

Fair Play: Why Reliable Data for Low-Tech Construction and Non-conventional Materials Are Needed

Original

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Eugenio Arbizzani · Eliana Cangelli ·
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Technological Imagination in the Green and Digital Transition

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Contents

1	From a Liquid Society, Through Technological Imagination, to Beyond the Knowledge Society	1
	Anna Maria Giovenale	
2	Opening Lecture: Digital Spaces and the Material Culture	11
	Pietro Montani	
Part I Session Innovation		
3	Innovation for the Digitization Process of the AECO Sector	21
	Fabrizio Cumo	
4	The Digital Revolution and the Art of Co-creation	27
	Maurizio Talamo	
5	Toward a New Humanism of Technological Innovation in Design of the Built Environment	37
	Spartaco Paris	
6	A BIM-Based Approach to Energy Analysis of Existing Buildings in the Italian Context	47
	Marco Morini, Francesca Caffari, Nicolandrea Calabrese, and Giulia Centi	
7	Short-Term Wind Speed Forecasting Model Using Hybrid Neural Networks and Wavelet Packet Decomposition	57
	Adel Lakzadeh, Mohammad Hassani, Azim Heydari, Farshid Keynia, Daniele Groppi, and Davide Astiaso Garcia	
8	COGNIBUILD: Cognitive Digital Twin Framework for Advanced Building Management and Predictive Maintenance	69
	Sofia Agostinelli	

- 9 Design of CCHP System with the Help of Combined Chiller System, Solar Energy, and Gas Microturbine** 79
Samaneh Safaei, Farshid Keynia, Sam Haghdaday,
Azim Heydari, and Mario Lamagna
- 10 Digital Construction and Management the Public’s Infrastructures** 93
Giuseppe Orsini and Giuseppe Piras
- 11 An Innovative Multi-objective Optimization Digital Workflow for Social Housing Deep Energy Renovation Design Process** 111
Adriana Ciardiello, Jacopo Dell’Olmo, Federica Rosso,
Lorenzo Mario Pastore, Marco Ferrero, and Ferdinando Salata
- 12 Digital Information Management in the Built Environment: Data-Driven Approaches for Building Process Optimization** 123
Francesco Muzi, Riccardo Marzo, and Francesco Nardi
- 13 Immersive Facility Management—A Methodological Approach Based on BIM and Mixed Reality for Training and Maintenance Operations** 133
Sofia Agostinelli and Benedetto Nastasi
- 14 A Digital Information Model for Coastal Maintenance and Waterfront Recovery** 145
Francesca Ciampa
- 15 Sustainable Workplace: Space Planning Model to Optimize Environmental Impact** 157
Alice Paola Pomè, Chiara Tagliaro, and Andrea Ciaramella
- 16 Digital Twin Models Supporting Cognitive Buildings for Ambient Assisted Living** 167
Alessandra Corneli, Leonardo Binni, Berardo Naticchia,
and Massimo Vaccarini
- 17 Less Automation More Information: A Learning Tool for a Post-occupancy Operation and Evaluation** 179
Chiara Tonelli, Barbara Cardone, Roberto D’Autilia,
and Giuliana Nardi
- 18 A Prosumer Approach for Feeding the Digital Twin. Testing the MUST Application in the Old Harbour Waterfront of Genoa** 193
Serena Viola, Antonio Novellino, Alberto Zinno,
and Marco Di Ludovico

19 Untapping the Potential of the Digital Towards the Green Imperative: The Interdisciplinary BeXLab Experience 203
 Gisella Calcagno, Antonella Trombadore, Giacomo Pierucci, and Lucia Montoni

20 Digital—Twin for an Innovative Waterfront Management Strategy. Pilot Project DSH2030 217
 Maria Giovanna Pacifico, Maria Rita Pinto, and Antonio Novellino

21 BIM and BPMN 2.0 Integration for Interoperability Challenge in Construction Industry 227
 Hosam Al-Siah and Antonio Fioravanti

22 Digital Twin Approach for Maintenance Management 237
 Massimo Lauria and Maria Azzalin

23 Digital Infrastructure for Student Accommodation in European University Cities: The “HOME” Project 247
 Oscar Eugenio Bellini, Matteo Gambaro, Maria Teresa Gullace, Marianna Arcieri, Carla Álvarez Benito, Sabri Ben Rommane, Steven Boon, and Maria F. Figueira

Part II Session | Technology

24 Technologies for the Construction of Buildings and Cities of the Near Future 263
 Eugenio Arbizzani

25 The Living Lab for Autonomous Driving as Applied Research of MaaS Models in the Smart City: The Case Study of MASA—Modena Automotive Smart Area 273
 Francesco Leali and Francesco Pasquale

26 Expanding the Wave of Smartness: Smart Buildings, Another Frontier of the Digital Revolution 285
 Valentina Frighi

27 Sharing Innovation. The Acceptability of Off-site Industrialized Systems for Housing 295
 Gianluca Pozzi, Giulia Vignati, and Elisabetta Ginelli

