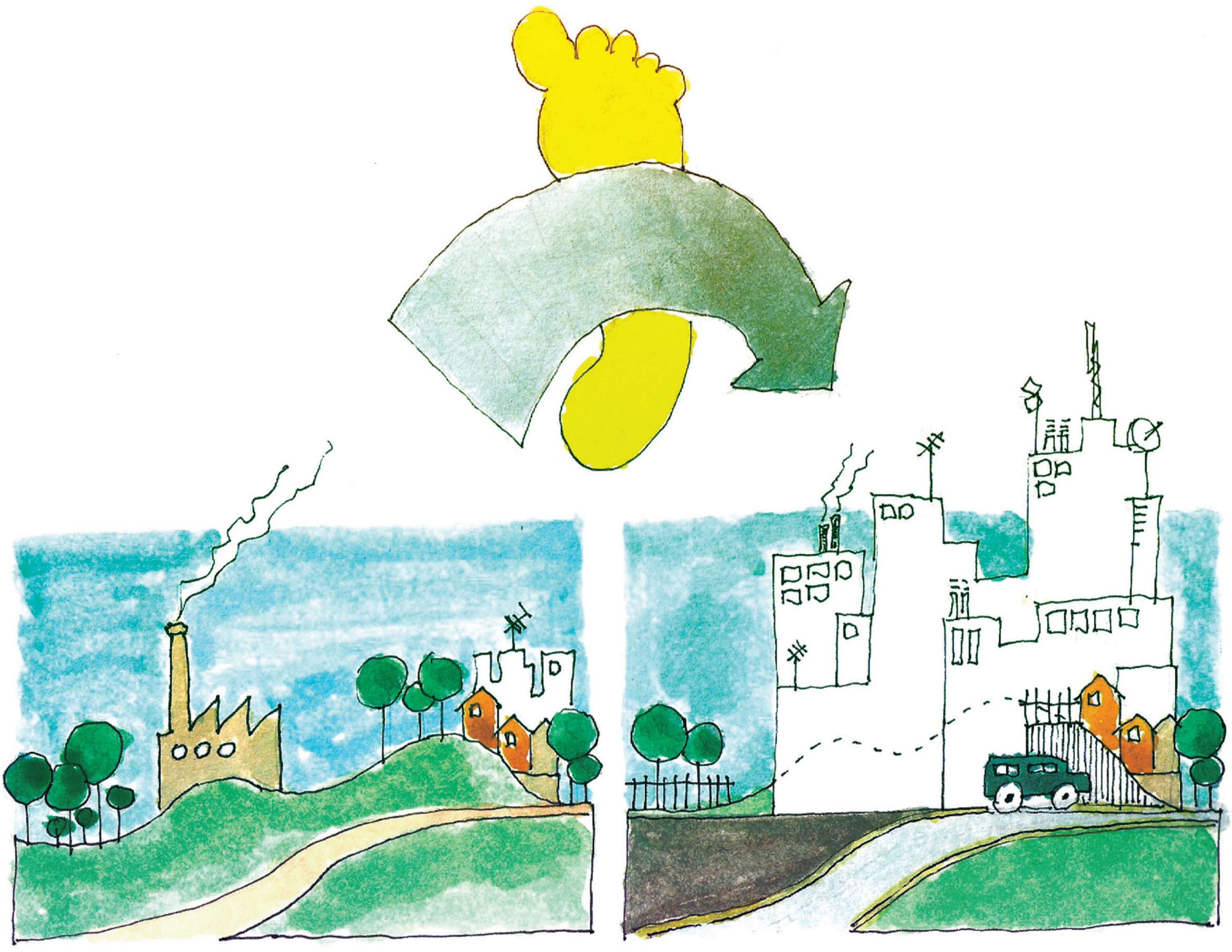
eISBN: 978-1-68108-098-7
ISBN: 978-1-68108-099-4

Ecological Footprint Assessment of Building Construction



Jaime Solis-Guzman
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ECOLOGICAL FOOTPRINT ASSESSMENT OF BUILDING CONSTRUCTION

Authored By

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FOREWORD

The publication is a contribution to scientific development, needed to generate standards and strategies for sustainable construction. The stringency of the contents, while its clear and informative language, makes this book a necessary publication for anyone wishing to learn or expand their knowledge on the Ecological Footprint linked to environmental aspects in the construction phase of a buildings.

The construction industry is well known for its high impact on the environment, especially during the building construction. In the present book, a methodology is defined as the first step towards the creation of an effective assessment of the Ecological Footprint (EF) of this type of activity. The EF indicator methodology has been adapted by the authors to the peculiarities of the construction sector. The procedure is based on the project budget and its bill of quantities, which is organized by means of a systematic classification of the resources into three main categories: materials, manpower and machinery. A calculation model is presented with some innovative aspects, such as including food intake and worker mobility, water consumption in the construction site and indirect costs analysis which are not normally included in the methodology of the indicator; footprints associated with cropland, pasture and fishing appear due to the inclusion of food.

The methodology and all the steps which are part of the calculation are explained, and approaches are proposed, making it easy to implement the EF assessment in any building project.

Dr. Solis-Guzman and Dr. Marrero belong to the research group ARDITEC and work in construction related problems such as construction and demolition waste management, CO_2 Footprint, Ecological Footprint and recycling of construction material. They have published over 30 articles in scientific and technical journals, and participated in over 50 conferences. They also have participated in research projects at regional and European level. Since 2009, both teach the subject Sustainable Construction in the School of Building Engineering, University of Seville, Spain.

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PREFACE

The construction industry is well known for its high impact on the environment; however, no mechanisms for its evaluation and control have yet been made readily available, due, fundamentally, to the difficulty of defining its boundaries and the corresponding pollutant emissions. The industry needs to establish the emission sources and, if applicable, its sinks and/or mitigating factors. From this perspective, buildings are directly responsible for the generation of pollutants during their construction and operation, for water and electricity use and waste generation and also, indirectly, for emissions due to the transportation of material and occupants to and from the building site.

In this framework, the Ecological Footprint (EF) methodology is adapted to the building sector, and a model which evaluates the particular case of the construction of buildings is presented. The EF is a relatively new indicator that aims to establish results that are more intuitive of the impact on the territory of economic activities. From this point of view, the relationship of the buildings with the territory, where they are located, is defined empirically and visually, and the associated impacts are identified.

Given the difficulty in establishing a general model for the building industry, the present book focuses on the study of the construction of buildings, which constitutes the most significant impact in the territory, and, undoubtedly, the most aggressive impact from the planning point of view, since the activity is performed intensively for a relatively short period of time.

A methodology is defined as the first step towards the creation of an effective assessment of the EF of this type of construction. The procedure is based on the project budget and its bill of quantities, organized by means of a systematic construction-work breakdown structure that divides the work into three major categories: materials, manpower, and machinery. Each stream generates partial footprints (*i.e.* energy, food, mobility, construction materials, and waste). The methodology is structured in such a way that it can be adapted to any construction project that has a detailed budget and that is based on a work breakdown system.

Therefore, the present work provides a step forward in the modelling and analysis of the effects of building activity on the environment in order to identify strategies for the reduction of this impact. The book is divided into two parts: the theoretical model for calculation of the footprint of residential buildings during their construction; and the case study of the construction of an apartment building in Huelva, Spain.

The first part describes the EF indicator and its adaptation to the building construction sector. The sources of impact are the most relevant part of the analysis due to the effect of a wide variety of building elements on the calculation of the EF. The main sources of impact are grouped into direct impacts, indirect impacts, waste, and built land. The direct impacts are those taking place directly on the construction site: energy (fuel and electricity) and water. The indirect impacts refer to the construction materials (embodied energy) and manpower (food and mobility).

