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Transition in Architecture Education? Exploring Socio-Technical Factors of Curricular Changes for a Sustainable Built Environment

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Abstract: Curricular changes in architecture can support to meet the increased demand for sustainability in higher education (HE). Identifying their associated factors is necessary to understand ongoing and future transitions in architecture education. Transition management (TM) frameworks have been frequently used to analyze structural changes in various institutions but have received little attention in architecture education. This study explores the Swiss Federal Institute of Technology (ETH Zurich) as a case study, focusing on its architecture curricula within 32 years from 1990 to 2022, corresponding to multiple generations of academic careers. A multiple-level perspective (MLP) document analysis on curricular changes is conducted in three steps, drawing on a specific perspective on sustainability in architecture. First, generic characteristics that may influence curricular changes are identified from the literature. Second, shifts in the undergraduate curriculum of ETH Zurich are systematically mapped. Third, a classification of implemented curricular shifts results in seven nuanced variations in generic factors. These socio-technical factors involve the development and dissemination of new disciplinary (1) and interdisciplinary (2) approaches to a sustainable built environment (SBE), a relocation of the viewpoint on sustainability from physiology/hygiene to building physics (3), experimentation with inquiry-based learning in niches (4), extended spheres of influence in teaching (5), early committed intra-faculty opinion leaders (6), and the formation of educational networks (7). The proposed approach based on longitudinal curriculum mapping offers a way to locate structural curricular changes, identify hidden educational trends, and inform institutional changes.

Keywords: sustainability; higher education; architecture education; transition; socio-technical factors; built environment; curriculum mapping; structural changes

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1. Introduction

Universities are currently increasingly transforming architecture curricula towards sustainability. It can be distinguished between implementing general introductory courses across disciplines, new field-specific classes, and new frameworks for entire programs. For instance, the University of Barcelona announced that from 2024 onward, a mandatory five-credit course on climate change will be launched for all of its 14,000 undergraduate and post-graduate students [1]. In 2021, a new educational framework by the Royal Institute of British Architects (RIBA) emphasizes the pertinent role of the built environment [2]. The accompanying implementation of climate literacy components will be mandatory for over 100 accredited schools. In Switzerland, the École Polytechnique Fédérale de Lausanne (EPFL) lists multiple objectives in its "2030 Climate & Sustainability Strategy" [3]. While a core sustainability class aims to provide education for all Bachelor's students starting in 2024/25, a university-wide working group on sustainability in teaching led by their

Vice President for a "responsible transformation" aims to train members in supporting the field-specific integration of sustainability into all degree programs. At the Swiss Federal Institute of Technology (ETH Zurich), the Bachelor curriculum in architecture is currently under revision based on the departmental strategy, which lists "answering the challenges of climate change" as the first of five strategic areas of action [4]. In any case, it presents a great challenge for those responsible for courses and curricula [5].

The problem of integrating the built environment in architecture education lies in combining theory and practice based on the architect's requirements rather than the disciplinary academic structure [6]. It is helpful to distinguish between declarative knowledge (facts, terms, etc.) and procedural knowledge (non-articulated, automated) [7]. If declarative and procedural knowledge is organized according to practical requirements, a technical–scientific task may be inquired effectively. To this end, requirements-oriented "problem-based learning" [8] or "inquiry-based learning" [9] to enhance not only declarative knowledge but also procedural knowledge using the creation of artefacts and associated analogies has been reported to be a promising strategy [10]. However, limitations of this approach to professional knowledge have been less frequent in the focus of investigations, for instance, without gaining deeper conceptual understanding, knowledge cannot be applied in the right situations and cannot be modified to new situations [7]. Distinct approaches that aim to bridge the gap between practice and theory for complex planning problems involving multiple interrelations without one single optimal solution have existed since the 1990s, such as "systems architecting" [11] and "reflective practice" [12]. Reflective practice relies on a "stance towards inquiry" of a problem and raises questions on bridging the gap between the necessary professional body of knowledge and societal expectations in rapidly changing environments. Arguments for a re-connection between architectural and academic practice in architecture have since reached an increased interest [13]. Taking into account the building sector's more than 39% of global energy-related carbon emissions [14], and approximately 50% of the global annual resource consumption and waste production [15], reflective practice is urgently needed. Especially in Europe, decarbonizing the building sector needs to focus on the existing stock and related building activity [16].

Science and the academic community might accelerate sustainable transitioning on the interface between science and society by acting as change agents [17]. In architecture education, the design of the architecture curriculum may be advantageous to support sustainable transitions in practice similar to engineering curricula, which show a combination of applicable technical and theoretical knowledge [18]. Although universities could be institutions that promote and lead sustainable transitions, they tend to resist change by relying on disciplinary boundaries [19]. That is particularly disadvantageous for sustainability in education, which is strongly dependent on interdisciplinarity [20]. That becomes also clear when reflecting on the fields that contributed to the introduction of sustainability in higher education, as shown by Tilbury [21]. In the 1970s, different areas such as ecology, outdoor education, conservation, and urban studies contributed to the introduction of environmental education. On a political level, the 1992 UN Summit in Rio de Janeiro, especially its Agenda 21, made the topic a global priority area in higher education by advocating for a role of education that improves people's ability to address sustainable development.

Sustainability as an overarching objective, notion, or process manages to contain a variety of strategies for new construction and building in existing contexts, which explains its attractiveness as well as its need for interpretation [22]. However, an acceleration in research on sustainability through the viewpoint of the built environment was only found from 2006 to 2013 [23], demonstrating a considerable extension of the semantic boundaries of sustainability in architecture over time.

Early research, for instance, from Cortese et al. [24], on introducing sustainability in higher education, emerged in the 1990s. Today, the content on sustainability in higher education programs varies considerably depending on the program [25] and the geographical location of the institution [26]. In 2006, the average architecture curriculum shows typically around 8% of the curriculum dedicated to environmental sustainability in Australasia [27], while in Asia, architecture schools tend to show a percentage of 5 to 25% in 2016 dedicated to relevant courses [28], and a study from 2017 including a sample of universities in the US and UK found a share of 29% in the US and 47% in UK [26].

Recently, Boarin and Martinez-Molina conducted an extensive literature review of 111 papers on assessments of curricula and teaching projects on environmental sustainability within architecture programs [29]. In addition to a significant part of the works dedicated to new design course concepts, they identify a recent shift in the research focus from questions on the course content and curriculum structure ("what") to pedagogy and implementation processes ("how"). The integration of new courses into the curriculum needs to address the relation from one course to the next one (vertical reference) and the link across different courses (horizontal reference) [30]. A frequent misconception of splitting "theoretical" and "applied" approaches can inhibit exploring core material in practice [20]. Altomonte presents five different strategies to include sustainability aspects in the architecture curriculum [31]: parallel to design and core courses, partially integrated into design and core courses, fully integrated into design and core courses, iteratively linked to design or core courses, or integrated into elective courses. Finally, regarding the current body of research, only very few studies investigate changes in the curriculum over more extended periods. Regarding sustainability in architecture education, curricular changes focusing on the built environment have yet to be explored in depth.

Ostwald et al. present one of the few large-scale longitudinal studies of 20 architecture schools in the Australasian region using data from questionnaires, interviews, and existing literature [27]. Courses in respective programs are structured according to seven categories: design, technology, history and theory, communication, practice, environment, and electives. Two different points in time are chosen to characterize significant trends: 1994 and 2006. The results proved helpful in identifying critical trends and to offer future recommendations. In comparison, Langenberg shows that architecture schools' "educational traditions" can be traced over more than 200 years [32]. Various methods can be applied to investigate curriculum renewal as demonstrated by researching curriculum renewal processes in East Africa towards sustainability using a mixed-method approach based on ethnographic study, document analysis, and interviews [33]. Finally, the emergence and formation of "building knowledge" and single subjects can be researched through historical perspectives on curricula. This is demonstrated, for instance, by Tomlan, who investigates the example of preservation as a subject in US education [34].

1.1. Aim of the Study

This study aims to inform decision making on transitions towards mediating a sustainable built environment as an objective in architecture education. Compared to the extensive literature on sustainability integration in curricula and courses, the overall objective of this work is to contribute by investigating a long-term (within transition management (TM), "long-term" horizons refer to periods of 30 years [35]) period and its curricular changes in architecture. So far, the systematic identification of characteristics of structural changes in education has not been investigated in the field of architecture to the authors' best knowledge. The main research questions of this work are:

- What are the crucial characteristics of the trends in curricular changes in the period of 1990–2022 towards sustainability in architecture based on the case study of ETH Zurich? Which fields contributed to changes towards an SBE in the curriculum?

This question is addressed with a longitudinal case study approach, focusing on environmental sustainability for the built environment in architecture education. An exploratory research design to the case study is used to thoroughly document and better understand the logic [36] of critical institutional factors dealing with the appearances and disappearances of courses and content using quantitative data on the curricular changes and qualitative documents on accompanying shifts in courses and associated actors in context. Finally, this study aims to derive key socio-technical factors specific to the architecture education field which can potentially inform transitions in architecture education beyond the case study.

1.2. Conceptual Framework

1.2.1. A Sustainable Built Environment in Architecture

In the UK, Hillier and Leaman concluded in a remarkable study already in the mid-1970s with several reasons why the built environment as a subject should emerge within architecture as a discipline in academia by arguing for a focus on "the requirements of designers" [6]. However, to elaborate on the potential accompanying implications, first, a definition is necessary. Moffat & Kohler present a system's perspective on the built environment and its interactions with ecosystems, which provides the conceptual understanding of sustainability in architecture in this work [37]. Their conceptual foundation of a connection between the built environment and interactions with ecosystems—historically established by the two scientific disciplines of thermodynamics and ecology—is considered to align well with a recent interpretation of the first definition of sustainability by Hans Carl von Carlowitz's in *Sylvicultura Oeconomica* from 1713. This contemporary understanding argues that only those parts from stocks may be withdrawn for which adequate replacements are provided according to the principle of constant renewal [38]. This underlines the relevance of existing resources and associated time horizons and argues for moderateness in an ongoing period characterized as "the great acceleration" [39].

1. The extension of system limits in time and space: Emerging from resource economics and industrial engineering, life cycle assessment (LCA) enables the extension of time scales forward and backward to phases of resource extraction and end-of-life.
2. A balanced system perspective to understand material and energy flows between the built environment, the construction industry, other sectors, and the ecosphere.
3. A shared framework for representing the built environment that is ultimately about information models, which involves developments in computer-aided design (CAD) and product-based data structures connected to environmental inventories.
4. A scalable perspective on the performance of the built environment, including urban stocks and systems, that overcomes market-oriented interests, including developing new technologies for new construction. Well-trained professionals maintain, preserve, and manage the complex historical composition of building stocks.