28 3D Printing for Housing. Recurring Architectural Themes 309
 Giulio Paparella and Maura Percoco

29 Photovoltaic Breakthrough in Architecture: Integration and Innovation Best Practice 321
 Guido Callegari, Eleonora Merolla, and Paolo Simeone

30 Reworking Studio Design Education Driven by 3D Printing Technologies 335
 Jelena Milošević, Aleksandra Nenadović, Maša Žujović, Marko Gavrilović, and Milijana Živković

31 The New Technological Paradigm in the Post-digital Era. Three Convergent Paths Between Creative Action and Computational Tools 345
 Roberto Bianchi

32 Technological Innovation for Circularity and Sustainability Throughout Building Life Cycle: Policy, Initiatives, and Stakeholders’ Perspective 357
 Serena Giorgi

33 Fair Play: Why Reliable Data for Low-Tech Construction and Non-conventional Materials Are Needed 367
 Redina Mazelli, Martina Bocci, Arthur Bohn, Edwin Zea Escamilla, Guillaume Habert, and Andrea Bocco

Part III Session | Environment

34 Technological Innovation for the Next Ecosystem Transition: From a High-Tech to Low-Tech Intensity—High Efficiency Environment 383
 Carola Clemente

35 Technological Imagination to Stay Within Planetary Boundaries 391
 Massimo Palme

36 Quality-Based Design for Environmentally Conscious Architecture 399
 Helena Coch Roura and Pablo Garrido Torres

37 Digital Transformation Projects for the Future Digicircular Society 403
 Irene Fiesoli

38 The Regulatory Apparatus at the Service of Sustainable Planning of the Built Environment: The Case of Law 338/2000 ... 417
 Claudio Piferi

39 From Nature to Architecture for Low Tech Solutions: Biomimetic Principles for Climate-Adaptive Building Envelope ... 429
 Francesco Sommese and Gigliola Ausiello

40 Soft Technologies for the Circular Transition: Practical Experimentation of the Product “Material Passport” 439
 Tecla Caroli

41 Imagining a Carbon Neutral University 449
 Antonella Violano and Monica Cannaviello

42 Life Cycle Assessment at the Early Stage of Building Design 461
 Anna Dalla Valle

**43 Design Scenarios for a Circular Vision of Post-disaster
 Temporary Settlements** 471
 Maria Vittoria Arnetoli and Roberto Bologna

**44 Towards Climate Neutrality: Progressing Key Actions
 for Positive Energy Districts Implementation** 483
 Rosa Romano, Maria Beatrice Andreucci,
 and Emanuela Giancola

**45 Remanufacturing Towards Circularity in the Construction
 Sector: The Role of Digital Technologies** 493
 Nazly Atta

**46 Territorial Energy Potential for Energy Community
 and Climate Mitigation Actions: Experimentation on Pilot
 Cases in Rome** 505
 Paola Marrone and Ilaria Montella

**47 Integrated Design Approach to Build a Safe and Sustainable
 Dual Intended Use Center in Praslin Island, Seychelles** 523
 Vincenzo Gattulli, Elisabetta Palumbo, and Carlo Vannini

Part IV Session | Climate Changes

48 Climate Change: New Ways to Inhabit the Earth 537
 Eliana Cangelli

**49 The Climate Report Informing the Response to Climate
 Change in Urban Development** 547
 Anna Pirani

**50 The Urban Riverfront Greenway: A Linear Attractor
 for Sustainable Urban Development** 557
 Luciana Mastrodonardo

**51 The Buildings Reuse for a Music District Aimed
 at a Sustainable Urban Development** 567
 Donatella Radogna

**52 Environmental Design for a Sustainable District and Civic
 Hub** 577
 Elena Mussinelli, Andrea Tartaglia, and Giovanni Castaldo

53 Earth Observation Technologies for Mitigating Urban Climate Changes 589
 Federico Cinquepalmi and Giuseppe Piras

54 A Systematic Catalogue of Design Solutions for the Regeneration of Urban Environment Contrasting the Climate Change Impact 601
 Roberto Bologna and Giulio Hasanaj

55 Digital Twins for Climate-Neutral and Resilient Cities. State of the Art and Future Development as Tools to Support Urban Decision-Making 617
 Guglielmo Ricciardi and Guido Callegari

56 The Urban Potential of Multifamily Housing Renovation 627
 Laura Daglio

57 A “Stepping Stone” Approach to Exploiting Urban Density 639
 Raffaella De Martino, Rossella Franchino, and Caterina Frettoloso

58 Metropolitan Farms: Long Term Agri-Food Systems for Sustainable Urban Landscapes 649
 Giancarlo Paganin, Filippo Orsini, Marco Migliore, Konstantinos Venis, and Matteo Poli

