A MATRIX FRAMEWORK FOR ASSESSING SUSTAINABLE HOUSES AND COMMUNITIES RESEARCH IN UK URBAN AREAS

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ABSTRACT. Methods for assessing the sustainability of urban areas comprehensively and systematically are needed urgently, yet the lack of an unambiguous definition of sustainability and a shortage of definitive evidence make the task of identifying sustainable and unsustainable urban forms insurmountable. Focusing on the UK urban domestic sector, considering how houses and their residents integrate with the wider urban environment, a matrix-based framework that is modular and flexible has been developed such that it is clear and comprehensive, while being able to adapt to our expanding knowledge over time. The matrix takes as strategic overview, and is not applicable at the project level. The matrix's axes represent *Sustainability Issues*, and *Aspects of Houses and Communities* while each element represents a *Relationship* based on current knowledge and theory.

Keywords: Sustainability, Sustainability Assessment, Housing, Matrix

1. INTRODUCTION

Sustainability is an evolving concept, the "Brutland Report" [1] is often cited as laying the foundations of Sustainable Development but failed to provide an unambiguous definition. While the lack of a clear definition is not necessarily a problem, as it allows sustainability as an ideology to evolve over time, it does present a problem for applying sustainability in practice, especially by non-expert parties. Hence, there is a need for ways to assess sustainability objectively with tools that are easy to use yet are able to accommodate our evolving understanding of sustainability. The goal of this paper is to produce a framework for collating and assessing sustainability research that can adapt to new discoveries, and present the latest knowledge in a clear and concise way so that it can be used as a tool for researchers.

The use of a matrix-based approach to sustainability is not new. The approach presented in this paper differs in that it does not adopt a "tick box" approach; therefore using the matrix will not produce a "sustainability score" or demark the object of study as either sustainable or unsustainable. Instead, it will inform the user about how different sustainably issues interrelate and connect with different parts of the built environment. Hence, the matrix presented in this paper is unfinished, and always will be, as it is necessary constantly to add new knowledge to the matrix to keep it up to date.

The matrix has been designed considering sustainability at a strategic level, therefore considers sustainability at the city or national scale. The matrix was developed to help research into the housing in the United Kingdom (UK) and therefore focuses on Sustainability Issues from a UK perspective. A proposed matrix is shown in Figure 3.

2. SUSTAINABILITY ISSUES

Sustainability is often divided into Environmental, Social, and Economic subcategories [2]. There is debate whether the pillars should be integrated or segregated [3]. The benefit of

integration is a more comprehensive assessment; the risk is that economic issues may dominate over social and environmental ones, and that the bias to economic issues may be hidden.

2.1 Environmental Sustainability

To begin to form the matrix, a list of sustainability issues must be compiled. The level of detail each issue represents must be considered. For example, is pollution categorised as a single issue or is every different pollutant its own individual issue? Life Cycle Assessment (LCA) Software can now consider hundreds of pollutants [4] including each one would make the matrix unwieldy. ISO 14040:2006 and ISO 14044:2006 outline procedure for LCA but do not specify what environmental aspect to consider [5], [6]. Others have written extensive guides on LCA [7–9]. Table 1 shows several different categorisation system used in different LCA systems, where possible similar categories have been compared.