Compared with the commonly known three-pillar sustainability model, this conception of the built environment clearly limits the research scope to a specific perspective on environmental sustainability. However, to comprehensively cover this research scope, it is necessary to consider several distinct contributing architectural fields.

1.2.2. Characteristics of Changes: Environmental Knowledge, Research, and Architectural Practice

Along historical lines, it is helpful to consider changes in the meanings of "the environment" over time. Haller et al. distinguish a distinct debate on the environment since the 1960s, characterized by a nexus of economic and ecological reasoning informed by quantifying environmental impacts, which has been criticized for co-modifying the environment. However, it is argued that this approach established a basis for global communication on environmental target agreements such as the Kyoto Protocol in 1997 [40]. During the second half of the 20th century, the economic situation, creation of distinct narratives, and new technologies played a role in the diffusion of environment knowledge as found by Cole [41]. After the 1970s oil "crises" led to an increased awareness of energy [42], the mid-to-late 1980s are seen as a focal point. A shift in narrative from "survival" to "responsibility and stewardship" first leveraged critical areas in environmental pollution and human health, environmental assessment coined as "green building practices", urban metabolism, and life cycle assessment (LCA), which initially focused on buildings' operational aspects (heating and cooling) diffusing into European codes and standards later. Linking academia and practice, green building practices included a range of technological approaches (e.g., low-tech and high-tech solutions), planning principles primarily for new construction (including, for instance, compactness of building envelopes, vertical and horizontal access, etc.), and planning frameworks aiming at extended time horizons, most notably, "integral planning", and lately, "resilience management" [43]. Several key conferences enabled the diffusion of topics to actors in academia and practice [41]. While in practice, the design of buildings began to consider more issues on human health and associated architectural features; for instance, the provision of sanitary services or daylight access already in the beginning of the 20th century. In the 1960s and 1970s, these issues were primarily placed in a new context of industrial pollution. Urban design research in the 1990s shifted its focus on district, city, region, and country scales by making energy use, water, waste, and transport productive topics [44]. Since the 2000s, Cole characterizes a recent narrative on "security" and associated questions that tackle problems of risk and uncertainty of "wicked" [45] long-term problems in planning, for instance, via the consideration of "multiple futures" in scenario planning [43].

1.2.3. Transition in Higher Education

A broad perspective is taken into account to assess the trends of changes in the curricula comprehensively. Yet, this perspective comes with its problems. The question asked by Markus, "Does the building industry suffer from collective amnesia?" [46] remains pertinent for knowledge transfers in the industry and higher education. The general implications of knowledge in the context of sustainability are elaborated by Ott [47]. If knowledge is always embedded in a person, knowledge transfers are difficult to achieve over long periods. This is underlined by the fact that established knowledge may be subject to variability over time, influenced by fluctuations in the understanding of science [48]. This problem is reflected to a certain extent in the frameworks of diffusion and Transition Management (TM) [35]: "In societal systems, structural change is often a result of individual actions as a response to changing societal conditions". However, TM does not only include actors but systems with interactions between actors. "Transitions are processes of structural change in societal (sub-)systems" that "(...) come about when the dominant structures in society (regimes) are put under pressure by external changes in society, as well as endogenous innovation". Incremental (continuous) and radical (discontinuous) novelties can be distinguished [49]: Radical novelty is challenging to create due to path dependencies and stability in systems. Path dependencies and their sources are significant incentives for incremental novelties. Leading to particular paths, these trajectories may create interdependencies between society, policy, and technology. Stability is provided by rules that can be cognitive (e.g., shared knowledge bases), normative (e.g., proper behavior), or regulative (e.g., technical standards). Diffusion of novelties has been documented to typically follow the trajectory of cumulative S-shaped curves over time, including the phases of slow growth, exponential growth, and stabilization [50]. Niches can be places that can provide "protected" incubation spaces for the learning processes of opinion leaders in the early phases of the diffusion process. The learning process involves the deviation from the rules of existing regimes. Rogers characterizes innovators in niches as "gatekeepers" by referring to their ability to import notions from outside the system's boundaries into a social system [50]. However, actors in niches must constantly engage to work on articulating a novelty [35], which may lead to excessive demands. Further, Hoover et al. emphasize contradictions and tensions resulting from hidden complexities in organizational change [51]. Lozano highlights the importance of pedagogies within the diffusion of sustainability issues in higher education while investigating a variety of disciplines [25]. After a certain amount of time within an adoption process, specific forms of teaching begin to develop and enhance diffusion. Loorbach adds the concept of "experiments" to this level, which describes the short-term (0-5 years) testing of novelties in projects or programs [35]. Geels adds that actors are embedded in interdependent networks [49]. In educational institutions, networks have various dimensions that may lead to positive impacts such as "powerful professional learning" and dysfunction, troublesome conflicts, and other adverse effects [52]. On the "landscape" level, societal and political debates play a role. The concept of a triad by Karl-Eugen Kurrer describes an entangled situation including public administration, industry, and research that explains the reciprocal relation of research and practice [53].

In comparison, Geels [49] presents an overview of a multiple-level perspective (MLP):

1. Landscape levels deal with societal and policy dimensions that may pressure regimes and open opportunities for novelties.
2. Socio-technical regimes include processes that lead to pathways, configurations, and adjustments, including technological, scientific, market-based, and policy aspects.
3. Niches include actors' articulation processes of novel concepts, products, or approaches in a specific way (e.g., technology, user preferences), linking elements to an entity.

Finally, Loorbach emphasizes the relevance of monitoring to reflect and learn from transitions [35], involving movements of individual and collective actors.

2. Materials and Methods

An exploratory case study approach with a nuanced perspective on sustainability in architecture is conducted to investigate trends of single-curricular changes via a multiple-level perspective (MLP). To derive trends, a new approach based on "curriculum mapping" [54] is elaborated in this section to identify crucial socio-technical factors for a temporal data series on architectural curricular changes. The multiple steps needed to describe the method are illustrated in Figure 1.

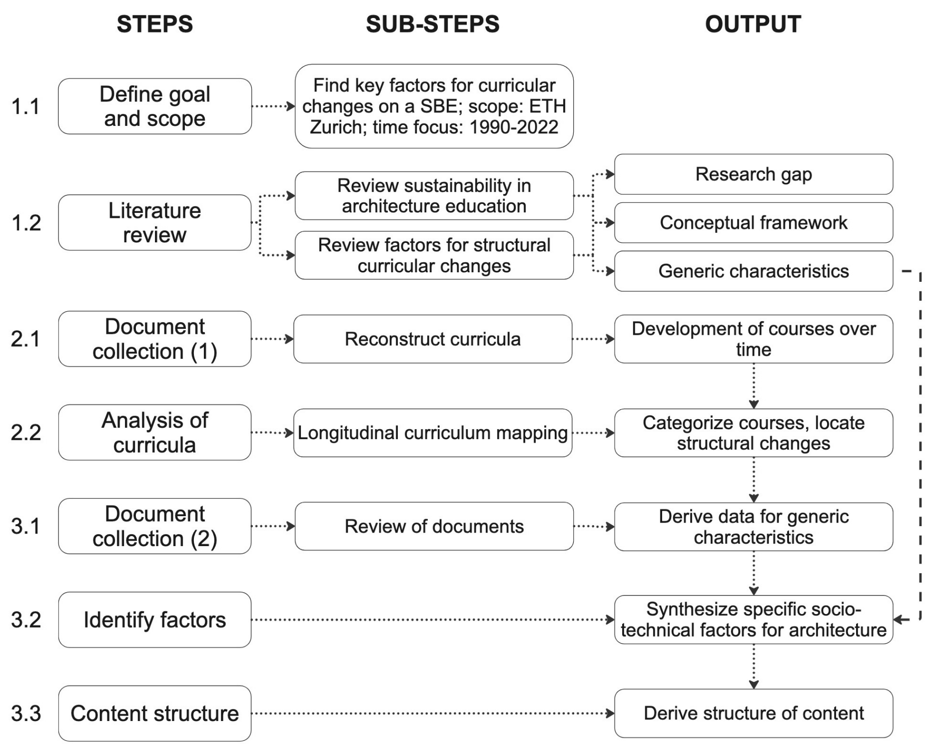

Figure 1. Representation of Research Strategy.

2.1. The Context: ETH Zurich and Its Architecture Program

In 1855, the *Eidgenössische Polytechnikum* was founded in Zurich (Switzerland) [55]. The Polytechnikum was organized within different schools, such as a school for architecture (initially headed by Gottfried Semper) and civil engineering (initially headed by Carl Culmann) until its renaming in 1911 to *Swiss Federal Institute of Technology* in Zurich (the acronym ETH indicates its new title *Eidgenössische Technische Hochschule*). An evaluation of the Department of Architecture (the Department consists of several main bodies, such as the Departmental Conference, the Professorial Conference, the Departmental Committee, and specialized bodies, for instance the Teaching Commission, which is responsible for teaching requirements, including the conception of curricula, its implementation, and examinations [56]) from 2012 shows how the departmental organization of teaching changed over time [57]: teaching and also research activities have generally been conducted within faculties since the 1920s. Sharing responsibilities between architects and engineers, as known today, was established in 1917 by reorganizing different courses. Practical experience via a mandatory internship has been included in the curriculum since 1931. In the 1960s, the foundation of various institutes was intended to enhance the scientific orientation. Following organizational changes in education at ETH [55], the introduction of departments started in 1989 and was completed in 1999. Now, the suspension of the faculties initially responsible for organizing teaching was replaced by a departmental organization including undergraduate, graduate, and post-graduate degree programs in line with the Bologna Process for higher education. A comprehensive investigation of the early developments of "polytechnic building knowledge" at the *Polytechnikum* in Zurich between 1855 and 1930 is provided in the seminal work by Hassler et al. [48]. They summarize the original educational model of the *Polytechnikum* as being based on the assumption that the mediation of formalized bodies of knowledge generates a "basic knowledge", a methodological–theoretical set of skills, or an "applied science", with which students should be enabled to solve practical professional problems. The scientific basis for this was mathematics and geometry. Today, ETH is one of the most renowned academic institutions globally in various fields [58]. Although Hassler et al. show that interdisciplinary teaching has already been ingrained in the model of the *Polytechnikum* since the beginning, the foundation of new degree programs in materials science, computer sciences, and environmental science in the 1980s mark an important structural change which accelerated influences across disciplines [59].

