Measuring construction for social, economic and environmental assessment

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Abstract

Purpose: The aim of this paper is to examine the issues that should be considered for a better gauge of the construction industry and built environment and to propose a set of indicators for measuring the social, economic and environmental value of construction.

Design/methodology/approach: The indicators proposed in this study use Pearce's schema, which presents a framework to evaluate the socio-economic value of construction and its contribution to sustainable development. After analysing the problems faced by the industry, solutions are raised and finally indicators for each pillar of Pearce's schema are established through a literature review. Since the proposed indicators can be used for cross country analysis, these comparisons are also presented as graphs including only those countries for which valid national data could be sourced from OECD databases.

Findings: The issues, suggestions and indicators related to each concern about the main domains of the schema are addressed through the related literature and supported by available statistical data.

Originality/value: Although previous studies have drawn attention to measures for better evaluation of the construction industry and the built environment, this study, distinctively, presents an integrated approach in order to gauge the true value and impacts of construction in a more comprehensive way. The work's contribution to the body of knowledge is in revealing the hidden input and impact of construction on sustainable development by determining the barriers to this and their solutions, in addition to the proposal of relevant indicators.

Keywords: Built environment, Construction industry, Pearce's schema, Sustainable development, Sustainability indicators, Wealth and well-being

Paper Type: Research Paper

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Introduction

Construction, as the creator of the built environment within which most other economic activities take place (Ball, 2014), is one of the major industries in any national economy regardless of its development level. The first step of the roads, airports, factories, hospitals, dams, power plants, urban spaces, all other living spaces and the infrastructure that makes those spaces habitable, begins with construction. Additionally, the quality of indoor environment is pivotal for our well-being, affecting the health and quality of life of citizens, and consequently the environmental and economic performance of countries.

Both in developed and developing economies, construction is the main axis of development. In the European Union (EU), the construction industry forms the largest industrial unit, with a total annual turnover of nearly 1000 billion Euros [1], representing one quarter of total output. The contribution of the construction industry to economic growth is measured by its share of Gross Domestic Product (GDP), the most well-known and conventionally tracked indicator. As the largest cluster employer in the EU, construction accounts for 10% of the gross domestic product (GDP) and 50% of the gross fixed capital formation (GFCF), with the capacity to provide employment for all levels of skills [2].

Over the years, economists have discussed the shortcomings of GDP measures and suggested alternative ways to measure national wealth and well-being. Even though GDP, as a macroeconomic indicator, provides a significant gauge of economic progress, it measures only income and production and does not reflect changes in the underlying asset base (Lange *et al.*, 2018). GDP is only concerned with the legal market transactions and excludes other activities that can have positive or negative impacts on overall social welfare (e.g. domestic/voluntary work or illegal activities). It does not integrate any measures of quality of life or quality of environment. Consequently, a rise in GDP does not always result in improved welfare. Various alternative indicators, which extend or complement GDP have been proposed; for example China's Green GDP [3] incorporates the cost of environmental damage caused by economic growth; Nature's Numbers [4] addresses the question of whether the U.S. economic accounts should be extended to include activities involving natural resources and the environment; Human Development Index (HDI) [5] emphasises that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone; the Index of Sustainable Economic Welfare (ISEW) and similarly Genuine Progress Indicator (GPI) are designed to more closely approximate the sustainable economic welfare or progress of a nation's citizens. The sustainable economic welfare implied here is the welfare a nation enjoys at a particular point in time given the impact of past and present activities (Lawn, 2003). Social Progress Index [6] measures 50 indicators of social and environmental outcomes to create a clearer picture of what life is really like for everyday people, rather than emphasizing traditional measurements of success like income and investment; OECD Better Life Index [7], as an interactive web-based tool created to engage people in the debate on well-being, draws upon the recommendations of the Commission on the Measurement of Economic Performance and Social Progress through 11 dimensions considered essential to well-being, from health and education to local environment, personal security and overall satisfaction with life, as well as more traditional measures such as income. On the other hand, Lange *et al.* (2018) state that wealth should be used as an indicator to complement GDP for monitoring sustainable development in a country, since GDP only indicates whether a country's income is growing, while wealth indicates the prospects for maintaining that income and its growth over the long term. To correctly evaluate economic performance then, it seems that the growth of both GDP and wealth need to be examined.

Clearly, the indicators above also address the question of whether GDP is a satisfactory measure for assessing the true value of construction and the built environment to the economy. Since the

construction industry is no longer focused on providing a single product, e.g. a building or a physical infrastructure, but a variety of services and improvement to the human environment more generally, performance-based building and sustainable built environment, as the trending new concepts, have created additional roles for the industry along with the need for new indicators to measure its performance and economic impact (Carassus *et al.*, 2006). Besides, buildings and construction play a key role in the green economy together with energy, transport, manufacturing, tourism, waste management -critical industries for the ecosystem, and the resource-based sectors of agriculture, forests, fisheries and water [8]. Another factor that makes the construction industry of utmost importance to the economy is the role it plays in sustainable development (Ruddock and Ruddock, 2008), which aims for a green economy without degrading the environment.

