the course of a theoretical discussion introducing their special issue, that “adaptability and flexible response” are success factors in strategies, rather than “prediction, planning and control”. In that same issue, Artigiani [2] argues from examples from naval history that systems need to be adaptive to survive under changing circumstances. Walker et al. [3] discuss a number of articles that outline actual adaptive approaches to deal with the deep uncertainties of the future.

Thus, having established that research on flexible infrastructures could benefit society, and acknowledging that it is researched from various perspectives, what about research on the *concept* of flexibility in this context? To assess what possible solutions can be found to make infrastructures more flexible, it is important to make clear what exactly is meant by a flexible infrastructure. Only then can the investigation be systematic and the findings discussed in comparison. In other words, clarifying the concept can make research on what it refers to more scientific.

This article puts forward a conceptualisation of infrastructure systems, presenting a framework drawing from the field of policy analysis [4], as well as the study of societal transitions [5] and socio-technical systems [6]. Using this, *flexibility* and the related concepts are framed and an encompassing definition for each and all is constructed. Which is to say, each definition of each concept will have the same form. In this manner, the concepts will not only be defined by their definition, but also by contrast – by how the definitions differ.

To demonstrate the validity and usefulness of this framework in a scientific manner, these differences will be compared with ‘empirical reality’. Because “meaning is use”, as Wittgenstein [7] already knew, the empirical test of a definition would be comparing it with the actual use of the concepts it refers to. In this article however, the empirical check will be whether the *differences* between the definitions reflect the differences in use of the concepts. Though this might seem an indirect approach, it is actually more appropriate for the aim of this article, since here the definitions are proposed for a specific context – infrastructures – which might cause them to deviate from other formulations.

The use of the concepts in scientific literature – the relevant empirical reality here – will be explored systematically using data-mining techniques. The ISI database will be queried for articles containing the word ‘flexibility’, its relatives, and the word ‘infrastructures’. The titles and abstracts retrieved will be analysed for their latent semantics in order to identify *discourses*. From these discourses, the one that is ‘closest to home’ in terms of research field will be selected, i.e. the discourse closest to policy analysis for infrastructure systems. Subsequently, within this discourse, the difference in use of flexibility and related concepts is studied by analysing their co-occurrence with certain disambiguating words – words that one typically associates with, say, flexible, but not with adaptive.

2. Context and conceptualisation

2.1. Context

Flexibility and flexible, derive from the Latin verb *flectere*, meaning to bend. This suggests already a number of things. First, that flexibility is a property, an ability of *something*, something endowed with a capacity, be it metaphorically, to bend, to change shape. Second, bending implies that some external force is applied; the something is flexible to some other thing or influence. Third, bending contrasts with breaking, suggesting that whatever is flexible can undergo change without changing itself. Fourth, bending is antonymic to stiffening, or becoming rigid, which are also ways to undergo change without changing.

The first meaning of flexible – and the one with the oldest uses – in the Oxford English Dictionary (second edition, 1989) states:

A. *adj.*

1. a. Capable of being bent, admitting of change in figure without breaking; yielding to pressure, pliable, pliant. **1548** HALL *Chron.*, *Edw. IV*, 212 Like a rede with every wind is agitable and flexible. **1562** W. BULLEIN *Bk. Sicke Men* 81a, Feele also the pacient..whither the partes be pained, or flexible, or haue loste their strength and are stiffe. **1606** SHAKES. *Tr. & Cr.* I. iii. 50 When the splitting winde Makes flexible the knees of knotted Oakes. **1626** BACON *Sylva* §796 And you shall finde. the Stalke harder and less Flexible, than it was. **1664** POWER *Exp. Philos.* I. 42 It hath a Cartilaginous flexible Tube or Channel. **1731** ARBUTHNOT *Aliments* ii. (1735) 40 An Animal, in order to be moveable, must be flexible. **1802** BINGLEY *Anim. Biog.* (1813) II. 373 These parts, with the tail, are covered by a strong flexible skin. **1823** W. PHILLIPS *Introd. Min.* *Introd.* 9 A flexible granular quartz is found in Brazil. **1874** BOUTELL *Arms & Arm.* ii. 17 The long, flexible and pointless weapons that are described by the Roman historians.

Words with a meaning close to flexible, or having overlap with it, are abundant, even when one restricts oneself to the context of infrastructure systems. Think for instance of words like *robustness*, *adaptivity*, *resilience*, and such. All these terms seem to entail a form of dealing with changing or changed circumstances. The differences in meaning appear to lie either in how this is accomplished or in the nature of the change in circumstances. For example, resilience seems to suggest the capability to resume normal functioning after a shock, whereas adaptivity seems much more to imply a change in normal functioning in response to a more permanently changed situation.

Before the differences and commonalities can be elaborated in a more systematic way, it is necessary to clarify what the subject is to which these properties apply. In other words, it is time to ponder somewhat on the topic of infrastructure systems.

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