In 2022, ETH hosted 25,022 students, including 4561 PhD students, 6743 researchers, and 567 professors. The ETH domain today comprises ETH, EPFL, and four different research institutes (Paul Scherrer Insitute–PSI, the Swiss Federal Institute for Forest, Snow and Landscape Research–WSL, the Swiss Federal Laboratories for Material Science and Technology–EMPA, the water research institute–EAWAG) and multiple centers including the Future Cities Lab Global (FCL). Within the architecture program, the undergraduate curriculum constitutes the basis of architectural education [60] and, therefore, forms the starting point of this study.

2.2. Description of Research Strategy

2.2.1. Goal and Scope Definition

The study's objective is to nuance key factors influencing structural changes in the architecture curricula based on the research strategy presented in Figure 1. The scope of the study is the architecture curriculum at the Swiss Federal Institute of Technology (ETH Zurich). Specifically, the study focuses on the undergraduate program. The investigated period spans 32 years, from 1989 to 2022. However, earlier developments are also considered when necessary.

2.2.2. Literature Review

A literature review is used to identify the research gap, develop a conceptual framework, and identify generic characteristics for changes in higher education (presented in Table 1). The conceptual framework is elaborated in detail in Section 1.2. It combines a specific perspective on sustainability with aspects of transition management (TM) and diffusion frameworks. Via a transfer of this framework to the context of architecture education as the subject of this study, single activities and changes are investigated as a tendency of a transition in architecture education.

Table 1. Identification of generic aspects (non-exhaustive) that may influence structural changes in architecture education based on the authors' selection of literature across disciplines, especially the existing lists by Hugé et al. [22], Hoover et al. [51], and Dlouhá et al. [61].

Potential Aspects of Changes	**Subfactors**	**Description**
1. Educational Strategy	Research/Novelties	Research on sustainability aspects that address inter-/transdisciplinarity, decision making, application, and education [61].
	Knowledge conception	Shaping institutional structures/practices via individual knowledge conception (immediately/longer term) [51]. Clear realms of educators' disciplinary knowledge conception inhibit maturing of system's thinking [41].
	Course conception	Influential individual course concepts [29,30].
	Educational experimentation in niches	Individual initiatives as driving forces for education for sustainable development [61]. "Policy entrepreneurs" can create momentum in niches [62].
2. Social Capital	Committed actors	High relevance of committed individuals [51]. Not one actor category but multiple; sustainability advocates may form/disappear quickly [22]. Sustainability "champions" between innovator and organization [63].
	Actors' values	Actors' ethical stance [51]. Open concept of sustainability provides various possibilities for visions [22]. Barriers influenced by actors' basic needs [63].
	Students' perspectives	Policies focusing on various social representations of sustainability [64].
	Students' agency	Transformative learning beyond "ad hoc" approaches to sustainability [65].
	Networks	Niches as spaces for influential networks [49]. Networks as a supportive mechanism [61]. Existing/new networks as a vehicle to create change [51].
	Dialogue, Narratives	Dialogue as a process to mediate between structure and individual [51]. Dialogue is situated in dominating narratives that change over time [41].
3. Educational Methods	Pedagogy	Formation of pedagogical principles as a step in the diffusion of any innovation in HE [25]. Explicit integration of sustainability aspects in courses' evaluation criteria [30]. Experimental educational settings [62].
	Interdisciplinarity	Change in teaching requires interdisciplinary approaches [66]. Balancing between cross-boundary activities and individualistic reward structures [51].
	Transdisciplinarity	Transdisciplinarity offers a catalyst role of actors in academia [17]. Crucial need for wider involvement of stakeholders [61].
4. Institutional Themes	Resources and Budget	Realistic budgeting as key in popularization phase [22].
	Curriculum design	Curriculum as facilitator for knowledge transfers between creative and scientific disciplines [20]. Whole curriculum may be permeated by various sustainability aspects [29]. Challenging transitions to sustainability-based curricula [33].
	Locating power	Locate abilities to affect change [51]. Empowerment of early adopters [63].
	Organizational culture	High impact of organizational culture on change processes [51].
	Institutional governance	Critical planning of longer-term management of change processes [22].
	Change monitoring	Evaluating, monitoring, and learning as reflexive institutional actions [35].
5. Physical Environment	Green campus, Campus design	Campus design with integrative function for multiple actors and bodies [67]. Potential links between education and green campus initiatives [61].
6. External Themes	External agents	External actors connected to institutional actors and decision making [49].
	Socio-technical context	Socio-technical contexts provide structuration of institutional actions [49].

2.2.3. Document Collection (1) and (2)

A two-step document collection process presented in Figure 1 is conducted. Quantitative and qualitative data are collected. First, the curriculum is reconstructed based on quantitative data regarding weekly course hours. This indicator is chosen because the credit system for courses was only introduced after completing the Bologna process in 2007/2008. For the period before 2007, no information on course credits is available. Longitudinal curriculum data at ETH Zurich between 1989 and 2022 are collected from programs, yearbooks, and the catalogs of courses (see Figure 2). Second, qualitative data on relevant actors in respective contexts (specifically, this includes a focus on backgrounds, research projects, and collaborations) is collected based on additional documents from the literature and archival sources. Precisely, this consists of the sources shown in Figure 2.

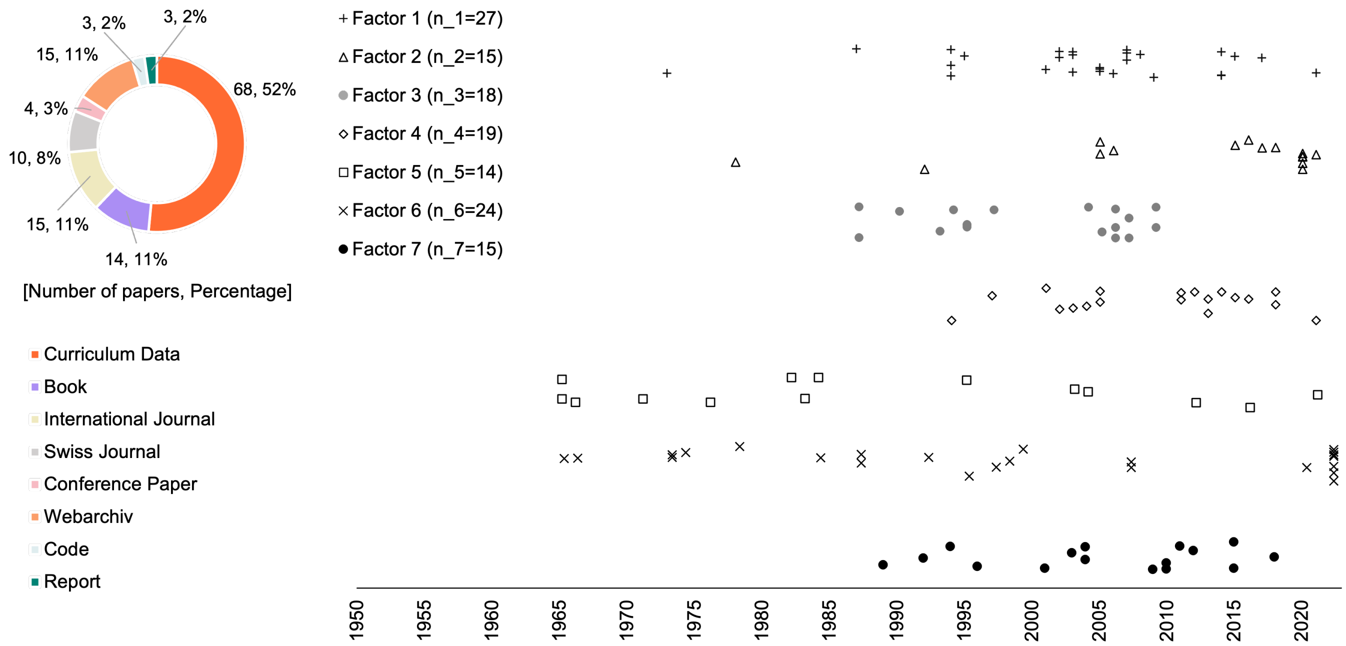

Figure 2. (**Right**): Scatter plot with data and associated publishing data of each data source used per factor, including curriculum data (yearbooks, programs, and catalogs) necessary for the specific argumentation of each identified factor in this study. (**Left**): Pie chart with overall source types used to argue the resulting socio-technical factors.

2.2.4. Analysis of Curricula

The analysis of curricula is conducted by extending "curriculum mapping" [54] in time via a longitudinal approach within the chosen time frame to investigate curricular changes in four sub-steps: (1) the categorization of clusters of courses, (2) the identification of various curricular changes over time, (3) the characterization of selected structural changes, and (4) the derivation of sub-periods. Curricular changes are identified based on a simple visual analysis of the inclinations of trend lines between yearly steps. In parallel, an analysis of past seminar weeks as opportunities to explore the built environment hands-on is conducted based on a keyword search of an online database of 2421 entries on seminar weeks from 1969 to 2022 as a starting point to investigate the diffusion of mainly disciplinary approaches to the built environment. The terms used for the keyword search are presented in Figure 3. The search was performed in English and German using the entire keyword and its word stem (e.g., "preservation" AND "preserv" AND "Erhaltung" AND "erhalt"). ETH's study regulations [60] show how the undergraduate program is currently structured. Three types of courses are distinguished: courses in the disciplines of design (1), scientific–technical courses (2), and humanities and social science courses (3). While the design courses stand at "the centre of education", other types of courses aim to ensure a "holistic" mastery of architectural tasks. Following this approach, the qualitative part of this work does not focus on design courses but on accompanying courses in the scientific–technical and social science domains. Elective courses, seminar weeks, and (post-)graduate programs are considered in a spotlight-like manner. Structuring curricular elements is based on Ostwald and William's approach [27]. Precisely, their characterization of blocks of courses for the following types are used: design and practice, history and theory, and electives. If possible, the data reliability on the conceptions of curricula is controlled using different sources (yearbook, course catalog, and program) simultaneously. In a few cases, the data sets did not match. Then, a most likely variant was assumed in the context of the temporal changes. As for the additional documents, in many cases, but not always, the documents described could be verified through multiple sources.