Accordingly, this study focuses on the sustainability aspects of the construction industry and built environment aligning with Pearce's schema (Pearce, 2003) by both pointing to the obstacles encountered together with their possible remedies and proposing indicators to accurately assess the performance of each problem. As a comprehensive view of the construction industry and its relationships with other industries, Pearce's schema situates construction within the sustainability paradigm, depicting the influences on the industry from different pillars of sustainable development (Werna *et al.*, 2009). A specific perception of sustainability that defines the term as raising per capita endowments of man-made, human, natural and social capital, is integral to this approach (Pearce, 2006), the main purpose being to help realise the social, economic and environmental value of construction in a holistic manner. The present study emphasizes the major indicators to be measured for comprehending the industry's contribution to the wealth and welfare of a nation by building on Pearce's principles, and is supported by other related literature and available statistics. By utilizing quantitative data, the study aims not only to bring out what kind of information is currently available to help measure the industry in terms of social, economic and environmental aspects, but also to provide an international comparison.

GDP versus wealth

The insufficiency of GDP and necessity of using wealth to complement GDP have been discussed as a factual gauge of economic success. Whereas wealth, as an indicator of sustainability, measures the flow of income that a country's assets generate over time, GDP, a significantly more challenging value to measure, does not reflect depreciation and depletion of assets, whether investment and accumulation of wealth are keeping pace with population growth, or whether the mix of assets is consistent with a country's development goals (Lange *et al.*, 2018). Shortcomings of GDP as a well-being indicator are well documented (Anielski, 2007; Daly, 1999, Posner and Costanza, 2011; Van den Bergh, 2009) and include: (1) GDP regards all expenditures as contributing to well-being regardless of what that expenditure is for and its effects. For example, money spent on pollution clean-up, addiction treatment, crime and car accidents contributes to GDP and is therefore counted as contributing to well-being; (2) GDP devalues goods and services that do not involve monetary exchange. For example, taking care of a child or a parent, housework and volunteer work are not factored in; (3) GDP is not forward thinking since it is a partial, short-term measure, whereas the world needs more wide-ranging and responsible guidelines to inform the way the economies of the future are built [9]. It excludes the inherent value of natural resource capital and ecosystem services. For example, a forest has no value unless you cut it down. Pearce (2006) was the first in the construction industry to draw attention to the definition of wealth in terms of ownership and accessibility. He pointed out that what is crucial in defining wealth is not personal ownership of a resource, but its accessibility and the use made of that access. Assessing the value of the built environment has changed since Pearce demonstrated that for an indicator of sustainable development what matters is wealth per capita not National Income Accounts (Pearce,

1993). Furthermore, GDP minimizes the value of expenditures on education, preventive healthcare, and environmental protection because it counts only the immediate expenditure and not the potential return on investment (4). Neither does GDP account for the distribution of income within a society. GDP counts any increase in income as positive, overlooking the social costs of income inequality and poverty. Wealth is now readily defined as the sum of four ‘capitals’ (a jarring term, but one that has come into general usage): man-made, human, natural and social (Pearce, 2006). Hence, a nation’s level of economic development is strongly related to the composition of its national wealth (Lange *et al.*, 2018).

Figure 1 illustrates the comparison of GDP and wealth per capita for OECD member countries (except for the Czech Republic, Israel and New Zealand due to missing data for those countries’ wealth accounts). The World Bank published the total wealth data from 1995 to 2014 [10] by summing up estimates of each component of wealth: produced capital, natural capital, human capital and net foreign assets. The construction of the wealth accounts is guided by the concepts and methods of the System of National Accounts (SNA) [11]. As shown in Figure 1, GDP is correlated to wealth, even where GDP outweighs wealth, as in Turkey, Greece, Italy and Ireland, for example.

Figure 1. GDP and total wealth per capita comparison based on 2014 data. The area of the circles corresponds to population.

While it is extremely valuable to have any wealth data at all, measurement of wealth is also problematic and depends on the discount rates used. It is largely correlated with GDP and does not provide all additional information that a wealth indicator would ideally comprise. In particular it does not capture all environmental and quality of life related impacts, which can nevertheless be very relevant to the residents of a country.