59 Resilient Design for Outdoor Sports Infrastructure 659
 Silvia Battaglia, Marta Cognigni, and Maria Pilar Vettori

60 Sustainable Reuse Indicators for Ecclesiastic Built Heritage Regeneration 669
 Maria Rita Pinto, Martina Bosone, and Francesca Ciampa

61 A Green Technological Rehabilitation of the Built Environment. From Public Residential Estates to Eco-Districts ... 683
 Lidia Errante

62 Adaptive Building Technologies for Building Envelopes Under Climate Change Conditions 695
 Martino Milardi

63 The Importance of Testing Activities for a “New” Generation of Building Envelope 703
 Martino Milardi, Evelyn Grillo, and Mariateresa Mandaglio

64 Data Visualization and Web-Based Mapping for SGDs and Adaptation to Climate Change in the Urban Environment ... 715
 Maria Canepa, Adriano Magliocco, and Nicola Pisani

65 Fog Water Harvesting Through Smart Façade for a Climate Resilient Built Environment 725
 Maria Giovanna Di Bitonto, Alara Kutlu, and Alessandra Zanelli

66 Building Façade Retrofit: A Comparison Between Current Methodologies and Innovative Membranes Strategies for Overcoming the Existing Retrofit Constraints 735
 Giulia Procaccini and Carol Monticelli

67 Technologies and Solutions for Collaborative Processes in Mutating Cities 745
 Daniele Fanzini, Irina Rotaru, and Nour Zreika

68 New Perspectives for the Building Heritage in Depopulated Areas: A Methodological Approach for Evaluating Sustainable Reuse and Upcycling Strategies 757
 Antonello Monsù Scolaro, Stefania De Medici, Salvatore Giuffrida, Maria Rosa Trovato, Cheren Cappello, Ludovica Nasca, and Fuat Emre Kaya

69 Climate Adaptation in Urban Regeneration: A Cross-Scale Digital Design Workflow 769
 Michele Morganti and Diletta Ricci

70 Adaptive “Velari” 783
 Alberto Raimondi and Laura Rosini

71 Temporary Climate Change Adaptation: 5 Measures for Outdoor Spaces of the Mid-Adriatic City 801
 Timothy Daniel Brownlee

72 A Serious Game Proposal for Exploring and Designing Urban Sustainability 811
 Manuela Romano and Alessandro Rogora

73 Energy Efficiency Improvement in Industrial Brownfield Heritage Buildings: Case Study of “Beko” 821
 Jelena Pavlović, Ana Šabanović, and Nataša Ćuković-Ignjatović

74 Industrial Heritage of Belgrade: Brownfield Sites Revitalization Status, Potentials and Opportunities Missed 831
 Jelena Pavlović, Ana Šabanović, and Nataša Ćuković-Ignjatović

75 Challenges and Potentials of Green Roof Retrofit: A Case Study 843
 Nikola Miletić, Bojana Zeković, Nataša Ćuković Ignjatović, and Dušan Ignjatović

76 Designing with Nature Climate-Resilient Cities: A Lesson from Copenhagen 853
 Maicol Negrello

77 New Urban Centralities: Universities as a Paradigm for a Sustainable City 863
Camilla Maitan and Emilio Faroldi

Part V Session | Health

78 Environment for Healthy Living 875
Francesca Giofrè

79 New Paradigms for Indoor Healthy Living 883
Alberto De Capua

80 Healthy and Empowering Life in Schoolyards. The Case of Dante Alighieri School in Milan 893
Valentina Dessì, Maria Fianchini, Franca Zuccoli, Raffaella Colombo, and Noemi Morrone

81 Design for Emergency: Inclusive Housing Solution 907
Francesca Giglio and Sara Sansotta

82 Environmental Sensing and Simulation for Healthy Districts: A Comparison Between Field Measurements and CFD Model 921
Matteo Giovanardi, Matteo Trane, and Riccardo Pollo

83 A Synthesis Paradigm as a Way of Bringing Back to Life the Artistic Monuments Inspired by the Motives of the People’s Liberation Struggle and Revolution of Yugoslavia 935
Meri Batakoja and Tihana Hrastar

84 Social Sustainability and Inclusive Environments in Neighbourhood Sustainability Assessment Tools 947
Rosaria Revellini

85 Inclusive Neighborhoods in a Healthy City: Walkability Assessment and Guidance in Rome 959
Mohamed Eledeisy

86 Tools and Strategies for Health Promotion in Urban Context: Technology and Innovation for Enhancing Parish Ecclesiastical Heritage Through Sport and Inclusion 969
Francesca Daprà, Davide Allegri, and Erica Isa Mosca

87 Nursing Homes During COVID-19 Pandemic—A Systematic Literature Review for COVID-19 Proof Architecture Design Strategies 981
Silvia Mangili, Tianzhi Sun, and Alexander Achille Johnson