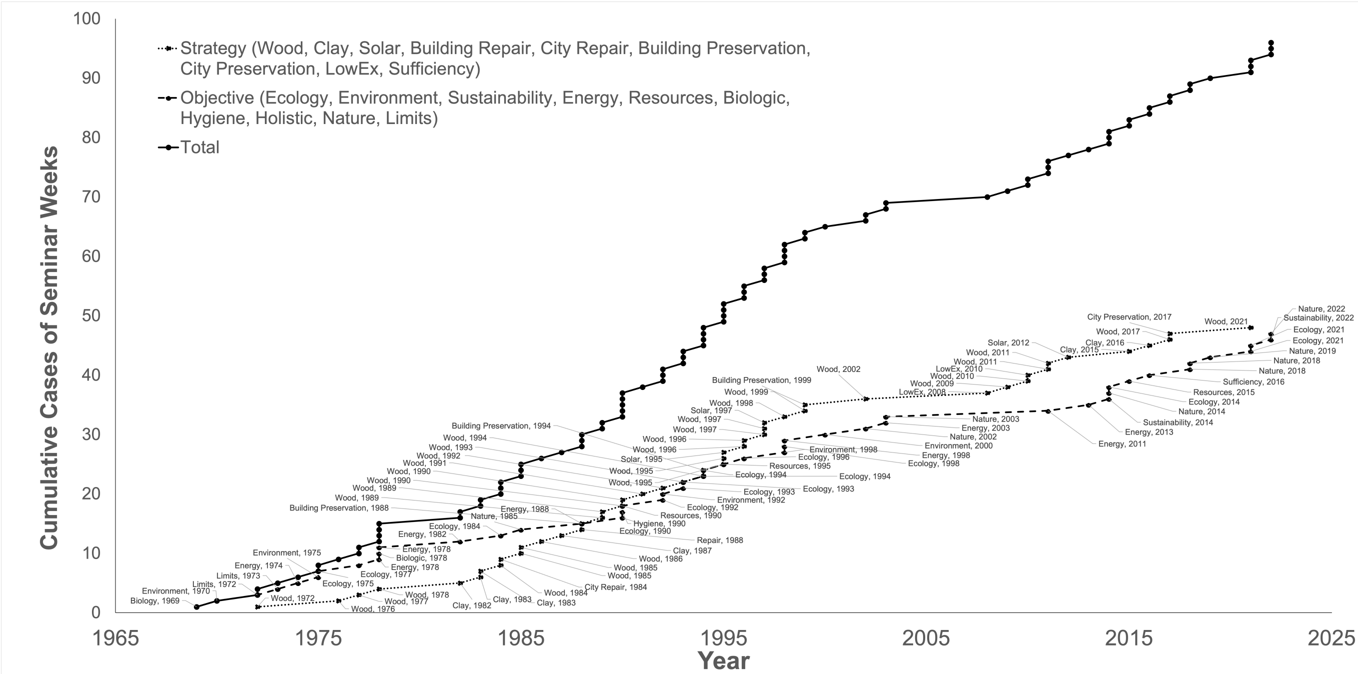

Figure 3. Cumulative cases of seminar weeks on an SBE theme within ETH's architecture curriculum from 1969 to 2022. Each data point corresponds to a seminar week organized according to a specific approach. The approaches are structured regarding strategies and objectives. The "total" line of topics corresponds to the sum of "strategy"- and "objective"-specific seminar weeks. The keywords used to perform the search are shown in the legend. The first appearances of relevant keywords date back to the period of 1969 to 1972 and include "biology", "environment", "limits", and "wood".

2.2.5. Determination of Socio-Technical Factors

A qualitative interpretation of accompanying documents of curricular changes is used to identify critical socio-technical factors on different levels (niches, institutional regime, and the socio-political landscape). The documents are collected from the literature and archives shown in Figure 2. Influential characteristics for the realm of teaching derived from the literature review on structural changes (see Table 1) narrow the focus of the analysis. Specifically, seven influential generic characteristics are chosen to develop nuanced variations in architecture: actors, niches, knowledge conception, networks, pedagogy, interdisciplinarity, and socio-technical context. Where possible, interconnections are made between the individual factors across levels to represent their complexity adequately. Therefore, an MLP document analysis process of the literature and archival material is conducted, focusing on actors in context, course contents, and didactic approaches. In this way, relevant generic characteristics derived from the literature are nuanced for the case of architecture education. Finally, the identified socio-technical factors for curricular changes in architecture are compared with the literature to reflect on their validity.

2.2.6. Limitations

Although based on empirical data and generic characterizations of factors from the literature, the analysis is limited in its potential for generalization by the subjective approach to the data. Specifically, different researchers might create a different classification based on the same data. Further, the proposed perspective on the curricula via the theoretical framework does not cover a comprehensive insight into all sustainability aspects in architecture education. Therefore, for instance, a general conception of competencies in sustainability would need to be applied, which may include critical competencies of systems-, values-, futures-, and strategies-thinking [68], to elaborate on the extent to which various courses in the architecture curriculum might be able to contribute to these competencies. However, the proposed approach allows us to consider pertinent directions to sustainability based on the development of an SBE in architecture. The level of administration, particularly the reasoning behind governance processes, organizational culture, monitoring, budgeting, and its interplay with bottom-up approaches, is beyond this work's scope. Regarding the level of different niches with experimental characteristics where novelties are articulated, academic actors in their respective fields and networks are used to describe influential activities that led to integrating distinctive approaches. This level allows us to reflect on didactic approaches. Although the students' perception exposed to didactic approaches could be a crucial factor for diffusion and transition [64,65], this lies beyond this work's scope. Also, transdisciplinary approaches are not investigated. On the "landscape" level, a comprehensive overview of societal and political activities on an SBE in Switzerland and their influence on higher education is not provided. Still, relevant events, projects, and networks that were influential for the developments at ETH's Architecture Department in the given context are presented. Finally, limitations on the scope of the curriculum need to be mentioned. The results do not systematically consider interactions between disciplines nor between higher education and building practice. The work also does not systematically analyze graduate or post-graduate programs and design courses. Therefore, the graphs only partially display curricular changes across undergraduate and post-graduate programs.

3. Results and Discussions

The interpretation of curricular trends based on an analysis of structural changes in the curriculum results in the following seven key socio-technical factors that influenced trends of structural changes towards an SBE in teaching:

- Relocation: relocation of the viewpoint on sustainability in the undergraduate curriculum from hygiene and physiology to energy and thermodynamics.
- Inquiry-based approaches: increased efforts on experimenting with inquiry-based approaches to teaching in educational niches.
- The diffusion of an SBE as a new research topic in teaching next to energy-aware new construction: engagement of a triad of researchers, industry partners, and public administration.
- Extended spheres of influence in teaching: expanded influence of actors in monument preservation via interdisciplinary collaborations and new teaching formats.
- Intra-faculty opinion leaders: early teaching efforts by committed actors focusing on ecology in building and planning.
- Transfer of methods: integration of interdisciplinary approaches to an SBE in teaching, especially from the fields of material science, civil-, and environmental engineering.
- Educational networks: formation of institutional and personal educational networks, especially across the disciplines of architecture, civil-, and environmental engineering.

A first overview of distinct viewpoints on objective and strategy from mainly architecture professors at ETH is shown in Figure 3. The results show the tendency for different viewpoints over time regarding the frequency of dedicated seminar weeks. Two aspects need to be highlighted: Compared to typical S-shaped growth curves for innovation diffusion [50], a decline from 2003 to 2008 and the following increase is of interest.

Although it would be naive to conclude on specific educational trends in terms of viewpoints on sustainability without investigating the content of the seminar weeks, this analysis offers a first insight into the development of an SBE in teaching, mainly from architectural actors. Further, it demonstrates how different approaches with experimental characteristics, such as on biologically appropriate buildings, low energy systems, or building repair, could be developed over time not only but also through seminar weeks. The format of seminar weeks as a "protected" testing ground to gather learnings seemed valuable for actors in architecture, as demonstrated by the repetition of many themes. However, the seminar weeks are assessed to have had only a limited impact on students because of the many possibilities to choose a seminar week that had nothing to do with sustainability. Future research could address the role of the seminar week as a starting point for the diffusion of novel concepts.

The identification process of distinct sub-periods for the architecture curricula between 1990 and 2022 is shown in Figure 4.