The second part consists of three steps. First, the general characteristics of the project under study are summarized: land type and actions to be taken on the land (detailed construction project, land subdivision, and project development). The second step explains how to apply the proposed formulation to the impact factor parameters. Finally, in the third step, the footprints associated with these impact factors are calculated: energy, water supply, food consumption, mobility, construction materials, waste, and constructed land footprints.

In an innovative approach, the evaluation is directed to professionals in the construction sector who normally deal with project budgets and well understand the work breakdown systems employed for the classification and organization of construction work units.

The methodology, applied here to a Spanish construction project, can equally be employed for construction classification systems of different countries. The aspects that are dependent on the region where the project is located are: the workforce food intake, the electric mix, the transportation systems, and the waste generation rates.

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CONFLICT OF INTEREST

The author confirms that this chapter has no conflict of interest.

ACKNOWLEDGEMENT

Ministry of Innovation and Science, through the concession of the R+D+I project: Evaluation of the EF of construction in the residential sector in Spain. (EVAHLED). 2012-2014. *Ministerio de Innovación y Ciencia, por la concesión del Proyecto I+D+i: Evaluación de la huella ecológica de la edificación en el sector residencial en España (EVAHLED). 2012-2014.*

We are grateful to Dr. Rafael Llacer-Pantion and Architect Patricia Gonzalez Vallejo for the all the diagrams and drawings that help explaining the proposed model.

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CHAPTER 1

The Ecological Footprint Indicator

Abstract: The Ecological Footprint (EF) calculations are generally performed by following the methodology defined by Mathis Wackernagel, based on top-down analysis, on macroeconomic data that estimates the footprints at various territorial levels: Earth, continents, countries, cities, *etc*. The present chapter establishes a reference frame, also top-down, in order to define the indicators and their relevance. The indicators have been used in the calculation of the impact of humanity on the environment, among which the EF is included. According to EF methodology, all consumptions, materials, energy, and waste absorption have their corresponding productive land requirements for their production or disposal.

Keywords: Conversion factors, Ecological deficit, Ecological footprint, Productivity factors, Productive land, Sustainability, Sustainable development, Standard productive territory.

INTRODUCTION

Indicators have been used in the calculation of the impact of humanity on the environment, among which the EF is included. A first approach to the growth indicators is traced in the models developed by Jay W. Forrester [1] in the 70s. Forrester, known worldwide as the father of Systems Dynamics, is also responsible for the dynamic theory implementation in growth modelling of population, economy, or cities. Among the models generated by Forrester, the most relevant to the present work is that of global dynamics, which employs systemic dynamics in global models.

His study focuses on two parts: the first took place in the early seventies as part of a project commissioned by the Club of Rome. The Club of Rome was an organization, composed by prominent personalities, which sought to promote stable and sustainable economic growth of humanity. The project analyses the effect of population growth and human activity in a world of limited resources. From this study arises the report "Dynamics of Growth in a Finite World" [2]. The

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second, developed thirty years later, determines similar objectives but with more powerful tools, and introduces concepts and definitions that did not exist in the seventies, such as: EF, overreaching, sustainability, collapse, erosion cycles, *etc*. This latest report is contained in the book "The Limits to Growth 30 Years Later" [3]. The report assesses the effect of population growth and human activity in a world of limited resources, and the behavioural modes and patterns through which the human economy interacts with the carrying capacity of the planet during the present century.

Carrying capacity is a dynamic concept, constantly changing with technological progress, consumption patterns, climate, and other factors. The term designates the number of people that in the current circumstances could be sustained on the planet without causing deterioration of the Earth's overall productivity.

Similarly, the dynamic model establishes that the world's growth and its indicators, such as the EF and human wellbeing index, are part of the predictive models in order to measure the behaviour of humanity with respect to Earth.

THE EF CONCEPT

The EF indicator was introduced by Mathis Wackernagel [4], who measured the EF of humanity and compared it with the carrying capacity of the planet. According to its definition, the EF is the amount of land that would be required to provide the resources (grain, feed, firewood, fish, and (CO_2)) of humanity [5]. By comparing the EF to the amount of land available, Wackernagel concluded that human consumption of resources currently stands 50% above the global carrying capacity [6].

EF is now considered one of the most relevant indicators for the assessment of impacts on the environment, and can also be used in conjunction with other indicators, such as the carbon footprint and water footprint [7]. The strengths of the indicator include its provision of an aggregation of multiple anthropogenic pressures and its easily understood strong conservation message. On the other hand, its main weaknesses are that neither can it cover all aspects of sustainability nor all environmental concerns, and that certain underlying assumptions are controversial [7].

A different approach establishes that the footprint can be considered the sum of the farmland, urban land and the land necessary to neutralize the pollutant emissions. It can also be enunciated as an index which measures the land area required to produce the resources consumed by citizens and to absorb the waste generated by them [6].

The indicator has been used since its inception to determine impacts on differing scales: to predict the impacts generated by mankind on Planet Earth [3], for the periodic calculation of the footprint of mankind on Planet Earth [5, 6, 8], or for periodically calculating the EF of different countries [9 - 14], cities [15, 16], neighbourhoods [17, 18], productive sectors [19 - 21] and industries [22 - 27]. In the work of Nye and Rydin [28], an innovative analysis of EF per building component is proposed.

Finally, following the procedure developed by Spanish researchers [27, 29] on corporate EF calculation, the process of building construction is studied [30 - 34]. This methodology, adapted to the unique characteristics of the construction sector, has been chosen for its comprehensibility, transparency, and adaptability [29].

AN APPROACH TO THE EF INDICATOR AS A SUSTAINABILITY PARAMETER

In order to introduce a sustainability parameter, it is necessary to define its scope first. Common concepts, such as sustainable development, sustainability, and strong sustainability, are commonly used, but what do they mean? What are the differences between them?

The most significant difference is found between the concepts of sustainable development and sustainability. Sustainable development is an objective while sustainability is a process. It means that the process of achieving sustainability (ecological, economic, social, cultural, *etc*.) will lead to the attainment the objective, thereby obtaining a sustainable economy, a sustainable society, a sustainable environment, *etc*. The system, which introduces sustainability as behaviour, can achieve the proposed objective. According to Edwards [35] there exist three perspectives on sustainable development, as seen in Fig. (**1**).

CHAPTER 2

The EF of Building Construction

Abstract: The EF indicator methodology has been adapted to the peculiarities of the construction sector during the construction phase. A calculation model is presented with some innovative aspects, such as including food intake and worker mobility, or water consumption in the construction site, which are not included in the general methodology of the indicator; footprints associated with cropland, pasture and fishing appear due to the inclusion of food.

The methodology and all the steps which are part of the calculation are explained and new hypothesis are proposed, making it easy to implement the current analysis in the EF evaluation of any dwelling construction project.

Keywords: Conversion factors, Dwelling construction, Ecological deficit, Ecological footprint, Food intake, Productivity factors, Productive land, Standard productive territory, Water consumption, Worker mobility.

INTRODUCTION

In the construction sector, the EF indicator has been applied to study the growth of high-rise districts in Tehran [1], peasant homes [2], hotels [3], and the rehabilitation of an old house [4], in order to have a developed tool to estimate the EF and carbon footprint of buildings [5]. Teng and Wu [6] analyzed the life cycle of buildings (project execution, use and demolition) and its EF (energy, resources, and solid waste CO_2), applying it to an exhibition centre in Wuhan (China). Two main studies, Bastianoni *et al*. [7] and Solís-Guzmán *et al*. [8] have chosen the EF indicator and have tried to adapt their methodology to the peculiarities of the construction sector; and both cover the construction phase of the building. Bastianoni *et al*. [7] calculated the EF of two Italian buildings, primarily considering the embodied energy of materials and the construction process (the last is estimated as 5% of the total energy of the materials). The results are reflected in land for CO_2 absorption, forest land (for wood materials), and the area occupied by buildings.