88	A New Generation of Territorial Healthcare Infrastructures After COVID-19. The Transition to Community Homes and Community Hospitals into the Framework of the Italian Recovery Plan	991
	Andrea Brambilla, Erica Brusamolín, Stefano Arruzzoli, and Stefano Capolongo	
89	Wood Snoezelen. Multisensory Wooden Environments for the Care and Rehabilitation of People with Severe and Very Severe Cognitive Disabilities	1003
	Agata Tonetti and Massimo Rossetti	
90	The Proximity of Urban Green Spaces as Urban Health Strategy to Promote Active, Inclusive and Salutogenic Cities	1017
	Maddalena Buffoli and Andrea Rebecchi	
91	Environmental Attributes for Healthcare Professional's Well-Being	1029
	Zakia Hammouni and Walter Wittich	

Chapter 33

Fair Play: Why Reliable Data for Low-Tech Construction and Non-conventional Materials Are Needed



Redina Mazelli, Martina Bocci, Arthur Bohn, Edwin Zea Escamilla, Guillaume Habert, and Andrea Bocco

Abstract The paper proposes considerations stemming from the analysis of twenty-two buildings that show different approaches to ‘vegetarian architecture’—a theoretical stance based on principles learnt from agriculture and nutrition. The first phase consisted in a systematic investigation of the constructional characteristics of each building, and the cataloguing of their components. The ‘cradle to gate’ embodied energy (EE) and ‘embodied carbon’ (EC) were then calculated, based on two open access databases: ICE and Ökobaudat. The applicability of these databases was considered, as they do not cover low industrialised bio-based construction materials. For some materials, data are missing; while in others, EE values are overestimated since high energy-intensive manufacturing processes seem to be assumed. In a second phase, the uses and production process of some non-conventional materials was investigated, evidencing their variability. Building technologies that are not just aimed at low operational energy but at a more holistic understanding of low

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environmental impact represent a paradigm shift in ‘sustainable’ construction practices. Despite ongoing actions and policies, as long as these materials and techniques are not suitably represented in reliable and accessible databases, it will be difficult to make such a shift happen. Manufacturers and contractors who produce and use such materials would benefit from the availability of easily applicable, scientific data demonstrating environmental advantages offered by non-conventional materials.

Keywords Environmental impact · Embodied energy · Embodied carbon · Non-conventional construction materials · Databases

33.1 Introduction

Embodied emissions will likely constitute the majority of emissions generated by new buildings built between now and 2050 (Simonen et al. 2017). It is increasingly recognised that embodied impacts can constitute more than half of the total life cycle impacts from new buildings, and they will grow both proportionally and in real terms with the reduction of operational impacts (Rasmussen et al. 2018). ‘Net-zero’ or ‘near-zero’ operational greenhouse gases (GHG) emissions mean that the GHG emissions budget becomes almost entirely allocated for embodied GHG emissions (Röck et al. 2020; Habert et al. 2020; Moncaster et al. 2019).

Current EU regulations mainly cover the operational energy performance of buildings, while the embodied impacts remain largely unregulated, despite the significant carbon reduction potential (Toth and Volt 2021). However, since 2017, the Netherlands has required all new residential and office buildings larger than 1000 m² to account for embodied impacts based on a simplified LCA. Switzerland has introduced LCA requirements for public buildings (Swiss Society of Engineers and Architects (SIA) 2017). Denmark’s National Strategy for Sustainable Construction will phase a LCA requirement into the building code, enforcing maximum CO₂ emissions of new buildings larger than 1000 m² from 2023 and for all new buildings from 2025 (The Danish Housing and Planning Authority 2021).

France’s new *Réglementation environnementale* RE2020 includes carbon thresholds for offices and educational buildings starting 1 July 2022; limits will be progressively lowered. France is the first country to apply a dynamic LCA approach to the construction sector (Ministère de la Transition écologique (MTE) 2022a; Ministère de la Transition écologique (MTE) 2022b).

These increasing efforts for setting legally binding limits to the embodied environmental impacts highlight the crucial need for developing accurate, equitable, and easily accessed data for construction materials and techniques.

33.2 Data and Methods

33.2.1 Case Studies

The reflections proposed in this paper stem from the analysis of twenty-two ecologically oriented buildings showing different approaches to ‘vegetarian architecture’—a theoretical stance based on principles learnt from agriculture and nutrition (Bocco Guarneri 2020), which advocates:

- natural, renewable, locally available construction materials, free of toxic chemicals, and as little processed as possible (Wolley 2017, 2016; Berge 2009; Ghavami 2014; Walker et al. 2009; Harries and Sharma 2016);
- minimization of energy-intensive, high-tech components;
- labour-intensive, small-scale production processes, and simple constructional techniques;
- passive solar design.

The case studies are located in Europe and Japan and cover a variety of functions—residential, commercial, educational, workspace—and different patterns of use. Their gross internal areas (GIA) range from 23 to 3 232 m². Both refurbishment of traditional buildings and new constructions are included to exemplify techniques that make use of bio-based and other natural materials.