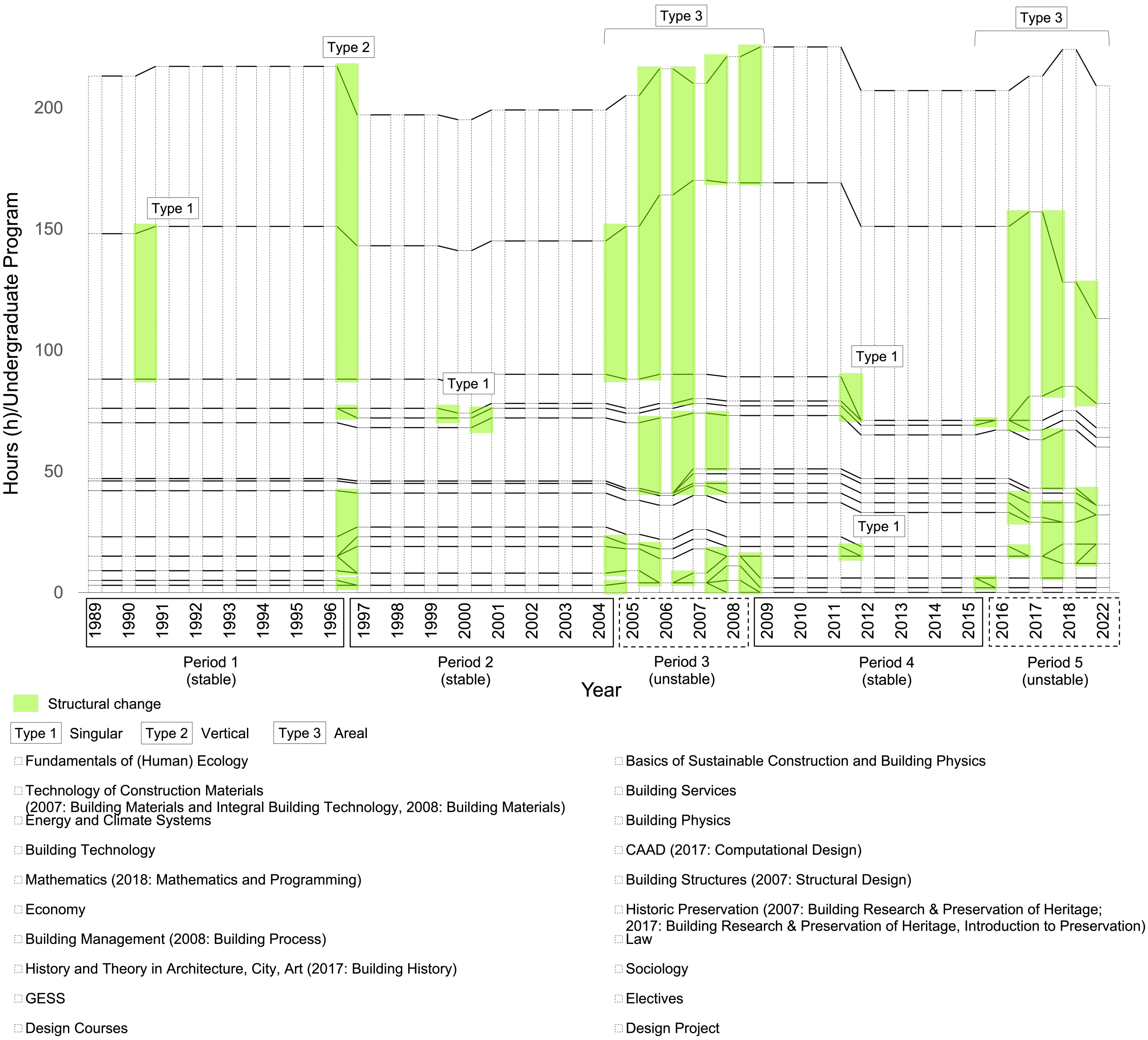

Figure 4. Five identified periods based on structural changes in the undergraduate architecture curriculum at ETH Zurich from 1989 to 2022. Changes are marked in green using a simple visual analysis of the inclinations of trend lines. Three different types are identified: singular changes (type 1), vertical changes (type 2), and areal changes (type 3). Type 1 changes are not assessed to mark different periods. The type 2 change between 1996 and 1997 marks the first significant implementation of a new curriculum. Two 4-year areal changes from 2005 to 2008 and 2016 to 2022 indicate implementation processes of new curricula.

A subsequent mapping of the undergraduate architecture curriculum at ETH Zurich is presented in Figure 5. Each course is plotted over time regarding the dedicated hours within the undergraduate curriculum. Courses in urban design and planning mark a particular case as they involve offers in design, history, and theory. A peak of efforts in the architecture core curriculum in this realm within the selected time frame can be marked with the curriculum of 2009. This curriculum included the 2 h core courses *Urban Design I&II* and the 2 h courses *History of Urban Design I&II*, both in the third & fourth semester;

the 2 h courses *Design and Strategy in Urban Space I&II* in the fifth & sixth semester; and the 6 h course *New Methods in Urban Simulation* in the seventh & eight semester.

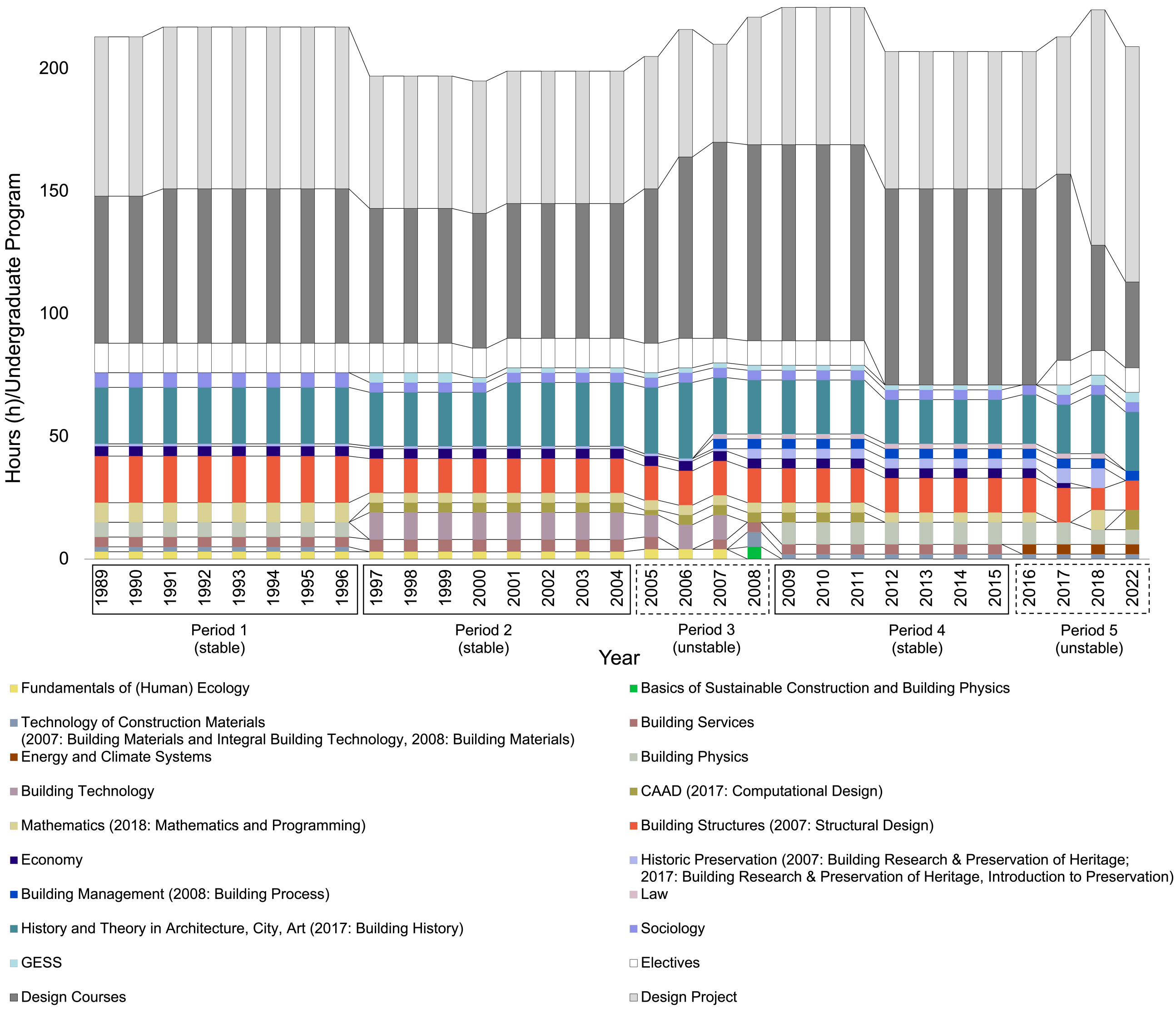

Figure 5. Changes in the undergraduate architecture program at ETH Zurich from 1989 to 2022. Different color coding corresponds to a course or block of courses. Overall variations in the total amount of hours in the program per year show the developments in the extent of the program in terms of dedicated time. The titles of courses were used according to the first appearance of the courses in 1989. However, adaptions of titles are given in brackets with the year of the new title if the title changes considerably. Solid and dotted lines of boxes on the time axis (x) represent the identified periods. A solid line corresponds to a "stable period" without considerable curricular changes; a dotted line corresponds to an "unstable period" with ongoing curricular changes. Seminar weeks and internships are not included in this graph.

3.1. Factor 1: Relocation

Considerable shifts in the undergraduate curriculum within the technologically oriented core courses during period 3 in Figure 4 are still relevant today. The course *Building Structures* (newly entitled *Structural Design* in 2007) has proven to be a constant throughout more than three decades with only minor variations in terms of scope This finding resonates with the high initial relevance of the subject as a link between the academic disciplines of architecture and civil engineering during the second half of the 19th century [48]. In contrast, a recent shift concerns *Mathematics*. Declining in size from 8 h (between 1989 and 1996) to 4 h (between 1997 and 2016), it disappeared entirely from the curriculum in 2018. However, in the same year, the 3 h course *Mathematics and Programming* enters the undergraduate curriculum. The title of this course already indicates its new conception on the intersection of mathematics and computer science. Further, the 8 h course *Computational Design* entered the curriculum in 2017. In comparison, the 4 h course *CAAD* (*Computer Aided Architectural Design*) was modified from a core course to an elective course in 2012 and has since been taught in parallel to *Computational Design*. In Figure 4, four courses are of particular interest regarding a tendency towards sustainability from the viewpoint of physiology to building physics and thermodynamics: *Building Physics*, *Building Services*, *Building Materials*, and *Fundamentals of (Human) Ecology*.

The latter course was lectured by members of the Institute for Hygiene and Applied Physiology of ETH between 2005 and 2007 by members of a team on environmental hygiene at the Center for Organizational and Occupational Sciences [69–71]. Not only core courses were lectured from the physiology viewpoint but also electives; for instance, *Housing and Environmental Physiology I&II* (original title: "*Wohn- und Umweltphysiologie I&II*") [72]. A script for *Fundamental of Ecology II* presents the elements of the course content: system's perspectives and circularity, work and health in construction jobs, light emissions, air pollution, environmental psychology, traffic noise, and practical sessions on the green building label *Minergie* and accessible buildings [73]. A detailed analysis of the influence of actors in environmental hygiene and physiology on the architecture curriculum at ETH Zurich is presented in Section 3.6.

While all four courses were part of the curriculum in the early 1990s, *Building Physics* descends from 1997 to 2007 while re-entering the curriculum in 2009. In parallel, the 4 h course *Fundamentals of (Human) Ecology* dropped from the curriculum in 2008. In the same year, a 4 h course entitled *Basics of Sustainable Construction and Building Physics* enters the curriculum, relocating the sustainability viewpoint in the undergraduate curriculum from hygiene and physiology to energy and thermodynamics. However, the newly established course *Basics of Sustainable Construction and Building Physics* already descends from the curriculum entirely after one year in line with accompanying personal changes. The course was lectured by Professor Heinrich Manz, a trained mechanical engineer, who led the Chair of Physics of Buildings for one year in between the periods of Professor Bruno Keller and Professor Jean Carmeliet.

Comparing the curricula from 2008 and 2009, the course *Construction Materials* is reduced in scope from 6 to 2 h. In parallel, a 9 h course on building physics re-enters the curriculum. Since 2016, *Energy and Climate Systems* have replaced the former course *Building Services*. This further demonstrates the change in the viewpoint on sustainability through building installations on the topic of energy by focusing not only but specifically on operational energy used for the heating and cooling of buildings. The approach to energy in building physics already included a broader perspective, including questions on embodied energy since the 1990s.