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Solís-Guzmán *et al*. [8] developed a similar calculation model with some innovative aspects, such as including food intake and worker mobility, or water consumption in the construction site, which are not included in the general methodology of the indicator; footprints associated with cropland, pasture and fishing appear due to the inclusion of food intake.

The last methodology has been successfully evaluated in 100 construction projects in Spain [9] and has shown itself to be sensitive to changes in building characteristics, such as whether the dwelling is detached, is of one or two floors, and whether it is a multi-family dwelling. These changes significantly affect the results. The methodology and structure defined can be adapted for use in other countries by means of regional or national construction breakdown systems, by following the proposed steps: define the budget quantities into construction systems; then transform these into impacts such as materials, manpower and machinery; and finally, determine the resources consumed and their corresponding EF.

In the present book, the previous model has been improved in order to predict the power demand on a construction site and the EF of the worker's meal. The indirect costs of the project budget that cover the rental of temporary offices and toilet facilities, and the leasing of cranes, among other general expenses, are analysed from an electricity-intensity standpoint; this power consumption can be also established for various projects.

Solis-Guzman *et al*. [8] and Gonzalez-Vallejo *et al*. [9], based on Domenech´s work [10], calculate the EF of the worker's meal from an economical point of view, where a 10-Euro cafeteria menu is evaluated. A new methodology is proposed where the reports from the Food and Agriculture Organization of the United Nations (FAO) [11] and the Global Footprint Network (GFN) [12] are analysed and combined (weighted averages) in order to determine the footprint of a daily meal.

As stated in Chapter 1, there are two well-recognized methodologies to measure EF: the component method and the compound method. While the compound method is based on national statistics of input-output flows (production, import, export), the component method is based on life-cycle data for each individual component involved in calculations. In general, in the case of the application of EF to any type of product, the application of the component method is preferred for the EF assessment, since it is based on the real life-cycle data of the processes. Furthermore, either of two perspectives, namely additive and mutually exclusive use of land, can be adopted.

In the present methodology for building construction, the component method is applied to materials (life-cycle data), and to direct machinery consumptions. However, input-output flows are also used in the food consumption analysis, where international statistics are employed in order to determine the average worker's meal, the food productivity, and energy intensity.

In the present book, the last methodology and all the necessary calculations are explained in detail, making easy to implement them in the EF evaluation of any dwelling construction project.

OBJECTIVES

The objectives focus on developing a methodology to calculate the EF of residential buildings. The area of study is centred on the construction, in the first phase of the building process, as shown in Fig. (**5**).

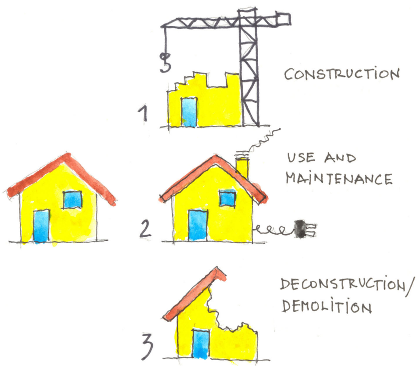

Fig. (5). Dwelling life cycle: dwelling construction, usage and maintenance, and demolition/deconstruction.

The complexity of the EF calculations limits the ability to extend the investigation to the other two phases of the life cycle of buildings, those of use and

CHAPTER 3

Direct Consumption: Energy and Water

Abstract: The impact sources of energy and water, which consume resources directly, are analysed. Both are crucial in the EF calculation. First, for energy consumption, both fuel and electricity are examined. The transformation of these two types of consumption into EF values is performed through the existing EF methodology, although certain procedures have to be adapted to the building sector. The conversion of energy to productive territory considers forest land as the productive land necessary for the absorption of CO_2 emissions resulting from burning fuel. In the energy footprint of the building, the average absorption factor obtained from urban vegetation is applied. Using the absorption and emission factors established, the energy productivity is obtained.

Secondly, the water supply EF is evaluated. Generally, all EF studies obviate this aspect due to the intrinsic difficulty of transforming water consumption data into a quantity of consumed land; a transformation is proposed. In the water EF, the forest productivity is employed, which is taken as 1,500 m^3/ha/year.

Keywords: Absorption factor, Conversion factors, Dwelling construction, Ecological footprint, Electricity, Emission factor, Energy, Forest productivity, Fuel, Fuel productivity factor, Productive land, Water consumption.

INTRODUCTION

This section analyses the impact sources of energy and water, which consume resources directly. Both are crucial in the EF calculation. First, for energy consumption, both fuel and electricity are examined. The transformation of these two types of consumption into EF values is performed through the existing EF methodology, although certain procedures have to be adapted to the building sector. Secondly, the water supply EF is evaluated. Generally, all EF studies obviate this aspect due to the intrinsic difficulty of transforming water consumption data into a quantity of consumed land. In this section, a transformation is proposed.

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ENERGY

The energy analysis follows the sequence described in Fig. (**7**), where energy consumption is grouped into two main types of consumption: fuel and electricity. Fuel is consumed by construction machines; and electricity is needed for electric machines and temporary offices and meeting rooms on the construction site, *etc*.

Electricity and Fuel

From the point of view of consumption impacts occurring in the building construction, electricity is one of the most prevalent. It is necessary to start from a primary energy source, which, throughout the twentieth century, was basically of fossil origin (coal, oil or natural gas), used in thermal plants which produced electrical energy. Alternative sources include nuclear, hydroelectric and, in the last 30 years, renewable energy plants.

It is necessary to ascertain the electrical energy sources in order to evaluate how the electricity consumption translates into the EF. In Table **5**, the energy sources in Spain for power generation are represented, and data from various bibliographic sources is provided in order to compare values.

Table 5. Electric mix in Spain.

Generation/ Percentage	**Andalusia 1996 [1]**	**Spain 2000 [2]**	**Spain 2005 [3]**	**Spain 2006 [4]**	**Spain 2007 [5]**
Fossil fuels	50	49.1	57.7	59.1	62.2
Coal	33	32.3	29.1	22.4	23.9
Oil	9	9.2	8.7	7.9	6.8
Natural gas	8	7.6	19.9	28.8	31.5
Hydroelectric	16	16.3	12.1	9.8	9.7
Nuclear	30	30.1	23.1	18.8	17.7
Renewable	4	4.5	7.1	10.7	10.4
Total	100	100	100	100	100

The first column shows data from Andalusia [1] and the following columns show Spain´s electricity generation sources (sequentially: [2 - 5]), all with very similar values from one year to the next. A tendency to reduce the use of nuclear energy