TABLE 1. Variation in environmental harm categorisation in selected LCA guides

CML [7]	**BEES** [8]	**Green Guide** [9]	**GaBi 4** [4]
Depletion of Abiotic Resources		Mineral Resource Extraction	Resource Depletion
	Fossil Fuel Depletion	Fossil fuel depletion	
Depletion of Biotic Resources			
Greenhouse Effect	Global Warming	Climate Change	Global Warming Potential
Depletion of Ozone Layer	Ozone Depletion	Stratospheric Ozone Depletion	Ozone Depletion Potential
Human Toxicity	Criteria Air Pollutants	Human Toxicity	Human and Eco Toxicity Potential
	Human Health		
	Indoor Air Quality		
Ecotoxicity	Ecological Toxicity	Ecotoxicity to fresh water	
		Ecotoxicity to Land	
Photochemical oxidant formation	Smog	Photochemical ozone creation	Photochemical oxidant creation potential
Acidification	Acidification	Acidification	Acidification Potential
Nutrifaction	Eutrophication	Eutrophication	Eutrophication Potential
Radiation		Nuclear Waste (higher level)	Ionising Radiation
Odour			Odour
Noise			Noise
Waste Heat			
Working Conditions			
Desiccation		Water Extraction	
Physical Damage to ecosystems	Habitat Alteration		
Damage to the landscape			Land Use
Direct or indirect human victims			
		Waste disposal	Land fill demand

As the table shows, there is no consensus on terminology what constitutes environmental harm, although there are many common themes. These themes have been incorporated into the Matrix to form 18 broad environmental sustainability issues. All of the examples in Table 1 include discussion of pollutants that are toxic to humans; in this framework, Human

Toxicity is considered part of the Health & Wellbeing Issue under Social Sustainability to avoid duplication.

2.2 Social Sustainability

Social sustainability, is less well defined than environmental sustainability [10], and has only more recently been integrated into assessments [11]. There are many different definitions of social sustainability all definitions highlight the need to meet all people's basic and aspirational needs [12–15]. Many of the precepts of social sustainability are pre-existing ideals such as justice and equality. Vallance *et al* [16] after an extensive literature review [17–19] identified three broad types of social sustainability. *Development Sustainability*; is meeting the basic tangible and intangible needs of people. *Bridge Sustainability*; is achieving the behaviour change needed for environmental sustainability. *Maintenance Sustainability;* is meeting people's need to preserve traditions and ways of life. Each of these sustainability types can complement or conflict with each other. The most obvious case is the conflict between the changes in lifestyle required by Bridge Sustainability, and the resistance to change from Maintenance Sustainability.

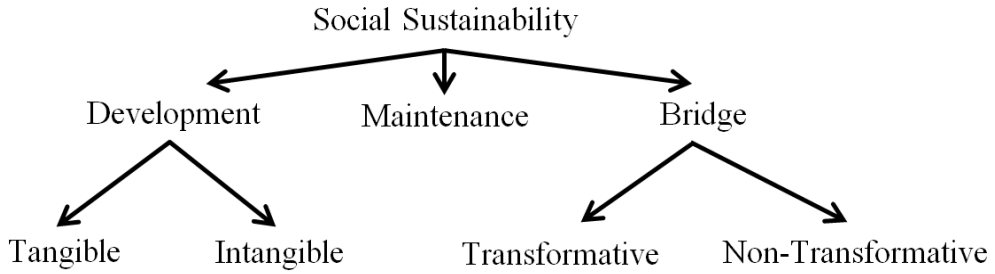

FIGURE 1: The Structure of Social Sustainability, adapted from Vallance *et al* 2011

The changes required by Bridge Sustainability can be divided by where they have a transformative effect on people's lives. Transformative changes are adopted more slowly than non-transformative because of people need for Maintenance Sustainability.

There is an emerging body of literature on the intangible aspects of Development Sustainability [10], [11]. The importance of inclusive and equitable communities with good access to decision makers [20] has been highlighted, and has resulted in policies to create mixed communities, with varied success [10]. Within the matrix, there are 16 social sustainability Issues (9 Development, 4 Bridge, 3 Maintenance). The different number of issues does not reflect relative importance, but rather the nature of the issues. Maintenance Sustainability Issues are often better defined and understood, whereas Bridge and Maintenance Issues are more malleable.