33.2.2 Data

The systematic investigation of each building’s technical and constructional features allowed to draw inventories and 3D models representing as-built situations. The ‘cradle to gate’ embodied energy (EE) and ‘embodied carbon’ (EC) were calculated by adding up the components manually, using a process-based LCA methodology and a purpose-designed spreadsheet. Impact coefficients were retrieved from two open access databases—the Inventory of Carbon and Energy (ICE) (Jones and Hammond 2019; Hammond and Jones 2011) and Ökobaudat (ÖBD) (BMI 2021).

Later, the most relevant non-conventional materials (NOCMAT) used were identified. NOCMAT encapsulate sustainable use of novel technologies and innovative uses of more established materials; many of them have their roots in traditional vernacular construction, including bio-based materials, and other natural materials such as stone, earth, lime (Ghavami 2014). For these materials, EE and EC values are either unavailable or show inconsistencies in the databases used. The production processes and the uses of such materials show a wide variability, which leads to a variability of the associated environmental impacts.

33.2.3 Reference Databases

ICE and ÖBD were chosen because open access and user friendly. More detailed sources are available but are proprietary and/or require a high level of expertise for their use. Using ÖBD and ICE to calculate the two basic environmental indicators was a sensible compromise between data availability and results uncertainty. Using the same set of values for all calculations guaranteed consistency.

ÖBD is managed by the German Federal Ministry of the Interior, Building, and Community; datasets must comply with EN 15,804. Data entries are constantly added, and the entire database is updated once a year. Datasets are based on the background database GaBi. Additional datasets based on EcoInvent background data are provided. In 2020, the new DIN EN 15,804 + A2 was adopted, which includes separate reporting of fossil, biogenic, and luluc GWP.

ICE is managed by Circular Ecology and the University of Bath. Version 2.0 (2011) was based on ISO 1404 and 14,044; 53% of sources dated before 2005. Carbon sequestration was excluded. Version 3.0 (2019) no longer includes energy factors. Carbon storage data are available for timber only. The values are the average of several sources, usually EPDs complying with EN 15,804. Data are updated for some materials. In our study, ICE V2.0 was used for all EE values and some EC values.

33.3 Results

33.3.1 On Case Studies' Embodied Energy and Embodied Carbon Values

While a rigorous internal methodology allowed for a detailed comparison between case studies (Bocco and Bocci 2022), it was difficult to verify whether these buildings have a lower environmental impact than conventional ones (Bocco Guarneri 2020). Systematic reviews (Simonen et al. 2017; Rasmussen et al. 2018; Birgisdottir et al. 2017; Dixit 2017; Hoxha et al. 2017; Röck et al. 2019; Säynäjoki et al. 2017; Schwartz et al. 2018) have not yet reached the degree of harmonisation which would offer benchmarks. The completeness of the underlying inventories is doubtful; the variations are up to two orders of magnitude (Rasmussen et al. 2018).

The average results of the analysed 'vegetarian' buildings do not appear significantly lower than those found of more conventional buildings. Moncaster et al. (Moncaster et al. 2019) found an average of 125 kgCO_{2eq}/m² for retrofitted buildings and of 254 kgCO_{2eq}/m² for new ones; we obtained 127 and 328, respectively, with ICE, and -132 and -74 with ÖBD (Fig. 33.1). The question about the reliability of databases, methodologies, and benchmarks stays open.

bldg. no.	GIA		EE (ÖBD)		EE (ICE)		GWP (ÖBD)		GWP (ICE)	
	m ²	kg	MJ/kg	MJ/m ²	MJ/kg	MJ/m ²	kgCO _{2eq} /kg	kgCO _{2eq} /m ²	kgCO _{2eq} /kg	kgCO _{2eq} /m ²
1	114	106 983	2.38	2 235	0.41	381	-0.18	-170	0.02	20
1(r)		80 934	3.15		0.54		-0.24		0.03	
2	23	25 738	4.75	5 318	1.36	1 524	-0.51	-570	0.12	131
2(r)		21 744	5.63		1.61		-0.60		0.14	
3	572	911 500	2.50	3 985	1.05	1 666	-0.09	-136	0.07	115
3(r)		204 818	11.13		4.65		-0.38		0.32	
4	411	469 598	3.35	3 823	2.30	2 633	-0.08	-92	0.15	174
4(r)		305 981	5.14		3.54		-0.12		0.23	
5	103	106 869	1.78	1 843	0.36	369	-0.46	-474	0.09	97
6	65	166 427	5.01	12 821	4.95	12 664	-0.09	-241	0.11	286
7	125	343 872	8.73	24 019	4.09	11 252	-0.37	-1 015	0.23	627
8	76	129 560	4.44	7 550	3.52	5 978	0.12	210	0.26	446
9	176	29 476	8.60	1 441	8.62	1 443	0.16	28	0.42	70
10	153	330 945	4.67	10 105	3.37	7 286	0.03	55	0.32	687
11	61	67 683	4.57	5 067	3.56	3 949	0.04	46	0.22	242
12	156	340 417	2.51	5 471	4.72	10 290	0.02	39	0.18	389
13	2 212	1 966 360	7.90	7 019	4.98	4 429	-0.05	-41	0.35	307
14	183	267 401	4.69	6 858	3.84	5 614	-0.01	-12	0.27	393
average			5.43	6 449	3.59	4 261	-0.07	-89	0.23	277