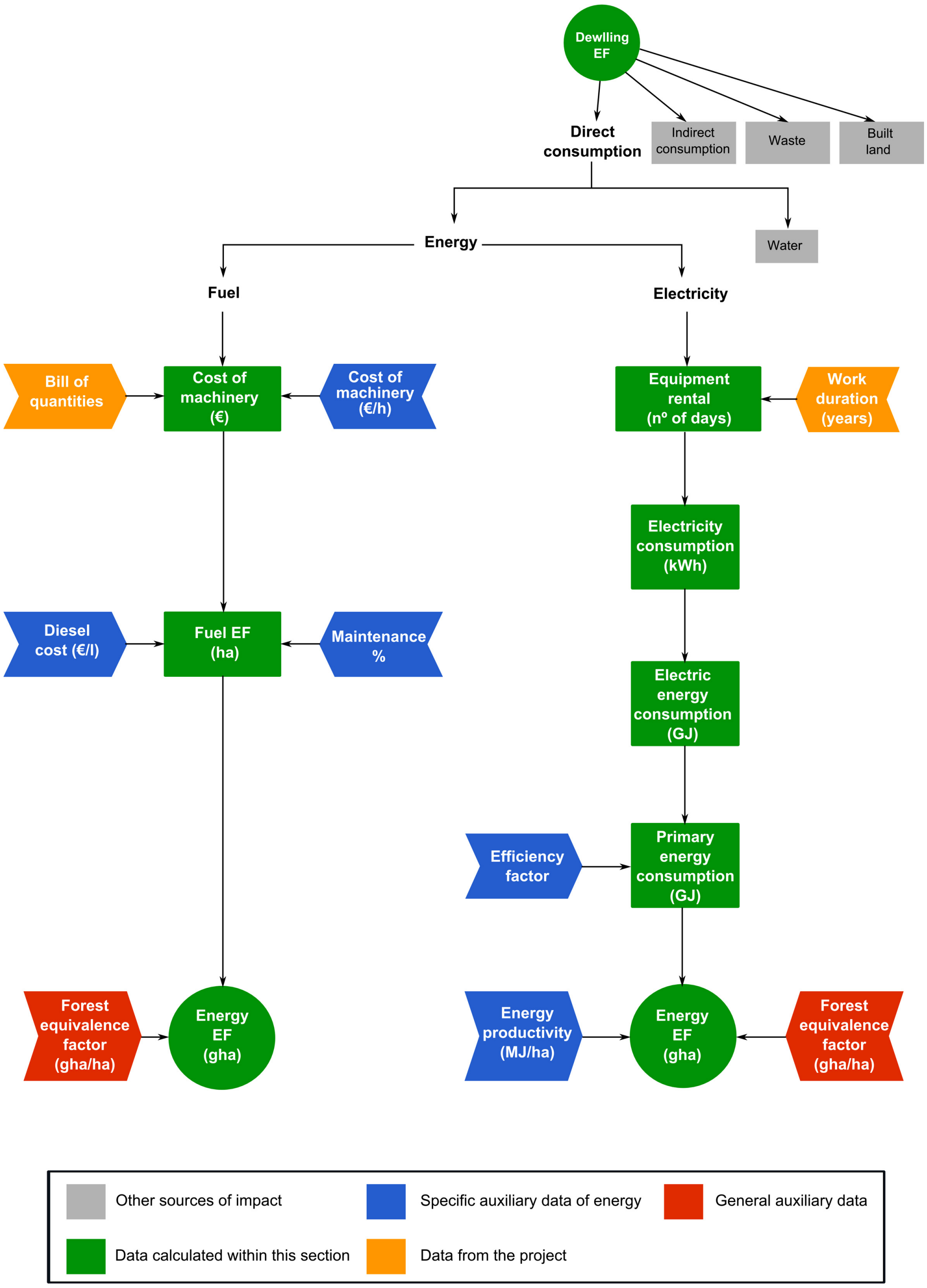

Fig. (7). Calculation of the energy footprint sequential.

CHAPTER 4

Indirect Consumption: Manpower and Construction Materials

Abstract: This chapter analyses the impact sources that consume resources indirectly, that is, the impact is caused not by the source, but by its components. For this study, we focus on two of these components: manpower and material consumption, both of great importance in the EF calculation.

First, the manpower consumption is studied by focusing on the most determinant aspects of its impact: food and mobility. The transformation of these consumptions into EF values is performed by previously documented processes which are adapted to the specific characteristics of the building sector. Second, the EF associated to the consumption of construction materials is evaluated during the building execution process; which takes into account the energy consumption deriving from the manufacture, transport and installation of each of the materials used in the construction of buildings.

Keywords: Absorption factor, Construction materials, Conversion factors, Dwelling construction, Ecological footprint, Electricity, Embodied energy, Emission factor, Forest productivity, Fuel productivity factor, Manpower, Mobility, Natural productivity, Productive land, Water consumption.

INTRODUCTION

This chapter analyses the impact sources that consume resources indirectly, that is, the impact is caused not by the source, but by its components. For this study, we focus on two of these components: manpower and construction material consumption, both of great importance in the EF calculation.

First, the manpower consumption is studied by focusing on the most determinant aspects of its impact: food and mobility. The transformation of these consumptions into EF values is performed by previously documented processes which are adapted to the specific characteristics of the building sector. Second, the EF associated to the consumption of building materials is evaluated during the

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building execution process. This section analyses the energy consumption deriving from the manufacture, transport and installation of each of the materials used in the construction of buildings.

MANPOWER

The consumption associated to manpower is divided into that arising from the workers' transportation and that caused by the food consumption on the construction site.

Food

The methodology follows the sequence described in Fig. (**12**). To calculate the EF of the building sector, it is necessary to take into account the consumption caused by all actors involved in the execution of the work. Therefore, food consumption is also an impact source to consider, although its impact is indirect. Food consumption, in all EF analyses at consumer level, appears as a parameter of study, and is considered in the consumption rates of the building sector.

Table 16. The EF of food.

Food	EF (gha per year per tonne)
Cereal	1.7 - 2.8
Pulses	3.6 - 4.4
Vegetables	0.3 - 0.6
Meat	6.9 (pasture) - 14.6 (animals in captivity)
Milk	1.1 - 1.9
Fish	4.5 - 6.6
Fruit	0.5 - 0.6

Consumer goods in general and food in particular, are usually expressed in tonnes consumed, and then transformed into hectares to obtain EF rates. In fact, in the analysis of the EF by component for regions or organizations, one of the typical components of study is food consumption, expressed in tonnes [1].

A summary of the results of this analysis is shown in Table **16**, and graphically in Fig. (**13**). It shows a list of the most important foods, classified into large groups,