2.3 Economic Sustainability

Literature on sustainable economics has a different nature to that on environmental and social sustainability. Whereas environmental and social issues are discussed in isolation, economic sustainability is almost always [2], [21–23] discussed within the context of the other two forms of sustainability, as unviable economic activities are not usually discussed. The Economists' lexicon does provide metaphor for the assessment of sustainability. Capital, to the economist, is "a stock of instruments existing at an instant of time," [24] alternatively, a pool of resources (money). Capital can be spent on consumption or invested to produce more capital. The maximum sustainable consumption would equal the amount of new capital

produced from reinvestment, thus the original capital is never depleted, and consumption can be maintained indefinitely. The metaphor of capital can be extended by the process of monetization [21] to social and environmental issues. Five capitals are often highlighted [21]:

Natural: All natural resources, processes, and systems;
Social: The networks between people and organisations;
Human: The value people create from knowledge, skills, and work;
Manufactured: Material goods, infrastructure, and buildings;
Financial: Money and debt.

In theory, each capital can be valued in a common unit of currency and any decision taken can be assessed against the gains and losses of each capital. Within this process, the 'weak sustainability' approach allows each form of capital to be interchanged, while the 'strong sustainability' approach does not [21]. From the five capitals the 'genuine' savings rate, an environmentally adjusted GDP, can be calculated [25]. To allow this kind of measurement, many counties have adopted environmental accounting techniques [26] which have developed into the System of Environmental-Economic Accounting (SEEA) [27]. All of these techniques rely on a pre-existing assessment of the environmental issues and merely absorb them into the economic analysis. It is therefore postulated that, 'Economic Sustainability' is merely a description of an economy, which achieves social and environmental sustainability.

The current economic crisis has been described a problem of unsustainable business practices [28]. In this case, the sustainability being discussed is a homonym, while on the face addressing similar concerns of behaviour which cannot be sustained [29], it does not sit within the philosophical framework of sustainable development. 'Economic sustainability' meaning avoidance of economic crises is synonymous with 'economic stability' [30]. Economic stability is likely to be practical prerequisite for sustainability, thus a new interpretation of existing sustainability thinking is presented below.

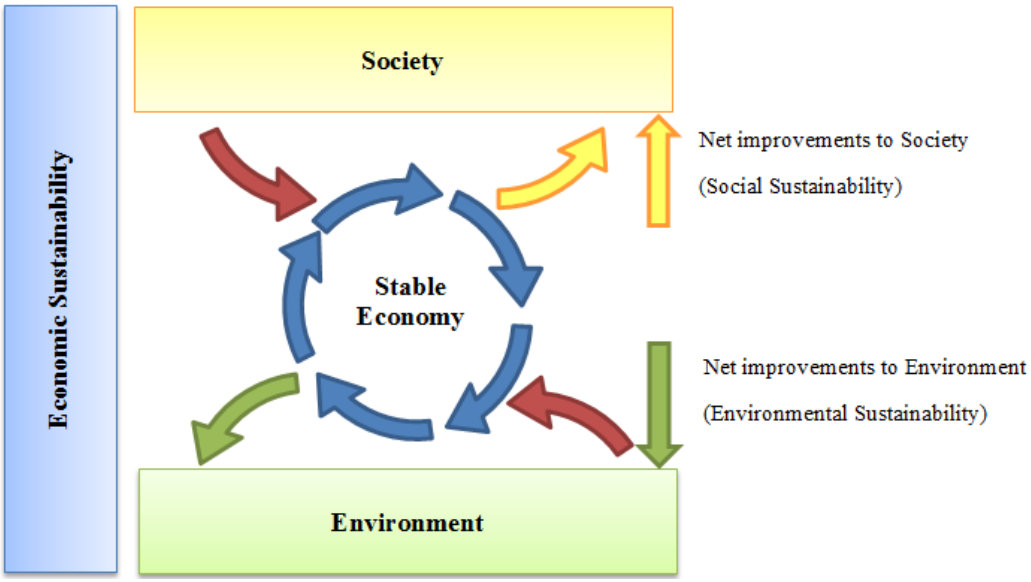

FIGURE 2. The sustainability framework adopted in this paper. Economic Sustainability covers the three areas, Social Sustainability, Environmental Sustainability, and Economic Stability.