Bruno Keller (full Professor of Physics of Buildings at the Institute of Building Technology from 1991 to 2007) retrospectively reflects on his understanding of sustainability in architecture consisting of three elements: humans (e.g., providing a high level of comfort in thermal, hygric, visual, and acoustic respect), culture (buildings as cultural assets), and technology (specifically low energy demands over the life cycle and environmentally friendly and durable building materials) [74]. He included the concept of "energy content" of materials and lifetimes of materials in the course *Technology of Construction Materials* in the 1990s according to course descriptions [75]. Early impulses towards energy as a viewpoint on sustainability based on thermodynamics were developed at the Department of Mechanical Engineering of ETH. In 1983, the Institute for Energy Techniques was founded by consolidating three laboratories (Fluid machinery, Internal Combustion Engines and Combustion Engineering, and Energy systems) [76]. The efforts on life cycle assessment (LCA) for energy flows of products and services at the Institute led by Professor Peter Suter resulted in a collaborative research project funded by the Swiss Federal Offices together with multiple Swiss research institutes from 1990 onward [77]. A significant outcome of the research project on life cycle inventories (LCI) on energy systems was the development of a public database entitled "ecoinvent", intended to facilitate consistent assessments of different energy technologies. Currently, the ecoinvent database is widely applied as the largest transparent LCI database on a global scale [78]. In Switzerland, most LCA studies and calculations in the building industry and higher education rely on its background data sets first published in 2003 with version v1.01 [79]. An example of how this database is currently integrated into core material for a Master's Thesis in architecture can be found in a script entitled "Vademecum" initiated by Professor Anette Gigon [80].

New Configuration: Building Physics and "Green Building Labels"

In the 2000s, the viewpoint of building physics on sustainability now plays a prominent role in the architecture curriculum and beyond. A new configuration between the physics-based viewpoint and "green building labels". Green building labels are instruments for implementing sustainability in practice [81]. They either focus on single indicators such as energy or assemble a variety of indicators on economic, ecological, and social aspects of sustainability within descriptive catalogs aiming to represent a comprehensive view of sustainability. They allow for comparability, standardization, and transfers of research findings to practice via indicators, which do not come without problems. For instance, to a certain extent, the variety of systems jeopardizes enabling comparability via the standardization of catalogs of indicators) enables a reflection on the debates between academia and practice. Internationally, the Green Building Council (GBC) presents a crucial global actor for promoting and regulating labels and certification schemes. In Switzerland, the 2000-Watt-society is a well-known concept in the industry that impacted the Swiss codes through SIA 2040 [82] and labels such as *2000-Watt-Areal* and *Minergie*. The concept intended as a framework for building practice focuses on energy and builds on the notion of a maximum energy budget per capita. Before its launch as a practical framework, the theoretical foundations were developed in the ETH domain in 1998 [83]. One of the main contributors to the project was Eberhard Jochem (a Full Professor for National Economy and Energy Economy from 1999 to 2007 at ETH Zurich). In a conference at ETH Zurich's Architecture Department in 2010, the approach was critically discussed by arguing for "zero-emission architecture" instead of a focus on energy as the leading indicator. The conference was accompanied by a declaration by the ETH architecture professors, arguing for this zero-emission strategy for the built environment. Within their collaborative position paper, a change in paradigm from energy savings to zero-emission approaches was advocated. During an accompanying symposium, instead of 2000 Watt of energy, 1 ton of CO_2 was argued to become the new leading target indicator, considering the concepts of embedded and renewable energy. Professor Hansjürg Leibundgut advocated for the concept of "low exergy". He presented a thermodynamical approach which relies not on insulation but on temperature differences to receive a high COP (Coefficient of Performance) for heating pumps rendered within a contextual change from air hygiene in 1980 to climate change in 2010 [84]. Overall, this new focus from building physics on sustainability via the topic of energy and later energy-related greenhouse-gas emissions diffused in the architecture curricula and influenced debates on "green building labels" in practice.

3.2. Factor 2: Toward Inquiry-Based Learning

Multiple approaches to a sustainable built environment in courses at ETH have been articulated by emphasizing the inquiry-based participation of students since the 1990s. These approaches involve tasks that deal with physical artefacts, digital tools, and games. A non-exhaustive collection of developed courses and procedures that demonstrate conceptual differences is presented in this section.

Digital parametric models were frequently used in teaching in the field of building physics. Two efforts explicitly aimed at architecture and civil engineering students reflect this approach. At the Chair of Physics of Buildings, not only software from the industry on life cycle assessment of buildings was applied, but also new digital tools were developed, such as the *Energy Design Guide* [85]. Based on the tools, the students in architecture and engineering were intended to conduct building simulations and inquire about the evaluation and optimization process of a building according to energy, comfort, and moisture behavior in regular course work, design-integrated disciplines, and elective projects [86]. The scope of the approach involved materials, the comfort of the inhabitants, energy needs, and the durability of buildings, including material choices, calculation of U-value and heat transmittance, acoustics, and airflow. A digital tool for design-integrated parametric approaches to buildings with a different user experience and a more specific focus on embodied aspects entitled *Bombyx* is currently applied in the course *Building Materials and Sustainability* offered at the Chair of Sustainable Construction at the DBAUG (since 2012, a permanent Chair has been established, and, since 2023, a full Professorship has been anchored [87]). The tool primarily aimed at architecture and engineering students focuses on the early design phase of buildings. It enables students to reflect while receiving real-time feedback when choosing materials, building systems, or geometries via a plug-in for Grasshopper based on Rhinoceros3D [88]. In comparison, a digital strategy to materiality from an architectural design perspective has been applied within a MAS (Master in Advanced Studies) program of the Chair for Architecture and Digital Fabrication. The focus lies on materials such as clay or wood and how questions on reversibility, recycling, and reuse can be integrated into design workflows [89]. Although not explicitly emphasized, both tools show at least similarities to the approach of "gamification". Games —in contrast to gamification—have been identified to facilitate learning [90] and to potentially leverage further integration of sustainability in higher education [29,91,92] in learning by including objectives, real-time feedback, contextualization, and a specific system of rules [90], which may facilitate a mode of inquiry. A prototype game on the long-term preservation of a historic hotel aimed at a younger generation is being tested in an interdisciplinary research project at ETH [93]. The strategy game seeks to enable the players' inquiry of a long-term perspective on existing buildings by providing engaging and interactive content based on a systematic connection of building life cycle impacts for maintenance, replacements, and refurbishment actions. However, the first tests indicate that it might be crucial to differentiate between subgroups of Generation Z as a target audience and their preferences to explore its full potential. Earlier game-based approaches that used models on a city scale can be found in the field of urban planning, for instance, by Walter Custer (full Professor for Architecture and Spatial Planning at ETH from 1960 to 1980), who focused on active and interdisciplinary approaches to spatial planning in his teaching activities [94]. Custer edited a game on spatial planning [95]. Localising the player in the city of Olten (Switzerland), this tabletop game would engage in different roles, such as politicians, citizens, planners, or "real estate speculators", and discuss conflicting interests on building renovation projects, demolition, listed monuments, and industrial pollution in cities. In comparison, a well-documented course developed since 2014 takes up repair as a concept from monument preservation beyond listed objects by using it as a didactic concept to leverage sustainable thinking. Therefore, students are encouraged to research the qualities of their everyday items, such as chairs, lamps, and headphones, with which they examine thoughtful handling of valuable existing fabrics. Repair concepts developed by the students may involve the 3D printing of spare parts and craftsmanship [96]. Recently, courses encouraging digital tool application have also been developed on architectural circular practices (offered by members of the Chair of Circular Engineering for Architecture at DBAUG). The five-credit course *Digitalization for Circular Construction* is dedicated to providing a framework for students in engineering and architecture to test a transition of construction projects from linear to circular processes [97,98] by enabling a first-hand experience of a circular workflow along different stages, which is achieved by experimenting with a vast range of technological applications and collaborations with industry experts. The course includes LiDAR scanning to survey demolition sites and their materials, scan-to-BIM techniques, computer vision applications to develop material inventories, creation of strategies for non-destructive building disassembly in cooperation with practitioners, and optimizing material stock using computational design tools.

An approach to action- and project-oriented teaching can already be found in 1994 within the concept of a post-graduate program on *Building Management* (original title: *NDS Gesamtleitung von Bauten)* by Paul Meyer (Professor of Architecture and Building Realization at the Institute of Building Technology between 1987 and 2004) and Hans-Joachim Schnäkel. "Active learning" is understood as group work, role play, and debates in interdisciplinary environments [99]. Further, in their teaching program, they highlight a "holistic" approach to building management and describe the new construction, renovation, and adaption of buildings, including "value analysis" of buildings as a priority area within their program, acknowledging the increased interest in the built environment in the 1990s in Switzerland.

The variety of efforts on new concepts, digital tools, and interdisciplinary articulations underscore single actors' commitment to providing learning frameworks that enable students to inquire about the implications of an SBE. However, many approaches in teaching were developed in niches and showed experimental characteristics, putting them at risk of being replaced (and revisited) without long-term learning processes for lecturers. Finally, the presented non-exhaustive documentation of original teaching projects could form the basis for a comprehensive investigation of inquiry-based learning for an SBE.

3.3. Factor 3: Diffusion of a Research Topic

The research projects entitled "Impuls Programme" (dealing with the rational use of electricity–RAVEL, renewable energy systems–PACER, and the maintenance and renewal of buildings–IP BAU) initiated by the Swiss Federal Government (1990–1995) represent a significant shift towards an SBE in research. The objective was to reduce resource and energy use, coined by "qualitative economic growth"). The IP BAU project focused on a long-term perspective on existing buildings and is documented in at least 14 accompanying publications targeted at different industry actors [100]. The projects were conducted with a triad of industry partners, educational institutions, public authorities, as well as professional associations. The documentation shows that a growing number of buildings in Switzerland were identified to require maintenance and renovation due to technical damages and defects. Therefore, the project aimed to develop guidelines for owners, public administration, planers, and construction companies, which were only available for new constructions so far. In parallel, two different works dealt with quantitative assessments of the built environment in Switzerland. In 1989, shortly before the IP Bau project started, Hannes Wüest and Christian Gabathuler published an early work on the Swiss building stock including future scenario developments [101]. Another diagnosis regarding the necessity for actions on the Swiss building stock was made by Jules Schröder in an article from 1989 [102], who was, at that time, a cantonal building inspector in Zurich. He highlights an increasing amount of new construction in Switzerland with decreasing quality while no methods or experience were available to target this situation. Subsequently, he presents an approach on the building component level for long-term economic planning of maintenance and renovation measures based on a quantitative condition state model. In the late 1990s, research efforts and collaborations on an SBE increased as indicated by publications such as the work on material flows ("Stoffströme") and the costs of the German building stock edited by Niklaus Kohler, Uta Hassler, and Herbert Paschen, which combined a top-down and bottom-up modeling approach on the building stock level [103].