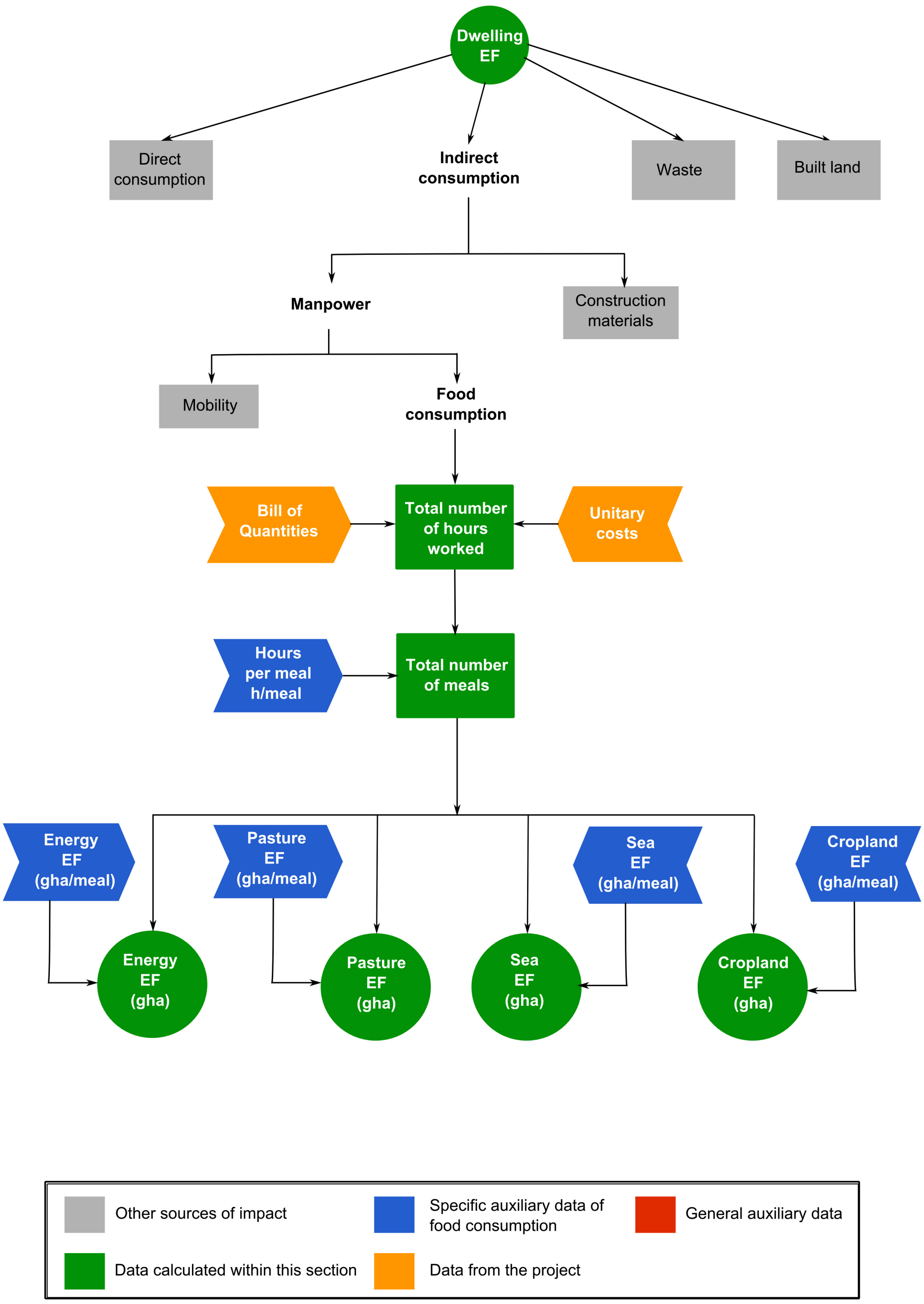

Fig. (12). Sequential calculation of footprint associated with food consumption.

CHAPTER 5

Waste and the Constructed Area

Abstract: In this chapter, the environmental impact of waste and the constructed area are analysed. The waste is defined as those residues most relevant to the present model: urban waste and construction and demolition waste. For the urban waste, the generation estimates per person per year from statistical data are employed. In the case of the CDW, generation estimates come from a software tool, developed, among others, by the present authors and, which gives, according to the residential typology considered, the CDW volume expected.

Once the expected waste volumes are determined, the waste analysis is based on the methodology found in Wackernagel´s studies into the determination of its footprint. His work establishes that the footprint associated with waste disposal, emissions, and/or discharges is calculated in the same way as for the materials: the same energy intensity (embodied energy) is applied but the percentage of energy that can be recovered for recycling is deducted.

In the constructed land EF calculation, only the land used for urbanization and buildings is considered. In this case, a conversion factor is unnecessary because the units are already in terms of surface area, and the area passes from m^2 to ha. The equivalence factor is that of agricultural land, since most of the infrastructure and built land are located in areas of agricultural quality.

Keywords: Absorption factor, Construction and demolition waste, Conversion factors, Dwelling construction, Ecological footprint, Embodied energy, Emission factor, Natural productivity, Productive land, Urban solid waste.

WASTE

In this section, the environmental impact of waste is analysed. This analysis focuses on those residues most relevant to the present model: urban waste and construction and demolition waste (CDW). The waste generated throughout the life cycle of the building are varied and of diverse origins. Focusing on the building construction phase, two main classes can be identified: municipal solid waste (MSW), generated on the construction site; and the CDW generated by the

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construction materials and their packaging. The municipal solid waste is distributed as in Fig. (**18**) [1] and the CDW in Fig. (**19**) [1].

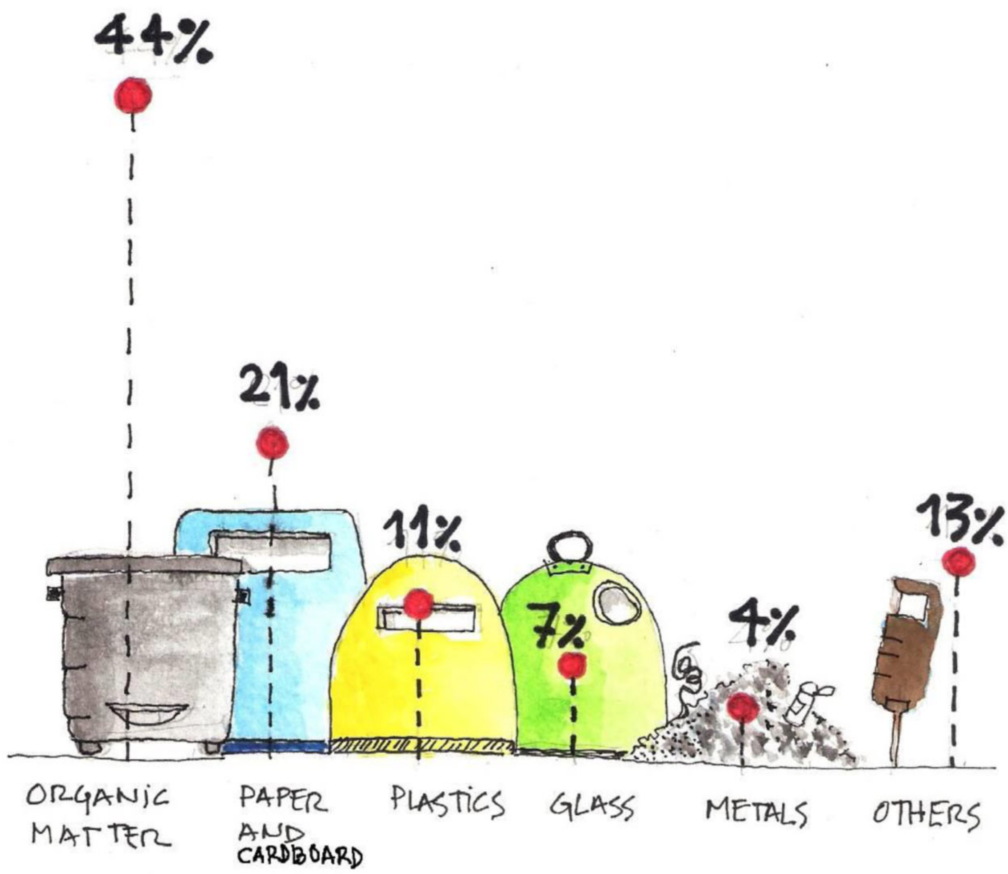

Fig. (18). The percentages of the MSW components.

Fig. (**20**) shows the methodology for calculating the waste EF to be followed in this section. In the same figure, the top level, or first step, is to determine the type and quantities of the waste generated. That is, the volume of waste that is produced on the construction site. There are the two main categories: municipal solid waste (MSW) and construction and demolition waste (CDW).