Figure 2 illustrates how the sustainability framework adopted in this paper differs from previous descriptions of sustainability by having economic sustainability as an overarching perspective of social sustainability, environmental sustainability, and economic stability.

Economic sustainability is achieved when a stable economy is environmentally and socially sustainable. There may be ways, other than economic, to gain a complete sustainability perspective, but they are not covered in this paper.

2.4 Economic Stability

If economic sustainability is removed from the core of the sustainability issues, economic stability issues must remain to link the interactions between society and the environment. The International Monetary Fund (IMF) describes economic stability as "avoiding economic and financial crisis [and] avoiding large swings in economic activity" [30]. Since 2007 the IMF has monitored global economic stability using six groups of risk indicators [31]:

Monetary and Financial Conditions, the availability and cost of funding linked to global monetary and financial conditions;
Risk Appetite is the willingness of investors to take on additional risk by increasing exposure to riskier asset classes and the consequent potential for increased losses;
Macroeconomic Risks are shocks with the potential to trigger a sharp market correction, given existing conditions in capital markets;
Emerging Market Risks are the underlying fundamentals in emerging markets and vulnerabilities to external risks;
Credit Risks are changes in, and perceptions of, credit quality that have the potential for creating losses resulting in stress to systemically important financial institutions;
Market and Liquidity Risk is the potential for instability in pricing and funding risks that could result in broader spillovers and/or mark-to-market losses.

The IMF uses a range of different data sources including third party indices to compile the risk level for each of the six indicators on a scale of one to ten. These six indicators have been used in the matrix to represent the Issues of global economic stability. Other authors have developed alternative methods of measuring financial stability [32]. For the matrix, the exact measures of stability are not as relevant as the identification of the main issues for economic stability.

The IMF approach to stability measurement focuses on national and international measures. The local economy is also likely to play a role. At the time of writing, the UK Government's Department of Environment and Rural Affairs DEFRA are consulting on updating their Sustainable Development (including economic) indicators [33]. These indicators are targeted at the national and regional level. There is some overlap between the DEFRA and IMF measures, as well as overlap between DEFRA economic measures and the Social Sustainability measures discussed above. As this framework covers socio-economic issues under social sustainability, only debt, costs, and income issues are included in the economic stability section of the matrix.

3. ASPECTS OF HOUSES AND COMMUNITIES

Houses and communities have been divided into three broad categories. *Dwelling Characteristics* describes characteristics, both internal and external, of houses. *Built Environment* describes the all aspects of the city outside the house. Finally, *Resident Population* describes the socio-economic, demographic, and behavioural characteristics of the resident population.

3.1 Built Environment

In this paper, the Built Environment is being used as an all-encompassing term for the shape, size, and arrangement of the city. Common areas of discussion in the literature are Land Use [34], Transport and Connectivity, and Infrastructure [35]. Many different urban structures and combinations have been proposed, and adopted around the world, and there is much debate about whether cities should be dense or sprawling, with the evidence suggesting that there is no single solution [36–38]. In this framework, the built environment has been divided into two categories: Urban Land Use, and Infrastructure.

Urban Land Use includes the characteristics of both that land use and the effects of different distributions of land use. Distribution of land use can manifest at both the micro and macro scale. At the neighbourhood level, there can be large areas with a single land use, e.g. a park, or a mix of different land uses. While at the city scale, different areas of residential, commercial, and industrial can be identified. The final aspect, Density, is a complex concept [39], which covers all the other land uses included in the matrix. High-density areas are typically associated with a reduction in green space and an increase in building height, although that is not always the case in reality [40]. Density can be used to describe both the distribution of people or buildings within an urban area [39], and can have different meaning when measured over different scales (site, neighbourhood, city). There is a significant body of research into the effects of density [41–44] which is therefore was included, despite its vague definition.