Sustainable development and construction

The relationship between economic growth and social welfare is not always directly proportional. A growing body of scientific evidence suggests that at a global level the magnitude of economic activity is disrupting critical ecosystem function and services and contributing to social decline [12] [13] [14] (Tedesco and Monaghan, 2009). If economic growth occurs at the cost of exhausting non-renewable natural resources, this growth is likely to be unsustainable and may have negative impacts on the social welfare of nations. The intended welfare benefits of economic growth are negated by the costs in terms of deteriorating natural capital, increasing pollution, and increasing social problems (Wilson and Tyedmers, 2013). Critics argue that growth-based economic policies have failed “the development project” (Banerjee and Duflo, 2011; Shiva, 2005; Stiglitz, 2002), hence, sustainable development, as an essential factor in creating new added value and innovation, while at the same time being able to contribute decisively to the economic development of individuals and society as a whole (Popescu et al., 2017), has been discussed (Costanza *et al.*, 2014; Daly, 1992). Despite the negative impacts related to increased production and consumption, the focus continues to be placed on economic growth rather than asking how the economy could be used as a tool to achieve sustainability goals (Fauré *et al.*, 2016).

Even though the construction industry as a whole has one of the lowest rates of productivity in the economy, actually it has at the same time a great potential to create significant value in achieving sustainability since it accounts for an estimated 40% of resource consumption, as reported by ECTP (2005b). Increasing efficiency will not only change the general perception of the industry’s negative performance, but also enable a sustainable development, creating economic, environmental and social consequences (Burgan and Sansom, 2006).

Both the existing built environment and the process of adding to it have numerous environmental, social and economic impacts including but not limited to raw material extraction and consumption, and related resource depletion; land use change, including clearing of existing flora; energy use and associated emissions of greenhouse gases; other indoor and outdoor emissions; aesthetic degradation; water use and waste water generation; increased transport needs, depending on site; waste generation; opportunities for corruption; disruption of communities, including that caused through inappropriate design or materials and health risks on worksites and for building occupants (Sev, 2009).

Given the above, and the high competition in the construction industry globally, a common international measure of the built environment in terms of both definition and measurement of construction activity needs to be established. Kohler (2006) questions the validity of the construction management indicators applied, drawing attention to the possibility of misleading conclusions based on them, since they only consider one aspect of construction. The definition and measurement of construction activity varies from country to country: as a consequence, relative indicators should be preferred over absolute statistical values for comparative analysis. The size of the informal industry and do-it-yourself activities within the industry are two issues hindering international comparisons. Moreover, as pointed out by Kohler (2006), the problems the construction industry in emerging economies faces differ from those in the EU or stagnating economies, requiring different measurements for performance and making it difficult to make comparisons based on the measurements alone.

The contribution of the construction industry to the economy has been measured based on National Income accounts. Pearce’s report published in 2003, became a seminal publication, being the first to propose the use of wealth per capita as an indicator of sustainable development in the construction industry. The report showed that National Wealth accounts provide a better way of assessing the value of the built environment than National Income accounts. So far, more than 15 years since the Pearce

report was published, there has been regrettably little progress on alternative approaches to the measurement of construction activity.

Strategies and measurement suggestions for evaluating the construction industry within sustainable development have been discussed in various studies (Spence and Mulligan, 1995; Uher and Lawson, 1998; Ruddock, 2002; Carassus *et al.*, 2006; Nelms *et al.*, 2007; Ruddock, 2007; Atkinson, 2008; Sev, 2009; Zhang and London, 2011 and Gibberd, 2015). Even though sound and well accepted sets of performance indicators are listed among the must-haves of an innovative construction industry, there is no general agreement regarding the alternative approaches to the measurement of construction activity. Pearce (2003) examined the applicable evidence and developed a roadmap for this new measurement process.

Overview of indicators for Pearce's schema

Since the construction industry and built environment make a substantial contribution to all aspects of society, economy and environment, careful integration with other national policies across a wide spectrum is required: transport (access and mobility), health and well-being, environment, security, productivity and education (Lorch, 2003).

There are significant obstructions hindering construction and the built environment from realising their potential in contributing to sustainable development. This study will be presenting these obstacles in terms of the inputs and impacts of the industry, and suggesting remedies by means of a literature review. Then a number of indicators will be proposed to measure the efficiency of these or any alternative solutions to the problems reported in the literature.

The indicators proposed in this study are based on Pearce's schema for the following reasons:

- i. The schema is not limited by production and use of the built environment but extends to its impacts (positive and negative) on society and economy by including economic competitiveness, health and wellbeing, and social and economic inclusion, as well as environmental impacts.
- ii. It acknowledges the significance of knowledge capital, human and social capital, natural capital, innovation, and productivity, and it establishes the possibility of linking these aspects together.
- iii. The strengths of the Pearce report stated by Meikle and Dickson (2006): (1) the report helps move the focus of construction industry analysis, research and policy from the management of the construction process towards an understanding of the benefits and disbenefits that arise from the industry's activities, (2) it suggests the need for both international and longitudinal comparisons, but recognizes the paucity of available and appropriate data sets, (3) it introduces to construction industry analysis a number of different approaches and (4) it provides a framework for analysis and measurement and recommends that these are actively pursued.