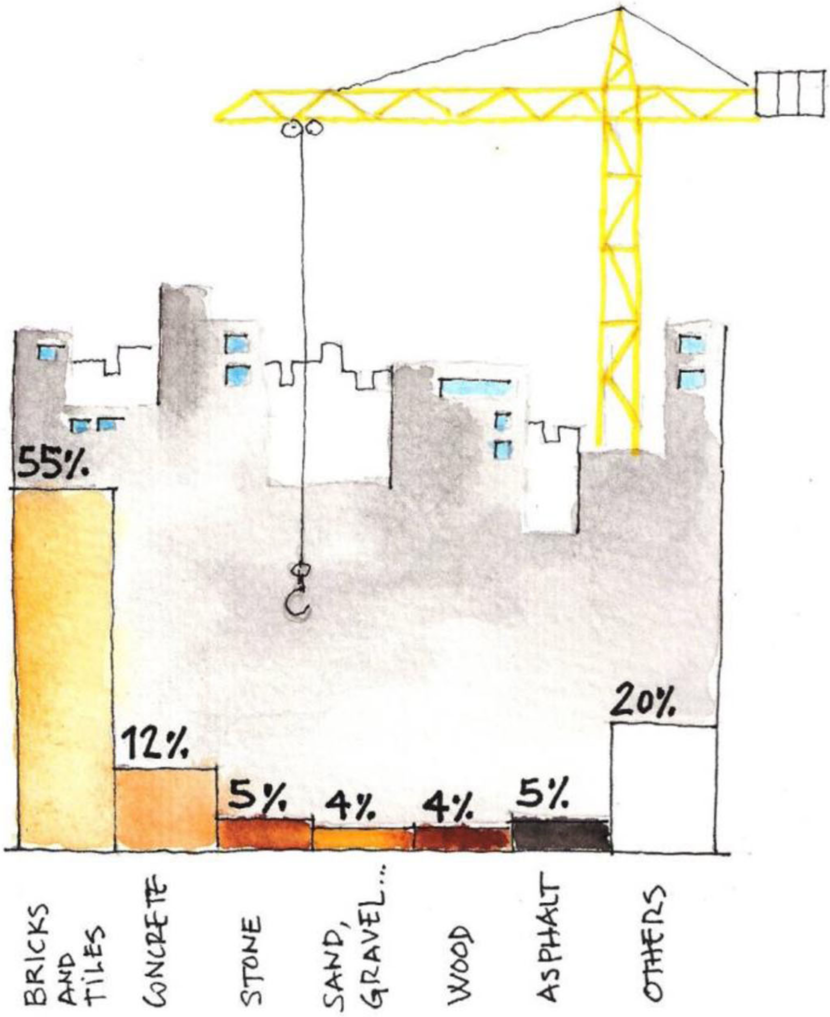

Fig. (19). The percentages of the CDW components.

In 2007, generation estimates are of 516 kg per person per year or 1.41 kg per person per day [2]. These amounts refer to household urban waste, with or without selective collection and without considering those from construction and demolition, or urban waste from industry.

The CDW, mainly generated during the construction and demolition phase, is waste, which, due to its high volume, needs to be managed properly. Spain

CHAPTER 6

Case Study

Abstract: A building and urbanization project of one hundred multifamily dwellings in Spain is studied in detail and its ecological footprint (EF) determined. The same methodology is then applied to the construction of other ten projects that include detached, semi-detached and multifamily dwellings. The impact factors are grouped into: direct consumption (energy and water), indirect consumption (manpower and construction materials), waste, and land occupied directly. The manpower impact in building construction is mainly food intake and mobility (workers commuting to the construction site).

For construction material analysis, the project bill of quantities is employed; each material quantity is transformed into its corresponding embodied energy, and expressed in terms of EF. A similar analysis, but using empirical and statistical data, is performed with the power consumption on the construction site and the workers' mobility. The waste generated, which is municipal solid waste and construction and demolition waste, is included in the analysis. Finally, the land directly occupied by the construction project also has a footprint. In summary, each element that forms part of the construction project uses resources (energy, water, manpower, materials) or generates waste, giving rise to an EF. The most important impact in all cases analysed is the embodied energy of construction materials, almost 90%, followed by the food intake by the workforce, 5-9%.

The partial and global footprints obtained are: forest, food, energy, built land, and total EF.

Keywords: Absorption factor, Construction materials, Conversion factors, Dwelling construction, Ecological footprint, Electricity, Emission factor, Forest productivity, Food intake, Fuel, Fuel productivity factor, Productivity factors, Productive land, Standard productive territory, Water consumption, Worker mobility.

INTRODUCTION

In order to validate the methodology proposed in the previous chapters, first, a

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representative dwelling project in Spain [1, 2] is studied in detail. In second place, the results from other 10 different projects, detached, semi-detached and multifamily dwellings, are analysed and the results compared.

The first project assessed is representative of the most common dwelling type in Spain [1 - 3], which corresponds to 4-storey blocks of flats and commercial offices at ground level, see Fig. (**23**); and the constructed areas per storey and block are listed in Table **34**.

Fig. (23). Representative dwelling building [5].

Table 34. Constructed area per block.

Floor	**Block 1 (m^2)**	**Block 2 (m^2)**
Underground level -2	1,476.09	1,312.08
Underground level -1	1,476.09	1,312.08
Ground floor	1,359.06	1,197.86
First floor	1,359.15	1,197.86
Second floor	1,363.35	1,201.53
Third floor	1,363.35	1,201.53
Roof	113.61	81.28
TOTAL	**8,510.70**	**7,504.22**
Total area constructed	**m^2**	**16,014.92**

At the end of the chapter the same methodology is applied to ten dwelling projects of different types and sizes: single family dwellings of 1 and 2 storeys, and multi-family buildings of 3, 4, 5, 6 and 10 storeys, (see Table **35**).

Table 35. Floor area of the ten dwelling projects.

Project number									
1	2	3	4	5	6	7	8	9	10
Number of floors over ground level									
1	2	2	3	3	4	5	5	6	10
Total floor area (m^2)									
2697	3836	5754	4440	4440	6661	6662	7772	12211	13320

In all the projects analysed, it is considered that the only activity that takes place on the land is that of the construction activities. This impact lasts one year; the time for the construction to be completed. During the analysis, the electric power and water consumptions are estimated from empirical data of similar building projects. Other impacts are determined from the project bill of quantities and its general characteristics.

METHODOLOGY

The methodology described in previous chapters can be summarized as follows:

1. Defining the impact factors. These are the generators of impact on the land and are classified into: direct consumption, indirect consumption, waste generation and built land. Direct consumption refers to direct use of resources on the construction site, such as energy expenditure (fuel or electricity consumption) and water usage. Indirect consumption is caused by the indirect use of resources, such as material or energy resources from other previous processing:
   - Manpower
   - Building material consumption

   The manpower during the building construction involves food intake by the operators (human energy source), and the use of fuel in the workers' transportation (commutes to the construction site).

   The building materials, the corresponding total kg of material consumed is determined from the bill of quantities; that amount is then translated into primary energy consumption or embodied energy, and finally expressed in terms of EF.