The Infrastructure category includes the main types of basic infrastructure present in the city: Energy, Water, Sanitation, Waste, and Communications [45]. Infrastructure also includes Transport and Connectivity, and Community Services such as schools and shops. While the community services category is vaguer than the others are, it was chosen to avoid listing every type of facility that is used by a subset of the community, such as churches. Whereas the specific types of infrastructure listed above have almost universal usage in developed countries [46].The Transport and Connectivity aspect, concerns how well the transport network connects each part of the city for each of the different modes of travel. How streets are interconnected out can have a significant impact on cities [47], [48], and influence the mode of transport chosen.

3.2 Dwelling Characteristics

Shelter is a basic human need, it is know that poor housing supply effects macroeconomic instability [49], and that poor quality housing results in ill-health, accidents, and even fatalities [50]. As the matrix was created to study the sustainability of first-world housing, the domestic characteristics are heavily represented in the matrix, whereas the characteristics of other urban buildings are excluded.

Study and assessment has be undertaken for many aspects of the dwelling including Energy Performance [51], Health and Safety [52], Internal Space [53–55], Crime Resistance [56], Water Consumption [57] and Value [58]. From which, many housing standards have been produced [51], [56], [59–61]. All of which interact with the Sustainability Issues highlighted above. In the matrix, dwelling characteristics have been divided into Physical, Economic, and Social to cover both the tangible (Physical) and intangible (Economic & Social) characteristics a dwelling can have.

3.3 Resident Population

The populations of cities have been studied for decades. Both the demographics and the wider socio-economic context of the population will have an effect on sustainability issues. It is well understood that low or no income, lack of education, poor health, and crime are causes and symptoms of poverty [62]. When considering the affect that the built environment has on social sustainability the differing socio-economic backgrounds of the residents must be accounted for. The categories selected for the matrix represent a basic set of often-measured [63] socio-economic characteristics.

While demographic differences can explain much of the difference between communities, research has highlighted that culture also plays a role, and that the same behaviour can be viewed differently by different social groups [64]. Therefore, a behavioural section is also included in the matrix to over research in this area [65], [66]. Behavioural characteristics may also correlate to demographic characteristics and so the interactions between these two categories should be considered.

4. RELATIONSHIPS

The intersection of each Sustainability Issue and each Aspect of Housing and Communities represents a relationship; these relationships are embodied by the published literature on the subject. For example, cell A6 represents the relationship between Green Space and Health & Wellbeing. Depending on the nature of the relationship and the amount of available literature, relationships fall into the categories show in Table 2. Any particular paper may cover more than one relationship.

Categorising the relationship immediately highlights where there are gaps in knowledge, and can show how many papers have been published on a particular topic. Ultimately, each cell in the matrix could contain a number identifying the number of papers on that topic, and colour coded to express the level of certainty in the research.

TABLE 2: Categories of relationship used in the matrix

Increasing Certainty →	■ Unrelated (Black)	Aspects and Issues are proven to not be related
	■ Self-Defined (Grey)	The Aspect and Issue are the same
	■ Quantitative Relationship (Green)	Causal Relationship is well understood in the literature and can be quantified
	■ Statistical Relationship (Blue)	Relationship is understood and correlation can be shown in the literature
	■ Qualitative Relationship (Pink)	Relationship is understood qualitatively but not quantitatively
	■ Conflicting Evidence (Orange)	Literature provides conflicting evidence for the nature of the relationship
	■ Known – Unknowns (Red)	Literature provides no conclusive information on whether the issues are related
	□ No Data (White)	No available literature

Only certain types of reference are suitable for the matrix, papers that include primary research or new analysis of secondary data are applicable, while theoretical research that does not yet have strong evidence is not suitable for inclusion, because they are not compatible with the categorisation discussed above.

5. GREEN SPACE EXAMPLE

Green space has been selected as an example that touches on a range of Aspects and Issues; the aim of this section is not to present new work on sustainability of green space or perform a comprehensive literature review of the topic, but to demonstrate the working of the matrix.