This paper addresses seven groups of indicators based on Pearce's schema. The first four groups are those providing input to the construction industry and built environment, namely human and social capital; natural capital; man-made capital; and the fourth group comprising technology, research, development and design. The indicators for measuring the impacts of the industry are those environmental and social consequences which affect quality of life, forming the other three groups, namely social and development impacts; market value; and environmental impacts. Aligning indicators with these schematic groupings not only helps provide a natural structure to present problems within the industry but also enables a clearer view of the suggested solutions and their relations to proposed indicators, selected through a comprehensive literature review. The proposed indicators aim to measure

the true value of the industry, thereby demonstrating that the complexities of construction and the built environment need to be assessed in a more sophisticated manner in the interests of sustainable development.

Realizing the potential contribution of the construction industry to sustainable development has been prevented by a number of obstacles. The contribution of this study will be threefold: (1) identifying these obstacles and listing them in alignment with Pearce's schema, (2) suggesting remedies for each of those listed obstacles and (3) proposing indicators aligned with the schema, to help overcome concerns over the reliability and comparability of construction statistics for those who would like to apply the schema.

In this section, the indicators for each group in Pearce's schema (Figure 2) are proposed and a table is presented for each one listing the problems encountered, how to overcome them, and how to measure them so that they can become manageable. The main indicators, among the available statistics commonly used by the industry are also briefly explained and listed in the text as a reminder of which indicators are used for each category, though these lists are by no means exhaustive. In Tables 1-9 below, the proposed indicators are presented together with the problems and suggested solutions. Tabular representation is preferred as it makes comparisons easier and sets the stage for discussion of the proposed indicators.

On the other hand, some statistical analyses based on OECD data [15] (for those aspects indicated in bold in the figure) are provided in order to demonstrate the depth of currently available data for the proposed indicators, to show that these data can be used in comparative studies at the international level, and to provide corroborating evidence for the main thrust of the paper as statistical patterns emerge.

Figure 2. Proposed indicators for Pearce's schema.

Human and social capital

As the first resources of the construction industry and built environment, human and social capital refers to skills, knowledge, experience and social networks. Table 1 presents the main problems encountered,

256 suggested remedies and indicators regarding human and social capital from the perspective of
257 construction.

258 The main indicators for human capital are total number of enterprises carried out by the industry, total
259 number of employees, and hours worked by employees. Data breakdown for industry groups can be
260 based on the International Standard of Industrial Classification and the available data can be accessed
261 through the Structural Statistics on Industry and Services (SSIS) database.

262 Even though researchers are also an element of human resources and their labour costs are higher than
263 those of other departments (their wages account for half of R&D expenditure), indicators related to
264 R&D are not used in this group, being addressed in more detail in the Technology R&D Design section.

265 Table 1. Human and social capital

Problem encountered	Suggested remedy	Indicator
Skills shortage	Better training and education	Educational attainment and labour market outcomes by skills
	Guidance on how to keep pace with technological change	Frequency of use of Information and Communication Technology (ICT) at work, by educational attainment
		Development of e-training methods and tools for construction workers
	Building a more human-friendly construction work environment	Proof of safe and adequate access to construction site
	Developing and implementing an architectural knowledge base in the construction industry	Databases created for this purpose and their usage of statistics
	Development of technical data sharing and archiving standards (e.g. CityGML, IFC and extensions) for virtual prototyping of infrastructures	
Global competition power of the industry	Enlarging the labour force focusing on innovative SMEs	Employment by activities and status (in construction)
	Interdisciplinary academic collaboration with social and medical sciences, environmental psychology, architecture and engineering, on the understanding that research will benefit from many perspectives	Entrepreneurship: share of self-employed in manufacturing or construction Number of interdisciplinary projects and/or R&D activities
Measuring health of human capital	Increasing labour and worker safety	Accident and fatality rates

Aging nature of the labour force	Enlarging the labour force by attracting talent from younger generation, by highlighting the intention of making construction processes knowledge-based and cutting-edge technology driven processes.	Employment with a limiting long-term illness from related census data
Low Efficiency	Comparisons of labour productivity with other industries	Labour productivity
	Developing performance-based criteria	Benchmarking Key Performance Indicator approach
	Supporting interactions between technology, environment, societal and economic impacts	ICT access and usage by businesses Statistics usage of e-training tools for construction workers
	Smart integration of new (high performance) technologies & devices (e.g. intelligent LED solutions, or nanomaterials)	
	Enlarging the labour force	Employment by activities and status (in construction)
	Development of e-training methods and tools for construction workers	Employment with a limiting long-term illness from related census data
	Earning a good reputation as an attractive sector to work in	Wages and salaries of employees
	Providing further opportunity to communicate knowledge and expertise	ICT access and usage by businesses

266

267 For productivity analysis, the underlying concept for labour input is total hours worked by all persons
268 engaged in production. Labour productivity growth implies a higher level of output for unit of labour
269 input (hours worked or persons employed). Productivity is also a key driver of international
270 competitiveness, e.g. as measured by Unit Labour Costs (ULC). As one of the indicators of low
271 efficiency for the human and social capital pillar, the comparison of labour productivity with other
272 industries by country is presented in Figure 3 (for those countries with available data only). Estonia
273 (EST) has the highest construction contribution to labour productivity with a value of 1.8%. This is
274 followed by the Netherlands (NLD), Greece (GRC), Italy (ITA), France (FRA) and Germany (DEU)
275 where the change is positive respectively. Whereas the change in Spain (ESP) and Sweden (SWE) is
276 zero, Latvia (LVA), Hungary (HUN), Poland (POL) and Ireland (IRL) have relatively high negative
277 changes.