   The third impact factor is the waste generated on the construction site, which

APPENDIX A. NOMENCLATURE

Variable	Expression	Meaning	Measuring unit
1	AA	Appropriate area for the production of each category	ha
2	C	Total Consumption	t,m^3,GJ
3	P	Productivity	t/ha, GJ/ha
4	aa	Appropriate area for the production of each category per habitant	ha/hab
5	N	Size of analyzed population	hab
6	ef_N	EF	ha/hab y year
7	EF	EF	ha/year
8	EF_W	Weighted EF	gha/year
9	e	Equivalence factor	gha/ha
10	Lsp	Standard production land	gha
11	Lp	Productive land	ha
12	Y	Yield factor	-
13	Lpc	Corrected productive land	gha
14	Ltp	Total productive land	gha
15	Lb	Land for biodiversity	gha
16	D	Ecological deficit	gha
17	Pee	Electric energy production	GJ
18	Fef	Efficiency	-
19	EP	Fuel productivity	GJ/ha
20	A	Absorption factor	kg CO_2/ha
21	E	Emission factor	kg CO_2/GJ
22	t	Time Lapse	year
23	FP	Forest productivity	m^3/ha
24	EF_{ww}	Weighted EF of water consumption	gha
25	e_f	Forest equivalency factor	gha/ha
26	NP	Natural productivity	t/ha
27	EF_{wf}	Weighted EF of food (fossil)	gha
28	EI	Energy intensity	GJ/t
29	E	CO_2 emissions	kg
30	Fc	Conversion factor	-

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Table contd.....

Variable	Expression	Meaning	Measuring unit
31	Eemi	Embodied energy	MJ
32	Cmi	Material consumption	kg
33	Esemi	Specific energy embodied of material	MJ/kg
34	CR	Conversion rate of non-hazardous waste	ha/t
35	EPi	Energy productivity	GJ/ha
36	%Rx	Recycling rate	-
37	%SEx	Percentage of energy saved by recycling	-
38	EFwws	Weighted EF of the waste	gha
39	CRx	Weighted conversion rate of non-hazardous waste	gha/t
40	e_f	Fossil energy equivalence factor	gha/ha
41	EF_{wb}	Weighted EF of built land	gha
42	S	Surface area consumed	ha
43	e_b	Equivalence factor of built land	gha/ha

APPENDIX B. ABBREVIATIONS

1. LCA: Life Cycle Analysis
2. cap: per capita (per habitant)
3. e: equivalence factor
4. GHG: Greenhouse Gases
5. GJ: gigajoules
6. ha: hectare
7. gha: global hectares
8. EF: EF
9. kWh: Kilo-watt hour
10. I-O: Input-Output Analysis
11. IPCC: Intergovernmental Panel on Climate Change
12. REAP: Resources and Energy Analysis Program
13. CDW: Construction and Demolition Waste
14. MSW: Municipal Solid Waste
15. t: ton

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APPENDIX C. GLOSSARY OF TERMS

1. Biocapacity: see capacity.
2. Capacity: number of people in the current circumstances on the planet could sustain over a long period of time (decades) without deteriorating the overall productivity of the land.
3. Compost: Compost (sometimes also called compost) is the product obtained from composting, and is an "intermediate" decomposition of organic matter, which is in itself a good fertilizer.
4. Direct consumption: those that generate direct consumption of resources on site.
5. Indirect consumption: those that generate indirect resource consumption, as consumption of energy or material resources come from previous resources.
6. Ecological Deficit: difference between the area available (capacity) and the area consumed (EF).
7. Sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
8. Embodied energy: energy content of the materials in the processes of raw material extraction, production, processing, transportation partners, laying, maintenance and disposal.
9. Equivalence or weighting factor: provides the differences in average global productivity among different types of landscape.
10. Factor productivity or performance: compare local productivity of each category of land about a hypothetical type of territory whose biological productivity is the global average of all territories.
11. EF: tract of land that would be needed to provide the resources (cereals, fodder, fuel, fish and urban land) and absorb the emissions (CO_2) of world society.
12. Weighted footprint: EF given in standard productive hectares (gha).
13. Energy intensity: energy consumption (GJ) for each tonne of agricultural resources already available to consumers
14. Natural Productivity: amount of land (ha) required to produce 1 t of resources (food).
15. Energy Productivity: amount of land (ha) required to produce 1 GJ of energy.
16. Recycling rate: is defined as the weight of material that is recycled to the weight of waste generated.
17. Territory for CO_2 absorption: area of forest required to absorb CO_2 emissions due to consumption of fossil fuels for energy production.
18. Productive territory: see capacity.

19. Standard productive territory: average surface biological productivity worldwide. That is, the productivity factor is 1

APPENDIX D. EMBODIED ENERGY FROM DIFFENT SOURCES

Table D1. The specific embodied energy of construction materials according to 6 different sources. Simple materials.

Material	**Specific embodied energy (MJ/kg)**					
Source	**[18]**	**[6]**	**[20]**	**[17]**	**[16]**	**[13]**
Commercial steel (20% recycled)	35	43	43	35-43	30.13	25
100% recycled steel (theoretical)	17					9
Stainless steel				177		
Primary aluminium	215	160	180	205	180	200
100% recycled aluminium (theoretical)	23					
85% recycled aluminium						45
Fired clay, brick and tiles	4.50				2.90	2
Fired clay, ceramics, vitrified materials	10			7.20		8
Fired clay. Sanitary ware	27.50					
Sand (aggregates)	0.10	0.10	0.10	0.10	0.08	0.50
Recycled aggregates				0.10		
Asphalt in fabric (oxy-asphalt)	10		10.00	10.00		
Lime				3.43		4.5-5.0
Plasterboard				7.90	5.73	5
Cement	7	7.20	7.20	7.00		3.6-4.0
Ceramic				2.3-2.5		
Glazed ceramic				13.00		
Primary copper	90	90	90	150		85
Fibre cement (of asbestos)	6			9.50		
Fibre cement (synthetic fibres or wood)	9			9.50		
Natural fibre				1.70		
Mineral fibre				2.35	18.40	
Synthetic fibre				30		
Fibreglass	30		30	22		35
Gravel	0.10	0.10	0.10			
Stoneware				10.90		

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(Table D1) contd.....

Material	**Specific embodied energy (MJ/kg)**					
Source	**[18]**	**[6]**	**[20]**	**[17]**	**[16]**	**[13]**
Temperate-climate wood	3	3	3	2.10		
Tropical wood	3					
Wood, formaldehyde-free chipboard	14	14	14	14		
Wood, chipboard with formaldehyde	14					
Wood, plywood	5	5	5			
Paper				31.10		
Plastic paint (water-based) green-compliant	20					
Plastic paint (water-based)	20	20	20	20	42.23	
Synthetic paints and varnishes (enamel), organic solvent-based, organic-compliant	100			90		
Synthetic paints and varnishes (enamel) based on organic solvents	100	100	100			
Stone				0.18		0.50
Lead				190		22
Polycarbonate				79		
Polychloroprene (neoprene)	100	120	120	100-120		
Expanded polystyrene (EPS)	100	100	100	100-115		125
Extruded polystyrene (XPS) with HCFC-type blowing agent	100			100-115		133
Extruded polystyrene (XPS) with CO_2-type blowing agent	100					130
Primary polyethylene	77	75		85		110
Recycled PE (over 70%)			75			
Primary polypropylene	80		77			115
Polyurethane (PUR) with HCFC-type blowing agent or dichloromethane	70			70	82.33	135
PUR with CO_2-type blowing agent or similar	70	70	70			135
Primary PVC	80	80	80	70	53.82	85
Terrazzo				2.30		1.50
Sheet glass	19	19	19	19	16.20	
Gypsum-plaster	3.30	3.30	3.30	2.57	2.45	1

Table D2. The specific embodied energy of construction materials according to 6 different sources. Compound materials.

Material	**Specific embodied energy (MJ/kg)**					
Source	**[18]**	**[6]**	**[20]**	**[17]**	**[16]**	**[13]**
Hollow brick wall	2.96		2.80		2.90	
Perforated brick wall	2.85					
Solid brick wall	2.86					
H-150 concrete	0.99					
H-175 concrete	1.03					
H-200 concrete	1.10					
Prefabricated concrete				2.30		1.50
M-40/a mortar	1					
M-80/a mortar	1.34					
Prefabricated mortar				2.0-2.5	2.25	1
Aluminium windows / doors					218	
Wooden windows / doors					26.85	

APPENDIX E. MATERIALS EMBODIED ENERGY

Table E1. Construction materials embodied energy.