Although differing considerably in formation conditions, the listed research works diffused into the Swiss building industry and academia via outreach activities. The Swiss engineering office Basler & Hofmann AG developed a software tool based on the method of Schröder entitled STRATUS and SPECTUS [104]. In academia, the foundations Schröder set were included in ETH teaching scripts by Meyer in his courses on the management of existing buildings [105]. In comparison, an actor-based diffusion of newly established approaches to the built environment can be traced through two main contributors to the IPBAU project: Niklaus Kohler, who joined the Karlsruhe Institute of Technology as a Professor from 1992 to 2007 before moving to ETH Zurich as a lecturer, and Hannes Wüest, a co-founder of the real estate company Wüest & Partner. Both actors were project leaders of the IPBAU project. Only in 2007 [106,107], at the Chair of Historic Building Research and Conservation, the 2-year MAS program *Sustainable Management of Man-Made Resources* was launched by Uta Hassler (a full Professor for Historic Building Research and Conservation at ETH Zurich from 2005 to 2015). The list of courses shows that Niklaus Kohler was listed as a lecturer from 2007 onward [107] and Martin Hofer, also a co-founder of Wüest & Partner, in 2008 [108]. The catalog of courses shows that sessions included the environmental assessment of existing buildings and future developments of the building stock during many years [86,109–111], where especially Kohler and Hassler could draw on the knowledge developed in their research projects.

The documentation demonstrates that establishing an SBE as a new field of research through the described projects in the early 1990s in the Swiss context influenced its introduction in teaching. Considering the developments, it is no surprise that in 1997, the SIA published the standard 469 on the technical preservation of buildings for the first time, with Jules Schröder as a member of the standard's committee [112]. However, a comparison with the advancements in energy-friendly new construction in practice during that time—which considerably entered the debates at ETH and EPFL, for instance, during the 1990s through a symposium on Swiss energy research held alternately in Lausanne and Zurich [113]—puts the diffusion of a new approach to an SBE in context: In 1995, three new documents were launched for the first time by the SIA on ecological new buildings regarding impacts of material choices for construction (D0123), building installations (D0118), and its teaching integration (D0122) [114]. Further, the recently archived version of SIA 493, first issued in 1997, on ecological characteristics of building materials [115] indicates that there is not necessarily a linear increase in more regulative documents and recommendations in this context. Finally, the still relevant documents SIA 2040 and SIA 2032, which take embodied energy into account, were only launched later in 2006 and 2008, respectively [116].

3.4. Factor 4: Extended Spheres of Influence in Teaching

Early contributions from researchers in the field of monument preservation and conservation on societal, technical, and environmental implications of the built environment are well known in monument preservation [117–119]. In this section, the presented courses and teaching projects include integrating research into teaching and vice versa. New course offers from the recent past are related to the reoccupation of a Professorship in (monument) preservation, now entitled *Construction Heritage and Preservation*. The examples show that as soon as the built environment entered the debates on sustainability in architecture, actors in monument preservation could contribute well to the overarching objective based on approaches that focus not only on knowledge of historic buildings and on the fabrics of existing building stocks, but also on the on- and off-site methods from preservation and construction history to gather empirical data as a starting point for further research. Within the selected new constellations presented in this section, monument preservation as a field expanded its sphere of influence in teaching. The aim that became clear, at least in the early 2000s, was that monument preservation should not only be considered a strategy to deal with the past but also a strategy for the future regarding its promising approaches to environmental and societal questions.

In the 2000s and 2010s, students could engage with the central notions in the field of monument preservation through the core courses *Historic Preservation* (until 2007), *Building Research & Preservation of Heritage* (2007–2017), *Building Research & Preservation of Heritage* (2017–2018), *Introduction to Preservation* (2017–2018), and a design-integrated discipline of monument preservation within the undergraduate curriculum shown in Figure 4. Further competencies in teaching were acquired through the Master's level course *Building* *in Existing Contexts* (from 2005–2015) [120,121] and the previously mentioned MAS program *Sustainable Management of Man-Made Resources (SUMA)* (from 2007–2013) [120,122,123]. The topic of man-made resources could also be revisited from a different viewpoint because Professor Klaus Daniels (full Professor at the Chair of Building Services from 1991 to 2005, retired in 2005) and his post-graduate (ND) program on *Dealing with Natural Resources in Construction* (original title: *Umgang mit natürlichen Ressoucen beim Bauen*) was terminated [107,124,125]. The course description of the SUMA MAS program shows how concepts and approaches from monument preservation were combined with economic and environmental aspects of building to develop long-term strategies for the building stock [109]. In 2011, the program included project work and theoretical inputs on preservation and building research, facility management, simulation and modeling, and sustainability and life cycle assessment for existing buildings. However, the SUMA MAS program was terminated already before the re-organization of the chair in 2015 [122], although the number of enrollments likely increased on a low level towards the end (the unpublished course documentation lists two participants from 2007 to 2009, one participant from 2009 to 2011, and four participants from 2011 to 2013). The disproportionate effort for a relatively small number of participants in the beginning could probably be balanced due to an overlap in the teaching efforts with another MAS program in *Conservation Science* running in parallel [122]. Changes in the undergraduate course offerings in preservation beginning in the mid-2010s shown in Figure 5 can be related to the retirement of Hassler in 2015. After a 5-year interim period with a high variability of relevant offers between 2015 and 2020, since 2020, preservation has not been a part of the core undergraduate curriculum anymore. It has only been offered as an elective course entitled *Practical Aspects of Monument Preservation* (original title: *Praktische Denkmalpflege*) [126,127]. However, in parallel, new courses since 2020, such as *Future Monuments* and the elective course *Repair: Encouragement to Think and Make* as well as a recent teaching project dealing with the conception of integrated design studios demonstrate the fields' potential to contribute to an SBE in teaching.

Outlook: Integrated Design Studios

To connect design studios with related disciplines, integrated design studios have been part of the undergraduate curriculum at ETH since at least the 1990s [128]. Focusing on building systems and technology for new and existing buildings, the Master in Integrated Building Systems (MIBS) at ETH presents an example of an interdepartmental effort to approach cross-disciplinary design projects in education since its initiation in 2013 together with the SIA [129]. Recently, within the ongoing curriculum revision of the architecture curriculum at ETH, a heritage-led teaching project combines a design studio, the elective course *Repair*, and a design-build seminar week "to teach students to apply the methods of heritage preservation to architectural design" as a prototype for future integrated design studios, supported by ETH's *Innovedum* fund for innovative teaching projects and monitored by a steering committee of the curriculum revision group [130]. This prototype project could demonstrate how horizontal and vertical alignment could be improved using existing courses dealing with an SBE in the future.

3.5. Factor 5: Early Intra-Faculty Opinion Leaders

Dennis L. Meadows, a co-author of the seminal work *Limits to Growth*, presented the work on growth dynamics in a lecture at ETH Zurich in 1973 [55]. Werner Jaray, at that time Professor for Architecture and Design, was well informed about the work of the Club of Rome. Already before the lecture and a well-documented exhibition at ETH entitled "rethink–change" (original title: *umdenken–umschwenken*) reached a larger audience with ecological concerns of economic practices [131], Werner Jaray hosted a seminar week entitled "Limits to Growth" in 1972 and a second one in 1973 (see Figure 3). A comparison of his inaugural lecture (1967) [132] with his farewell lecture (1985) [133] reflects a change in his reasoning on ecology over time. His early reasoning is coined with the statement that the "most durable is always also the most affordable" (only towards the end of his career as a Professor at ETH in the 1990s, he attempts to formulate a model for a long-term economic view of buildings emphasizing durability and maintenance. Original statement: "Das Dauerhafteste ist immer auch das Preiswerteste."). This approach is also reflected in his early teaching offers, for instance, the core courses *Economy of Building I&II* (original title: *Oekonomie des Bauens*), which he lectured in the seventh and eighth semester of the architecture curriculum in 1967 and 1968 [134,135]. Further, during the start of his career, he lectured a core course on a project management method using graphical (network) representations of process chains entitled *Netzplantechnik im Bauwesen* together with Professor Hans von Gunten (a full Professor for Structural Analysis and Design at the Faculty of Architecture from 1969 to 1995 and rector of ETH Zurich from 1983 to 1995) [135]. In retrospect, it does not surprise us that his vocabulary and methods, mainly drawn from the field of economics, could be developed towards his later reflections, increasingly articulated from an ecologist's viewpoint. At the same time, his early economic critique does fit with a specific strand of publications during the early 1970s in the German-speaking area, including growth critiques from architectural perspective [136,137]. His later reasoning on "holistic" approaches in architecture was most likely transferred from the field of biology according to his farewell lecture. Jaray lists the biologist Adolf Portmann (1897–1982), a former Professor of Zoology at the University of Basel, as an influence for his general perspective on the reductionist characteristics of natural sciences and the combination of natural science and art. Portman advocated for inter- and transdisciplinarity,holistic approaches, and aimed for a connection between natural sciences, mathematics, andarts [138]). However, his continuous teaching activities over two decades render his figure as an opinion leader who brought early environmental concerns into the curriculum. Next to his architectural design studio, which he taught together with Professor Franz Oswald at ETH, for instance, in 1977/78 [139], he lectured two elective courses *Ecology and Planning* and *Building and Ecology* during the 1970s and 1980s. In *Ecology and Planning*, course descriptions in ETH Programs show that Jaray focused on construction's economic and political implications, including environmental policy making and waste management [139]. In *Building and Ecology I&II*, the courses' documentation shows that he articulated a critique of current practices in architecture on distinct levels (buildings, areas, communities, and regions) based on considerations of resource extraction, material manufacturing, building operation and maintenance, building adaptions, and demolition [140]. Jaray's elective courses terminated with his retirement. However, ecology remained a part of the architecture curriculum, for instance, with the newly introduced elective course *Ecology in Case Studies* lectured by Professor Helmut Krueger (a Professor of Ergonomics and director of the former Institute for Hygiene and Applied Physiology at ETH Zurich from 1983 to 2005) [141]. In 1987, this course that included "current environmental and hygiene threats" in architecture was lectured collaboratively by Krueger and Professor Hans Urs Wanner (he completed his doctorate under the supervision of Professor Étienne Grandjean at ETH and later established the Institute for Hygiene and Work Physiology as a professor) [142]. Further, he was described as a pioneer of ventilation systems and solar energy. During his time as the federal commission's president on the topic of air hygiene from 1986 to 1996, milestones in environmental policy making could be implemented by the Swiss Federal Council, which the commission advised, for instance, the introduction of emission and exhaust gas limits in transport [143]). Their role as relevant actors in the architecture curriculum from the field of environmental physiology is presented in the following section.