Figure 3. Annual percentage change in industry contribution to business sector labour productivity based on 2016 data. BDE: Mining and utilities, C: Manufacturing, F: Construction, G: Wholesale retail trade, accommodation, food services, transportation and storage, J: Information and communication, K: Financial and insurance activities, MN: Professional, scientific and technical activities, Administrative and support service activities.

It is also worth emphasizing that for a valid assessment of the economic performance of the construction industry in terms of its productivity, it is important that the economic benefits for the industry from technological change are properly recognized but the impact of such benefits may be ‘hidden’ due to measurement issues, as innovative activity and investment in intangible assets have both gone unrecognized in official statistics (Ruddock and Ruddock, 2009).

Nonetheless, Figure 4 examines the number of construction businesses providing training to develop ICT related skills. The ICT training provided is largely uncorrelated with the size of the workforce, however the richer countries such as Norway (NOR), Austria (AUT) and the United Kingdom (GBR) typically provide ICT training for a larger fraction of the workforce than poorer countries including Italy (ITA), Poland (POL) and Slovenia (SVN). The figure also provides the numbers of employees in the construction industry.

Figure 4. Construction businesses that provided any type of training to develop ICT related skills of the persons employed based on 2016 data. The area of the circles corresponds to the number of people employed in the construction industry.

Natural capital

As the second group of Pearce's schema that provides input to the construction industry and built environment, natural capital concerns the indispensable resources for all living creatures, such as clean air and water. Freshwater resources are of major environmental, economic and social importance. Important indicators used are freshwater resources (total renewable per capita), water abstractions (total and per capita) and total water made available for use.

The air pollution caused by emissions of CO₂ originates from burning oil, coal, natural gas and waste materials for energy use. Disaggregating the emissions estimates shows substantial variations within individual sectors. Emissions of greenhouses gases (GHG) from human activities leads to Global Warming and other consequences for the Earth's climate. Climate change is of concern mainly as regards its impact on ecosystems (biodiversity), human settlements and agriculture, and on the frequency and scale of extreme weather events.

The application of natural capital within the construction industry and built environment is represented in Table 2.

314 Table 2. Natural capital

Problem encountered	Suggested remedy	Indicator
The exhaustion of natural resources	Drastically reducing consumption of materials and energy-use	CO ₂ emissions
	Lowering emissions from products in use	Total gross emissions
	Where possible implementing zero-waste construction activities	Total resultant waste
	Allowing recycling and reuse of materials	The share of urban population exposed to different levels (low-high) of air pollution
	Reducing greenhouse gas emissions	Total gross emissions expressed in CO₂ equivalents as well as emission intensities per capita
	Developing the smart and sustainable management of buildings and infrastructure	Industry recognised green assessment tools
	Developing energy-positive retrofits for existing buildings	Amount of produced energy
	Targeting a net balance of approximately zero for the energy consumed	The ratio of energy supply to GDP vs The ratio of energy consumption to GDP (total final consumption/GDP)

315

316 Greenhouse gas emissions data are of great importance as one of the indicators for the exhaustion of
317 natural resources. Figure 5 compares countries by their annual greenhouse gas emissions. Germany
318 (DEU) and Canada (CAN) followed by Turkey (TUR) have the highest values for all years covered,
319 while Estonia (EST) has the lowest CO₂ equivalent. Even though the values are fluctuant for most
320 countries, the general tendency is for reduction in greenhouse gas emissions, except in Germany (DEU),
321 Turkey (TUR), Australia (AUS), Hungary (HUN) and Canada (CAN), the last of which has seen a
322 noticeable increase over the years.
323

Figure 5. Annual greenhouse gas emission of manufacturing industries and construction.

Man-made capital

The next group of those providing input to construction is man-made capital. Some systems, particularly civil infrastructure systems (transport and services), require huge public investments (ECTP, 2005b). Such systems are expected to serve several generations - very long periods of time considering the dramatic social and technological changes society will be undergoing. Deciding whether to construct new infrastructure or upgrade and maintain existing systems is another challenge waiting to be addressed, and this again calls for a better way of assessing the value of the built environment.

There is a potential for improvement of the construction process, achieving reductions of up to 30% of life-cycle costs, 50% of delivery time and 50% of work-related accidents (ECTP, 2005b).