Although green space has been selected as the Aspect to be studied, there are complementary Aspects of interest. External Private Space (Row 20) and Public Space (Row 5) are all similar to Green space (Row 6) and so the researcher could choose to include or exclude these aspects in their search. If the researcher chooses to consider all three Aspects, they will need to consider up to 132 relationships with the 44 Sustainability Issues.

In practice, not all the relationships will be of interest. For example, out of the 3.9 million articles on green space [67] the authors were unable to find research linking the amount of green space to people's access to government. Thus, there would be far less than the theoretical maximum number of relationships to investigate. The researcher may also wish to focus on a selected number of Sustainability Issues due to their research aims.

Having identified the relationships of interest, the researcher will immediately be informed of the strength of the evidence (by the colour of the cell) and the number of relevant papers (by the number within the cell). Depending on the nature of researcher's work, they may be interested in areas of strong or weak evidence.

The researcher could view a specific relationship, e.g. Green Space vs. Health & Wellbeing [68] and see the constituent papers what have been used to categorise that relationship, hence the researcher has a detailed literature list on that topic. The matrix is not unidirectional, and researcher can start by investigating a Sustainability Issue, or investigate the interconnections between different Sustainability Issues.

6. ONLINE MATRIX

The proposed sustainability matrix is only useful if it contains up-to-date data, the volume of data required to complete the matrix is too large for the author to collate alone. Therefore, an online version of the matrix is under development and will be available at www.sustainableresearch.org containing a reference list contributed by the authors. This matrix is in on-going development and will eventually allow other academics to contribute references to the matrix by registering with the site. The matrix will allow users to see the references contained within the matrix. This will allow researchers to understand the balance of evidence for each relationship, and go beyond the initial categorisation.

7. PRELIMINARY FINDINGS AND LIMITATIONS

As stated above more references need to be added to the matrix before it will become a useful reference tool. A few innate limitations in the matrix's design should be acknowledged: Firstly, the framework is limited in its ability to consider international sustainability issues as it focuses on the direct relationships between the built environment and sustainability, which

will tend to emphasize local effects. Secondly, condensing many research papers down into a single categorising may be problematic if the evidence from different papers carries different strengths of evidence. For example, if a small preliminary survey conflicts with a large-scale longitudinal study. Correctly handling conflicts of evidence will be critical to the matrix's usability. Finally, the selection of categories is likely to have involved some unavoidable subjectivity on the part of the authors. The matrix form can easily adopt new categories, or combine exiting ones, if the selection of categories is limiting, but this risks producing an explosion of categories and undermining the clarity of the matrix.

8. CONCLUSIONS

The purpose of this paper was to investigate a new way to interpret current research into the sustainability of houses and communities in urban areas of the UK. In the current literature, specific social and environmental sustainability issues can be identified, while economic sustainability is commonly viewed as an economic analysis of environmental and social sustainability. By comparing social, environmental, and economic Issues against different Aspects of Housing and Communities, it is possible to produce the matrix-based research tool shown in Figure 3. This tool is intended to allow researcher to understand current level of knowledge and quickly identify how different Sustainability Issues and Aspects of Housing and Communities interact. This paper has outlined the process of creating the research tool, but the tool will only become useful once it is populated with references. To this end an online version of the matrix will be developed such that researcher can access the information and ultimately contribute new references.

This research tool could facilitate better integration between different disciplines by highlighting areas of complementary and conflicting research, and revealing gaps in knowledge. As sustainability is an evolving concept, the matrix-based format allows the categorisation of issues to be changed over time, thus the framework itself can adapt to changes in knowledge. Ultimately, a completed matrix could be used as a starting point for any research within the field. The matrix could also be used by planners and developers to produce assessment tools that are more sensitive to the interconnectedness of many of the problems faced by cities.