Fig. 33.1 GIA, weight, EE, and GWP of each case study, calculated both with ÖBD and ICE

33.3.2 On Vegetal Materials

The analysis highlighted a divergence of the profiles for timber and timber-based products in the two databases. Data for highly industrialised products such as timber-based boards and window frames are widely available and cover a good range of variations; this comes less for untreated solid wood. ÖBD provides very high values for EE, reflecting German processing: kiln drying; industrial debarking and sawing machinery; and an average distance between forest and sawmill of 144 km (Fig. 33.2). While timber was widely used in most of our case studies, it was often low processed and underwent little treatment, if any. In most cases, timber was air-dried, while most sources for both databases consider kiln drying at high temperatures—an energy—and carbon-intensive process that alters timber’s properties. Where elements were hand-sawn (5), debarked and cut on site (21), and untreated (5, 6, 21), the impact risked to be overestimated (Fig. 33.3). In case 21, the whole structure—which makes a relevant portion of the building’s weight—was manually debarked, and most of the lumber came from the site or district forest. In 5, timber was obtained from the ecovillage’s forest and transported with horses to the site, where it was assembled with hand tools. No data are available for *brettstapel* (7, 13, 17, 22) as opposed to various entries for laminated timber: the lack of glue and nails reduces the environmental impacts of the first. Wood chips (21) and loose wood fibre (10) are not covered, as opposed to wood fibre boards for which ÖBD includes five entries and ICE two.

Straw was employed in ten case studies in a range of ways: load-bearing bales (6, 7, 21), thatch (2), bale infill (12, 20), bale retrofit (3), loose insulation (1, 6, 15, 21); ropes, mats (1), and chaff (2) are also used. Only values for standard size bales



Fig. 33.2 Timber dried at low temperatures in a greenhouse at Kitokuras sawmill (Kagawa prefecture). *Photo* Andrea Bocco Guameri



Fig. 33.3 Manual debarking of trees at Biotal site. Untreated logs are used as structural columns in the building. *Photo* Christoph Bosch

with a density of 100 kg/m^3 are given in the databases, forcing an approximation for products like jumbo and round bales and loose straw. Not only does the crop cultivation vary (in 5 and 21 it is harvested from local organic farms), but also the baling process is expected to influence the overall impact. In many of these buildings, straw represents a large portion of the weight: divergences can therefore influence the overall environmental impacts. Reported values for straw bales are disorienting: in ÖBD, the EE value for straw (17.13 MJ/kg) is seventy times higher than that found in ICE 2.0, and higher than that of structural steel (14.14 MJ/kg) and more than three times higher than that of fired, solid bricks (4.85 MJ/kg). The reliability of the EE value for straw in ICE may be low, since it is based on four references only, the latest dating from 2003; but that in ÖBD (based on an EPD provided by FASBA) is high compared to recent studies: e.g., nearly 5 times higher than Upstraw School of Natural Building's 2021 EPD (Up-Straw—School of Natural Building (SnaB) 2021).

Databases seem also ill-suited for representing other vegetal materials. No data are present in either database for bamboo, not only for whole culms but also for products such as mats, panels, and laminated bamboo. In 9, locally harvested bamboo culms make up the entire structure (Fig. 33.4). Loose hemp shiv is not covered, which makes it difficult to assess, for instance, hemp-lime building components (8, 13). Only hemp mats are found in ÖBD (Fig. 33.5): these include 15% polyester fibres and are impregnated with soda.



Fig. 33.4 Structure of the Bamboo Ark consists of radially arranged frames, composed of a base truss and arches. The culms were harvested from a nearby grove. *Photo* Toki Hirokazu

Fig. 33.5 Bamboo mats in Iya Valley, Japan. *Photo* Andrea Bocco Guarneri



Analogously, there are no data for loose flax fibres (21), just for mats. In ÖBD, the same assumptions as for hemp fibre mats are applied. ICE V2.0 reports that most of the impacts are due to the polyester binders and fire retardants (Schmidt et al. 2004). No data are present in either database for reed mats (4, 6) and jute (6), while building paper (10, 13) is covered by ÖBD only.

33.3.3 On Other Natural Materials

Earth construction techniques are poorly represented: ICE just reports data on earth (it is unclear whether this is rammed or bulk earth); ÖBD includes data on rammed earth, adobe, plaster, earth panels, and bulk earth. Data sheets do not provide enough information on basic features, such as the presence of additives or fibres, or the size of the adobes. The entry for earth plaster in ÖBD has an ambiguous description, which does not even seem to refer to an earth-based product. ÖBD also assumes processes such as the artificial drying of adobes (Fig. 33.6).