The construction industry should therefore be leading in the development of industry-recognised green assessment tools for buildings to promote sustainability in the built environment and raise awareness among owners, architects, developers, engineers, planners, designers, contractors and the public about environmental issues and therefore also lead the way towards a sustainable built environment for future generations.

The main indicators in this group are the available statistics on businesses and business activity, such as value added, production, employment and the number of business units in the construction industry (Table 3). Value added at factor costs¹ can be used as data specific to the construction industry.

Table 3. Man-made capital

Problem encountered	Suggested remedy	Indicator
Aggressive international competitiveness	Increasing productivity and innovation	Share of small and medium-sized enterprises (SMEs) in sector innovation
	Using advanced technology	Gross domestic expenditure on R&D
	ICT-based information systems (using e.g. widespread real-time monitoring)	
	Developing new sustainable models, design and building techniques	The number of researchers working on experimental development ² of R&D
Inefficiency	Knowledge-driven and high-tech construction processes	Construction time
	Transforming research into economic activity	The number of researchers ³ working on applied research
	Making the most of the available Nano-, bio- and information technology	The number of researchers and patents registered

¹ The definition for value added is consistent with that described in the 1993 System of National Accounts. The valuation of value added when described as the sum of the gross operating surplus and compensation of employees, is called value added at factor costs (VAFC).

² Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed towards producing new materials, products or devices, installing new processes, systems and services, or improving substantially those already produced or installed.

³ The number of researchers is measured in full-time equivalents and expressed per thousand people employed in each country.

Small and medium-sized enterprises (SMEs) have high potential for innovation and are often therefore supported, so the indicators in this area need to consider size classes, referred to as Business Statistics by Size Class (BSC) in the OECD database. Table 4 represents the technology, research and development and design related issues, solutions and indicators.

Table 4. Technology R&D design

Problem encountered	Suggested remedy	Indicator
Bridging the gap between “knowledge production” and “knowledge use”	Developing the architectural knowledge-base and its implementation in construction	Number of such databases available and their usage statistics
	Deep involvement in research and development	Gross domestic expenditure on R&D
	Development of technical data sharing and archiving standards (e.g. CityGML, IFC and extensions) for virtual prototyping of infrastructures	Number of patents Number of researchers
	Supporting robust technologies development that connect human behaviour and requirements for safety, energy-efficiency, etc.	Gross domestic expenditure on R&D Number of patents
High construction and maintenance costs	Any type of MMC, an innovative process of building construction using a concept of mass production of industrialised systems (identical and modules), produced at the factory within controlled environments can be used to achieve the ultimate goal of reducing the overall cost of construction (economy of scale in manufacturing of multiple repeated units)	Use of Modern Method of Construction (MMC) and/or modular construction methods
Requirement to extend lifetime of existing infrastructure	Facilitating speedy use of innovation	Number of patents
Innovative solutions	Revealing the innovation potential of SMEs	Statistics on business by size class

Quality of life

As an impact of construction and built environment, quality of life is composed of the social and development impacts, market value and environmental impacts. ECTP (2005b) reported that within the EU, setting targets for efficiency even for the construction process alone, let alone all stages of production activity, would make it possible to invest at least 200 billion Euros per year in extra work to improve the built environment of European citizens.

Climate change could have significant consequences for human well-being and socio-economic activities. The effects of outdoor air pollution on people's health are a globally growing concern.

Modular construction methods provide sustainable design and construction solutions for improved environmental impact by taking most of the production away from the construction site (Lawson *et al.*, 2012; Kobet, 2009; MBI, 2010). Removing approximately 80% of the building construction activity from the site location reduces site disruption, vehicular traffic and improves overall safety and security.

Modern Method of Construction (MMC), modular construction methods and offsite construction industry systems are preferred due to the advantages and benefits they provide (Lawson *et al.*, 2012). Modular construction methods achieve better construction quality, efficiency and productivity, reduce risks related to occupational safety and health, speed up project duration, are flexible (in terms of reuse, movability, deconstruction and refurbishment) and achieve the ultimate goal of reducing the overall cost of construction (economy of scale in manufacturing of multiple repeated units).

Table 5. Quality of life

Problem encountered	Suggested remedy	Indicator
The need for every individual to have access to the services and facilities they need	A holistic approach	Share of urban population with exposure to particulate matter (PM2.5) below the national average
The need for improving the working environment	Developing new construction, maintenance and demolition techniques	Use of Modern Method of Construction (MMC) and/or modular and offsite construction systems

Social and development impacts

Improved health, comfort, accessibility, usability and safety within the built environment are the main concerns for social and development impacts. An ECTP (2005b) report highlights some of the significant socio-economic challenges faced by European cities (e.g. some 80% of Europe's citizens live in cities). In addition to the ageing population, today millions of people from other parts of the world constitute Europe's new citizens, leaving the construction industry to find solutions for integrating diverse cultures, languages and social structures, to guarantee peaceful lives, mutual development and to meet social and personal needs. The report revealed that the solutions demand a paradigm shift in order to embrace all European citizens, hence promoting the approach "design for all" throughout the built environment.