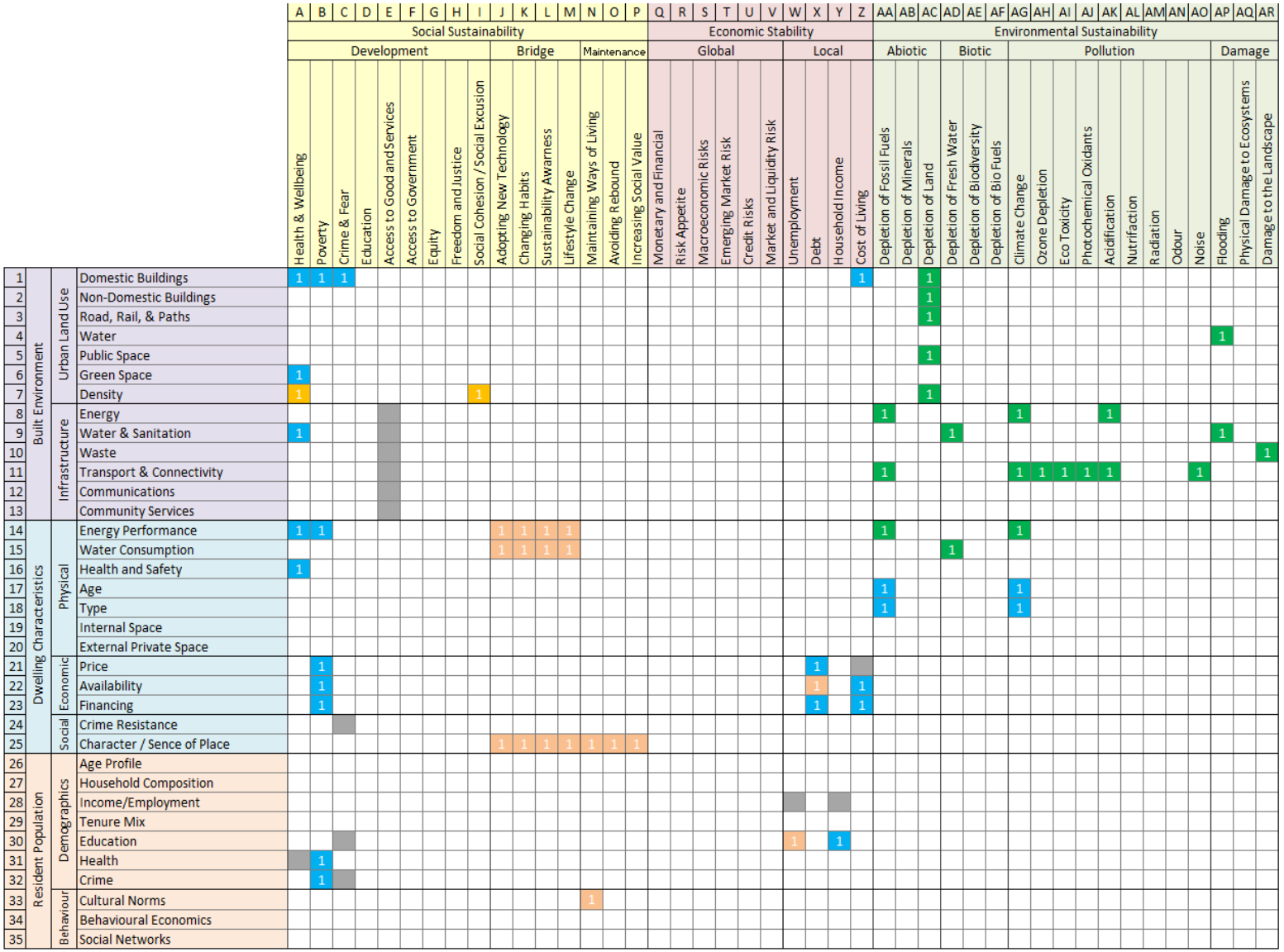

Figure 3. The sustainability matrix, with some data added: □ No Data ■ Unrelated ■ Self-Defined ■ Quantitative Relationship ■ Statistical Relationship ■ Qualitative Relationship ■ Conflicting Evidence ■ Known – Unknowns

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