Construction material	**u**	**Mm (u)**	**Cc (kg/u)**	**Cm (kg)**	**Eiem (MJ/kg)**	**Eim (MJ)**
Acrylic						
Acrylic block label	u	4.0	0.27	1.0	90	96
Acrylic door label	u	218.0	0.27	58.2	90	5,238
Acrylic story label	u	28.0	0.27	7.4	90	673
Aluminium						
Aluminium folding door	m2	14.4	9.36	135.2	200	27,044
Aluminium sliding door	m2	327.6	20.00	6552.0	200	1,310,400
Aluminium grid	u	428.0	0.00	1.7	160	274
Aluminium air vent	u	667.9	0.33	220.4	160	35,266
Air conditioned input mesh	u	856.0	0.04	36.8	160	5,889
Aluminium sliding door	m2	470.2	9.36	4401.4	200	880,271
Recessed alarm button	u	12.5	0.05	0.6	160	102
Aluminium sliding door	m2	110.8	9.36	1036.8	200	207,365
Brass						
Handle brass	u	38.6	0.01	0.5	100	46
Plain key lock	u	16.2	0.22	3.6	100	356
Plain key lock	u	84.1	0.22	18.5	100	1,851
Main door lock	u	107.6	0.22	23.7	100	2,367
Brass knob set	u	107.6	0.31	33.3	100	3,334
Brass knob or handle set	u	864.6	0.35	302.6	100	30,262
Main valve diam. 8 mm	u	214.0	0.48	102.7	100	10,272
Main valve, faucet 1 1/4"	u	4.0	0.50	2.0	100	200
Main valve, diam. 1"	u	163.5	0.75	122.6	100	12,263
Main valve, diam. 3/4"	u	968.0	0.65	629.2	100	62,920
Angle main valve diam. 1/2"	u	1070.0	0.50	535.0	100	53,500
Spyhole	u	108.3	0.05	5.3	100	531
Hasp	u	38.6	0.29	11.3	100	1,134

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(Table E1) contd.....

Construction material	u	Mm (u)	Cc (kg/u)	Cm (kg)	Eiem (MJ/kg)	Eim (MJ)
Cabinet brass bolt, 11 cm	u	3009.7	0.11	331.1	100	33,107
Handle	u	967.7	0.26	247.7	100	24,774
Sliding door handle	u	4.4	0.32	1.4	100	141
Door badge	u	11.5	0.05	0.6	100	58
Sliding door system	u	4.4	1.00	4.4	100	442
Brass lid of siphon sink	u	214.0	52.54	11243.6	100	1,124,356
Sluice valve diam. 1 1/2"	u	15.0	19.00	285.0	100	28,500
Ball valve diam. 2 1/2"	u	4.0	3.24	13.0	100	1,296
Sink valve with chain and lid	u	107.0	0.31	33.2	100	3,317
Main input valve of meter	u	117.0	6.00	702.0	100	70,200
Retention valve, dia. 1 1/2"	u	4.0	0.35	1.4	100	139
Meter main output valve	u	117.0	6.00	702.0	100	70,200
Cement						
White cement in sacks	t	7.1	1000.00	7110.0	7	49,770
Cement in sacks	t	173.1	1000.00	173069.0	7	1,211,483
Ceramic						
Tile 15×15 cm	u	335658.5	0.30	100697.6	8	805,580
Floor tile 14×28 cm	u	145339.5	0.74	107551.2	3	311,899
Brick 25×11.5×7 cm	mu	6.7	2100.00	14007.0	3	40,620
Brick 24×11.5×7 cm	mu	4.4	1320.00	5742.0	3	16,652
Brick 24×11.5×9 cm	mu	239.6	1550.00	371395.5	3	1,077,047
Brick 24×11.5×44 cm	mu	144.4	1948.00	281291.2	3	815,744
Brick 24×11.5×5 cm	mu	318.6	2100.00	669018.0	3	1,906,701
Perforated brick	mu	5.7	2100.00	11961.6	3	34,091
Slimed format brick	u	255.0	0.74	188.7	3	547
Plinth 14×28 cm	u	2860.0	0.74	2116.4	3	6,138
Concrete						
Block 40×20×12cm	u	22803.1	11.00	250834.2	2	501,668
Concrete ventilation duct	m	834.9	191.67	160023.4	2	320,047
Cellular concrete	m3	303.7	500.00	151870.0	1	151,870
Concrete HA- 25	m3	1271.4	2500.00	3178425.0	1	3,178,425
Concrete HA- 25	m3	2985.4	2500.00	7463462.5	1	7,463,463

(Table E1) contd.....

Construction material	u	Mm (u)	Cc (kg/u)	Cm (kg)	Eiem (MJ/kg)	Eim (MJ)
Concrete HA- 30	m3	1184.4	2500.00	2961062.5	1	2,961,063
Concrete HM- 20	m3	156.7	2500.00	391687.5	1	391,688
Concrete HM-20	m3	6.6	2300.00	15157.0	1	15,157
Reinforced concrete lid	m2	10.1	100.91	1016.2	2	2,032
Copper						
Coaxial cable TV	m	32.0	0.01	0.3	100	32
Cable 1×1 mm2/750V	m	1070.0	0.01	15.0	100	1,498
Cable 1×1.5 mm2/750 V	m	25698.7	0.02	488.3	100	4,882,760
Cable 1×16 mm2/750 V	m	10.1	0.18	1.8	100	177
Cable 1×2.5 mm2/750 V	m	43950.0	0.02	966.9	100	96,690
Cable 1×35 mm2/1000 V	m	45.8	0.43	19.8	100	1,977
Cable 1×4 mm2/750 V	m	606.0	0.05	27.3	100	2,727
Cable 1×6 mm2/750 V	m	10606.3	0.06	668.2	100	66,820
Stripped copper wire	kg	50.6	1.00	50.6	100	5,059
80 A fuse set	u	342.0	0.42	143.6	100	14,364
Triple copper wire	m	3474.6	0.02	55.6	100	5,559
50 A fuse set	u	115.0	0.06	6.3	100	633
Electric ground	u	116.0	0.10	12.1	100	1,206
Tube dia. 5/8"	m	532.3	0.33	175.7	100	17,567
Tube dia. 1 1/8"	m	562.1	0.60	337.3	100	33,726
Tube dia. 13/15 mm	m	1920.8	0.39	749.1	100	74,910
Tube dia. 16/18 mm	m	1639.1	0.48	786.8	100	78,676
Tube dia. 20/22 mm	m	2937.8	0.59	1733.3	100	173,332
Chromed tube dia. 8 mm	m	267.5	0.19	51.9	100	5,190
Glass						
Colourless glass 4 mm	m2	778.3	12.50	9728.1	18	175,106
Textured colourless 3-4 mm	m2	119.5	10.00	1194.7	18	21,505
Gypsum						
Metallic frame, 46×600 mm	m2	3835.6	2.70	10356.2	7	72,493
Metallic frame, 46×400 mm	m2	9162.4	2.70	24738.5	7	173,169
Gypsum-cardboard 13 mm	m2	21253.5	10.00	212534.5	7	1,487,742
Gypsum-cardboard 15 mm	m2	11216.7	12.00	134600.3	7	942,202

SUBJECT INDEX

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