394 Table 6. Social and development impacts

Problem encountered	Suggested remedy	Indicator
The needs of specific groups such as disabled people, ethnic minority communities, elderly people, children and young people and faith groups	Enabling equal opportunities in society	Design appraisal
	Embracing diverse approaches to problem solving and community involvement.	(Public/community) Inclusive design

395

396 **Market value**

397 As Mäler (2007) states, one cannot ignore the roles of ecosystems within the economy; however,
398 particularly those ecosystems that are not formally owned or managed are not recorded in the accounts,
399 having no markets, and hence are neglected in many indicators. The difficulty of quantifying or valuing
400 the ecosystem services, and evaluating their stocks are two reasons for their omission. Today the
401 construction industry questions the economic value of the built environment, urgently looking for means
402 of analysing the totality of activities involved in the production of the built environment. Any answer
403 will be unsatisfactory unless it acknowledges the value of ecosystems.

404
405 In terms of market value, understanding the pricing mechanisms of ecosystems is not straight forward
406 in the sense that the pricing mechanisms generated by economic growth models supplied by the
407 literature cannot be applied to the ecosystems. In order to define the value created by ecosystems, Mäler
408 (2007) uses concepts such as resilience, a concept borrowed from ecologists. The service levels of
409 ecosystems vary depending on the perturbation level of the system because of their natural dynamics⁴.
410 Resilience plays a critical role in determining the value of future supply of ecosystem services.
411 Resilience of an ecosystem is a kind of threshold pair, when it is reached the services provided by the
412 ecosystem change rapidly, and then when the upper threshold is also exceeded services are no longer
413 available. This band is defined as the resilience of the ecosystem in question. Even though neither
414 measuring nor valuing resilience is an easy task, it is included in the table as a suggested indicator with
415 the rationale explained.

416 Increased competitiveness coupled with identifying new business opportunities in turn will generate
417 employment for construction workers.

418 A systematic summary of economic transactions of an economy with the rest of the world, for a specific
419 time period, measured by the balance of payments, is an important indicator for industry-specific target
420 monitoring as well.

421 In terms of market value, municipal waste is a concern not because of its share in the total waste (only
422 one part of total waste generated in each country is municipality originated), but because of the cost of
423 managing and treating public waste, which is often more than one third of the public sector's financial

⁴ Ecosystem pricing and dynamics are beyond the scope of this paper, for a detailed explanation of ecosystem dynamics please refer to Mäler (2007) and The Economics of Non-Convex Ecosystems, <https://www.springer.com/gp/book/9781402019456>

424 efforts. If neglected, inappropriate waste management has high potential risks to human health and the
 425 environment (soil and water contamination, air quality, land use and landscape).

426 Table 7. Market value

Problem encountered	Suggested remedy	Indicator
Low efficiency	Reducing construction costs	Construction cost indices
	Improving quality control	Quality incidents
	Adopting 'preventive' maintenance approach	Audits and supervision visits
Acknowledging the value of ecosystems	Working closely with ecologists	Use of environmental assessment tools (e.g. BREEAM)
Risks	Quantifying and managing the impact of natural and external hazards	Resilience
	Potential risks to human health and the environment due to inappropriate waste management	Disability-Adjusted Life Year (DALY)
Identifying new business opportunities	Innovation centric approach	Recycling
International Competitiveness	Increasing the level of gross domestic expenditure on R&D	Municipal waste generation by capita
Making decisions whether or not to upgrade the old infrastructure to a new status, demolish the old one and build a new one, or combine the old infrastructure with a new one	Evaluating with cost-benefit optimisation	The number of researchers working on experimental development of R&D
		Gross domestic expenditure on R&D
		Number of patents
		Cost-benefit analysis

427

428 Environmental impacts

429 As much as 50% of all materials extracted globally are transformed into construction materials and
 430 products. These same materials, when they enter the waste stream, account for some 22% of all final

waste. Moreover, including energy in use, the built environment accounts for as much as 40% of all energy use. Therefore, the amounts of raw material and energy used in construction need to be reduced. The energy content of construction materials must also be reduced.

Environmental issues closely related with the industry include: reducing greenhouse gas emissions, mitigating existing polluted areas, enhancing energy efficiency and conserving natural resources such as green field spaces, water, energy and balanced ecosystems (ECTP, 2005b). Buildings and the built environment in general need to be progressively transformed from elements with a negative environmental balance (particularly energy and water consumption) towards a neutral or positive environmental balance.