Fig. 33.6 Light-earth external skin applied onto battens in a new house in Darmstadt. *Photo Franz Volhard*

No data are provided for earth paints, which are usually ready-made products (4, 8).

In many case studies, earth products were made at the construction site (Fig. 33.7): adobes in 10 and 12; manually compressed earth blocks in 13; earth plasters in 2, 5, 6, 10, 12, and 21 made with various mixtures, in some cases including fibres, sand, or lime; clay mortar in 4; tamped earth floors in 1, 4, 5, 6, 12, and 14 (coated with earth finishing in 6 and 12). Earth was also used with straw for infilling wooden or bamboo frames (1,2,4,15,21).



Fig. 33.7 Construction of the lecture theatre of the WISE at the Centre for Alternative Technology. The attractive load-bearing rammed-earth walls, 500 mm thick, are pneumatically tamped and left unfinished on both faces. *Photo Pat Borer*

Emblematic is the case of stone: while being one of the most common materials in vernacular constructions, its use has drastically shifted from massive blocks that require minimal (if any) dressing to 1 ~ 3-cm-thick cladding slats. Both databases just provide values for thin elements that underwent cutting and finishing processes. In ÖBD, entries for 2 ~ 4-cm-thick granite and limestone elements assume processing—steel grit, grinding road, saw, and multi-blade saw. ICE V2.0 acknowledges that data sources were generally poor, except for stone slates. Quarried stone blocks are then associated with a risk of overestimating their embodied impacts if the custom values are employed. Even in cases when thin paving stone slabs were used, ecological considerations resulted in specifying little-processed elements: in 7, 50 ~ 70-mm-thick soapstone flooring slabs were obtained on site by cutting conglomerate rock boulders; in 21, 9-mm natural stone tiles were hand-cut with pliers and left unpolished.

Animal-origin products are also little represented, if at all: for felt (7), the only data available is the EE value in ICE V2.0; for sheep's wool (8, 18), no values are available in either database.

33.4 Conclusions

The quality of the environmental assessment of buildings depends heavily on the quality of the data used, which remains a major challenge. Most of the processes mentioned here could be modelled with tools such as EcoInvent: but doing so requires skills and time that are beyond the possibilities of an average designer or contractor. ÖBD and ICE, while open source and easy to use, are focused on conventional materials and do not satisfactorily cover bio-based and little-processed materials. Even when they do, the values provided are regional or global averages, not representative of specific production patterns in terms of processes or efficiency, electricity mix, and transportation distance (Zea Escamilla and Habert 2014).

A proper assessment requires significant expertise, time, and financial resources, which are less likely available for alternative construction materials. Furthermore, meeting the impact thresholds set by current and future regulations pushes towards using certified conventional construction materials, a tendency that is not consistent with decarbonizing the building trade. Data availability is then a key issue in the implementation of environmental reduction policies.

The development of appropriate data for non-conventional construction materials should be supported by a bidirectional technological transfer between the research and industry sides. Current research efforts should be aligned to make the results reliable and widely available. This will rebound on an easier introduction of these materials in the construction market and help achieve the ambitious emissions reduction targets.

References

- Berge B (2009) *The ecology of building materials*, 2nd edn. Architectural Press, London
- Birgisdóttir H, Moncaster A, Wiberg AH, Chae C, Yokoyama K, Balouktsi M, Seo S, Oka T, Lützkendorf T, Malmqvist T (2017) IEA EBC annex 57 'evaluation of embodied energy and CO₂eq for building construction.' *Energy Build* 154:72–80. <https://doi.org/10.1016/j.enbuild.2017.08.030>
- BMI (2021) *Deutsche Bundesministerium des Innern, für Bau und Heimat. Ökobaudata 2021*
- Bocco A, Bocci M (2022) Reflections on the environmental impact of “vegetarian” buildings, and on the reliability of databases. *Constr Technol Archit* 1:395–404. <https://doi.org/10.4028/www.scientific.net/CTA.1.395>
- Bocco Guarneri A (2020) *Vegetarian architecture: case studies on building and nature*. Jovis Verlag GmbH
- Dixit MK (2017) Life cycle embodied energy analysis of residential buildings: a review of literature to investigate embodied energy parameters. *Renew Sustain Energy Rev* 79:390–413. <https://doi.org/10.1016/j.rser.2017.05.051>
- Ghavam K (2014) Non-conventional materials and technologies for sustainable engineering. In: *Proceedings of 14th NOCMAT, 24–27 Mar 2013, João Pessoa*. Trans Tech Publications, Dürnten
- Habert G, Röck M, Steininger K, Lupisek A, Birgisdóttir H, Desing H, Chandrakumar C, Pittau F, Passer A, Rovers R, Slavkovic K, Hollberg A, Hoxha E, Jusselme T, Nault E, Allacker K, Lützkendorf T (2020) Carbon budgets for buildings: harmonising temporal, spatial and sectoral dimensions. *Build Cities* 1:429–452. <https://doi.org/10.5334/bc.47>