Table 8. Environmental impacts

Problem encountered	Suggested remedy	Indicator
The negative environmental impacts of construction	Developing performance indicators for products validated throughout their service life	Performance indicators for products
	Zero-waste construction	Waste generated by construction
	Making all new buildings cost-efficiently energy-positive	Life cycle cost analysis
	Developing mitigation and re-use of brownfield and polluted areas	Percentage of sites Site-level success
	Reducing environmental impact (pollution, vibration, radiation, noise) of day-to-day activities	Pollution and noise indicators of urban spaces

Achieving zero-waste construction is one of the remedies for minimising negative environmental impacts and can be tracked through construction waste generation. Figure 6 displays the construction waste per unit of Gross Value Added (GVA). The amount of waste produced per unit GVA added is typically higher for larger well developed countries such as the Netherlands (NLD), France (FRA) and Germany (DEU), while countries such as Greece (GRC), Portugal (PRT) and the Slovak Republic (SVK) with a small construction contribution to GVA typically have a much lower level of waste per unit GVA.

Figure 6. Construction waste per unit GVA based on 2014 data. The area of the circles corresponds to the construction contribution to GVA.

Wider social value and sustainable development

Achieving attractive, comfortable, accessible, usable and healthy indoor environments in all buildings (not only the newly built ones but also considering the upgrade, renovation and rehabilitation of existing building stocks) is crucial for society. Furthermore, improving the preservation, rehabilitation and integration of cultural heritage, leading to an appreciation of the collective memory, also demands environmental life-cycle approaches.

Atkinson (2008) defines the sustainability of a sector (e.g. construction) or company as its contribution to the development path on which that society is found. Table 9 is an attempt to list the possible problems encountered by society to which the construction sector may provide solutions and even lead in their eventual implementation.

The development of a sustainable built environment for all is essential for the realisation of a society based on equal rights and opportunities. Many people in today's society depend on an accessible built environment in order to live autonomous and active social and economic lives. The built environment is expected to meet a number of unavoidable and urgent social demands (for further detail please refer to ECTP, 2005a).

468 Table 9. Wider social value and sustainable development

Problem encountered	Suggested remedy	Indicator
The negative impacts of construction's whole life-cycle	Environmental life-cycle approaches employed for design, construction work, maintenance and operation, as well as in product development	Life-cycle assessment (LCA)
Problems related to diverse populations including urban areas with large immigrant populations.	Developing infrastructure and living spaces to allow better integration of all members of society	Satisfaction surveys
Neglected cultural heritage, other socio-economic and human aspects	Using consequence-based advanced technologies and practices	Gross domestic expenditure on R&D
The cultural heritage of the existing built environment has been eroded	Including collective memory in the built environment by integrating design and planning processes across a wider range of different activities focusing on conservation	Conservation statistics

469

470 **Discussions and conclusion**

471 The construction industry shaped by the socio-economic conditions of a country, plays an indispensable
472 role within that economy by providing wide ranging activities and development to the human
473 environment. The increasing demand for, and tendency towards, a performance-based approach on the
474 one hand, and ever more worrying sustainability concerns on the other, are forcing the industry towards
475 more integrative solutions. As already discussed, an integrated approach aims to judge the components,
476 value and impacts of the construction industry and built environment more thoroughly. To achieve this,
477 the indicators, including the human, social, natural, man-made and technological aspects, as well as
478 societal, economic and environmental impacts for the entire life cycle, should be determined. The more
479 clearly specified the indicators and solutions, the more comprehensive and accurate the assessment will
480 become.

481 The major indicators proposed in this study are based on contextualisation of Pearce's schema and a
482 related literature research. Most importantly, suggestions are made on how to measure these indicators,
483 and the question of whether the corresponding data are available or not is also addressed. Even though
484 the fragmented nature and complexity of the industry and difficulty in acquiring the related data bring
485 along challenges, methods of evaluating construction and the built environment should go well beyond
486 their weight in GVA. Overall wealth indicators should complement this process. Despite some
487 obtainable statistical data for each indicator visualisation which enables the possibility of cross country
488 analysis, the industry lacks specific data for a true measurement of construction value for sustainable
489 development.

For instance, in most countries, the primary sources for measuring actual hours worked are labour force surveys; however, certain countries may use additional sources which might affect the comparability of labour productivity levels, while comparisons of labour productivity growth and changes in Unit Labour Cost (ULC) are likely less affected. As Ruddock and Lopes (2006) state, a prerequisite for making valid international comparisons of national construction sectors must always be the availability of valid, reliable and transparent data. Users should be careful when comparing the R&D intensity of countries that have and have not capitalised R&D in their national accounts. Moreover, the methodology used for counting patents, for example, can influence the results, as simple counts of patents filed at a national patent office may have weak international comparability, patent values being highly heterogeneous.

This study, in its central motivation, intends to propose a basis for the correct measurement of construction using a new set of indicators. It also attempts to raise awareness of the importance of higher accuracy in assessment through the presentation of certain statistics. It is hoped that development of the proposed indicators and international comparisons through increasingly comparable data will be the starting point for future studies.

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