- Hammond G, Jones C (2011) Inventory of carbon and energy. Circular Ecology and University of Bath
- Harries K, Sharma B (2016) Nonconventional and vernacular construction materials. Woodhead Publishing, Sawston
- Hoxha E, Habert G, Lasvaux S, Chevalier J, Le Roy R (2017) Influence of construction material uncertainties on residential building LCA reliability. *J Clean Prod* 144:33–47. <https://doi.org/10.1016/j.jclepro.2016.12.068>
- Jones C, Hammond G (2019) Embodied carbon—the ICE database. Circular Ecology and University of Bath
- Ministère de la Transition écologique (MTE) (2022a) Décret n° 2022a-305 du 1er mars 2022a relatif aux exigences de performance énergétique et environnementale des constructions de bâtiments de bureaux et d'enseignement primaire ou secondaire en France métropolitaine, Journal officiel, n°0052 du 3 Mars 2022, Texte n°48
- Ministère de la Transition écologique (MTE) (2022b) Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (Cerema). Réglementation Environnementale des Bâtiments Neuf (RE2020)
- Moncaster AM, Rasmussen FN, Malmqvist T, Houlihan Wiberg A, Birgisdóttir H (2019) Widening understanding of low embodied impact buildings: results and recommendations from 80 multinational quantitative and qualitative case studies. *J Clean Prod* 235:378–393. <https://doi.org/10.1016/j.jclepro.2019.06.233>
- Rasmussen FN, Malmqvist T, Moncaster A, Wiberg AH, Birgisdóttir H (2018) Analysing methodological choices in calculations of embodied energy and GHG emissions from buildings. *Energy Build* 158:1487–1498. <https://doi.org/10.1016/j.enbuild.2017.11.013>
- Röck M, Saade MRM, Balouktsi M, Rasmussen FN, Birgisdóttir H, Frischknecht R, Habert G, Lützkendorf T, Passer A (2019) Embodied GHG emissions of buildings—the hidden challenge for effective climate change mitigation. *Appl Energy* 258:114107. <https://doi.org/10.1016/j.apenergy.2019.114107>
- Röck M, Balouktsi M, Saade M, Nygaard Rasmussen F, Hoxha E, Birgisdóttir H, Frischknecht R, Habert G, Passer A, Lützkendorf T (2020) Embodied GHG emissions of buildings—critical reflection of benchmark comparison and in-depth analysis of drivers
- Säynäjoki A, Heinonen J, Junnila S, Horvath A (2017) Can life-cycle assessment produce reliable policy guidelines in the building sector? *Environ Res Lett* 12:013001. <https://doi.org/10.1088/1748-9326/aa54ee>
- Schmidt AC, Jensen AA, Clausen AU, Kamstrup O, Postlethwaite D (2004) A comparative life cycle assessment of building insulation products made of stone wool, paper wool and flax. *Int J LCA* 9:122. <https://doi.org/10.1007/BF02978571>
- Schwartz Y, Raslan R, Mumovic D (2018) The life cycle carbon footprint of refurbished and new buildings—a systematic review of case studies. *Renew Sustain Energy Rev* 81:231–241. <https://doi.org/10.1016/j.rser.2017.07.061>
- Simonen K, Rodríguez BX, De Wolf C (2017) Benchmarking the Embodied Carbon of Buildings. *Technol Archit Des* 1:208–218. <https://doi.org/10.1080/24751448.2017.1354623>
- Swiss Society of Engineers and Architects (SIA) (2017) SIA 2040: Effizienzpfad Energie
- The Danish Housing and Planning Authority (2021) National strategy for sustainable construction. Ministry of the Interior and Housing, Copenhagen
- Toth Z, Volt J (2021) Whole-life carbon: challenges and solutions for highly efficient and climate-neutral buildings. BPIE
- Up-Straw—School of Natural Building (SNaB) (2021) Environmental product declaration In accordance with ISO 14025 and EN 15804:2012+A2:2019 for: Straw as insulation material-UK
- Walker P, Ghavami K, Paine K, Heath A, Lawrence M, Fodde E (2009) 11th International Conference on Non-conventional Materials and Technologies—NOCMAT 2009 Proceedings. University of Bath, Bath

- Wolley T (2016) *Natural building: a guide to materials and techniques*. The Crowood Press, Ramsbury
- Wolley T (2017) *Building materials, health and indoor air quality*. Routledge, Abingdon
- Zea Escamilla E, Habert G (2014) Environmental impacts of bamboo-based construction materials representing global production diversity. *J Clean Prod* 69:117–127. <https://doi.org/10.1016/j.jclepro.2014.01.067>

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