Finally, the investigation of the role of "opinion leaders" in education [63] does not offer comprehensive documentation of all early efforts, given the context. Still, this work uses the case of Jaray to reflect on the implications of an early exemplary opinion leader (the former rector of ETH Konrad Osterwalder emphasizes Jaray's role as a pioneer in raising students' awareness for holistic and early sustainable thinking in architecture education at ETH over two decades [144]) in the given context for the architecture curriculum. After his retirement, other approaches to ecology in the curriculum based on physiology and hygiene likely benefited from a more robust theoretical positioning.

3.6. Factor 6: Transferring Interdisciplinary Methods

Multiple actors outside the architecture discipline contributed to establishing courses on the human–environment interaction and, second, a sustainable built environment by transferring methods to the architecture curriculum at ETH. Differences in approaches and associated overlaps with efforts from actors in architecture can be demonstrated through core and elective courses. Overall, the approaches from different disciplines, especially material science, civil, and environmental engineering, likely enhanced the quality and scope of teaching aspects of a sustainable built environment in the architecture curriculum. Finally, this documentation raises the question of how these efforts that partly overlap with offers from architectural actors can be organized in the architecture curriculum to achieve the most effective vertical and horizontal alignment with other courses.

3.6.1. Physiology

In a retrospective article from 1984, Hans-Urs Wanner and Kruger elaborate on the agenda of Professor Étienne Grandjean, who succeeded Professor Wilhelm von Gonzenbach, Professor for Bacteriology and Hygiene, at the Chair for Hygiene and Work Physiology at ETH in the 1960s [145]. They describe how Grandjean intended to shape his expertise so that it could be transferred into other curricula at ETH, specifically the curricula of engineering and architecture. Further, they describe a particular focus of his work on "environmental hygiene", meaning the protection of people from harmful emissions in residential and recreational areas in the context of the latest regulations of the Swiss Environmental Protection Act. This focus is reflected in the architecture curriculum of the 1960s. First, Grandjean offers a core course on *Construction Hygiene* (original title: *Bauhygiene*) in the seventh semester of the curriculum of 1965 [146]. From 1966 onward, Grandjean lectured the core courses *Housing and Work Physiology* (original title: *Wohn- und Arbeitsphysiologie*) in the second semester and *Urban Hygiene* (original title: *Stadthygiene*) in the eighth semester [147]. Thereby, actors from physiology and hygiene could continue their long-term involvement within the architecture curriculum at ETH that dates back to at least the 1920s. With courses on hygiene and physiology for architects and civil engineers [148], these actors further developed and expanded their educational competencies in architecture education by adapting their courses to the context of ecology (notably, van Gonzenbach engaged with the topic of water pollution control in the 1920s, which should later become a core theme of the early environmental movement in Switzerland [149]). The shift towards "ecology" occurred after the retirement of Grandjean in 1983, as well as the retirement of Jaray in 1985, with the first introduction of the core course *Fundamentals of (Human) Ecology* to the architecture curriculum in 1987 [150]. This long-term background of physiology and hygiene in the architecture curriculum demonstrates the significance of the change in trend towards building physics since at least the 2000s, elaborated in Section 3.1. The architecture curriculum at ETH included the core courses *Fundamentals in Human Ecology I&II* within the first two semesters from 1987 to 2007, shown in Figure 5. The course was first lectured by Krueger and Hangartner and included the topics of housing and work physiology (first semester) and environmental physiology (second semester). A course description from 1987 [150] describes the course's aim on environmental hygiene to embed the building in its environment and the ecological cycles. Further, specific topics included ecological cycles of materials, air, odor, sound, wastewater, and waste and soil pollution.

3.6.2. Building Physics and Material Science

Technological approaches to sustainability based on building physics in the architecture curriculum were extended in scope via the involvement of institutions within the ETH domain. Since at least the 1970s, actors at EMPA considerably contributed to the architecture curriculum with courses on new construction and maintenance. In the 1970s, EMPA's division for Building Physics was led by Robert Sagelsdorff [151]. In an annual report from 1973 [152], the division lists its key achievements, including developing measuring tools for existing buildings and increasing teaching activities at ETH's architecture and civil engineering faculty. Within this report, a list of lecturers at ETH shows that Sagelsdorff was among 14 other lecturers at ETH Zurich during that time. First, he offered a course entitled *Building Physics Internship* (original title: *Bauphysikalisches Praktikum*), which can, for instance, be found in the ETH Program of 1974 [151]. While this course highlighted a practical approach to methods in building physics, in the 1980s and 1990s, Robert Hastings, a researcher at EMPA's building physics division, engaged with "solar buildings". A view on past seminar weeks and elective courses allows for further insights into their focus area within sustainability in architecture: together with Klaus Daniels, Professor for Building Services at ETH, Hastings launched several seminar weeks on the mentioned thematic area in parallel to lecturing the elective course *Construction and Use of Solar Energy* (original title: *Bauen und Sonnenenergienutzung*) from 1992 onward (See Figure 3). While Sagelsdorff offered two seminar weeks on *Energy-aware Construction* (original title: *Energiebewusstes Bauen*) in the late 1970s [153], Hastings lectured seminar weeks in 1995, 1997, 1998, and 1999 on *Glass dreams* (original title: *Glassträume*), *Solar architecture*, *Energy-aware Construction*, and *Environmentally friendly Construction* (original title: *Umweltgerechtes Bauen*). A different approach that dealt with existing buildings was lectured by members of EMPA's group that dealt with structural damages. Two courses that engaged with building maintenance are of particular interest: The elective course *Structural damage, analysis and prevention* (original title: *Bauschäden, Analyse, und Verhütung*) (first lectured in 1981) and the core course entitled *Building Materials Science* (original title: *Baustoffkunde*) [154]. While in the 1980s, actors from EMPA conducted the course on *Building materials science*; in the 1990s, this course was renamed as *Technology of Construction Materials* (see Figure 5) and taught by members of the Chair for Physics of Buildings. This situation indicates that in the 1980s, responsibilities in teaching in the field of building physics and materials shifted from EMPA to ETH, at least since the appointment of Keller as a full Professor of Physics of Buildings in 1991.

3.6.3. Outlook: Civil and Environmental Engineering

Today's undergraduate architecture curriculum presents several elective courses on methodological approaches to environmental sustainability offered by actors at the DBAUG and the Department of Environmental Systems Science (DUSYS), including the courses *Prospective environmental assessment* (3 h course that emphasizes different methods for emerging technologies and the evaluation of "long-term environmental impacts caused by today's activities" using dynamic material flow analysis (MFA) and life cycle assessment (LCA) [97]), *Design-Integrated Life Cycle assessment*, *Materials and Construction*, and *Re-/Source the Built Environment*. The catalog of courses gives further information on the articulation of sustainability: By focusing on uncertainties, discounting environmental impacts, system dynamics, and temporal differentiation, it offers a general approach to environmental assessment methods on distinct scales. The remaining courses add a more specific viewpoint on the role of architecture and civil engineering in an SBE. The 2 h course *Design-Integrated Life Cycle assessment* aims to specifically integrate the LCA method into the design process to improve the environmental performance [97,98]. In comparison, the 2 h course *Materials and Construction* focuses on technological systems [97,98]. Further, the course focuses on regenerative materials such as earth, bio-based, and reused materials and questions on their properties, material behavior, durability, and applications within retrofitting. A theoretical and practical viewpoint on the built environment is combined in the 2 h elective course *Re-/Source the Built Environment* by including different lecturers from academia and practice. For this purpose, two parts are foreseen [97,98]: A first part deals with general conceptions such as on resilience or contexts, for instance, in material criticality. In the second part, guest lecturers cover distinct approaches). Thus, a remarkably large methodological area towards an SBE is currently covered by electives. Application-oriented approaches and the comprehensive coverage of theoretical viewpoints by including reflective practitioners are worth mentioning. These courses can form a valuable starting point for future curriculum transitions by further anchoring methodologically well-founded offers.

3.7. Factor 7: Formation of Educational Networks

Various courses have been offered since the 1990s on maintaining and managing existing buildings, infrastructures, and landscapes at the DBAUG and the DARCH of ETH. Regarding the courses at DBAUG, the outreach to architecture students most likely remained negligible as the courses were rarely integrated into the architecture curriculum and because of pre-requirements in Mechanics or Mathematics. However, a perspective on the organizational level of these efforts adds another layer to this work. Therefore, this section focuses on examples of the formation of networks in teaching by distinguishing between personal ("individual-actor networks") and institutional networks ("collective-actor networks") [52]. In the early 1990s, Professor Folker Wittmann (a Full Professor for Building Materials from 1988 to 2001) lectured an elective course on *Durability and Maintenance of Reinforced Concrete Structures* (original title: *Dauerhaftigkeit und Instandsetzen von Stahlbeton-Bauwerken*) [155], which should be followed by more efforts in teaching the durability of buildings and building maintenance. Since at least the mid-1990s, Professor Peter Baccini (a full Professor for Resources and Waste Management at ETH's DBAUG from 1991 to 2004, affiliated with EAWAG, leading the research group on *Stoffhaushalt+Entsorgungstechnik*). His dual function was typical for environmental engineering, with connections to all institutions within the ETH domain. Later, he was well known for contributing to the development of theoretical foundations of material flow analysis and the concept of hinterland [156]. Regarding his understanding of sustainability in teaching, he postulated an image problem of the building sector that fell behind other topics in political debates (for instance, the environment in the 1970s, energy and safety in the 1980s and 1990s, and bio- and information technology in the 1990s) which manifested in a 30% decrease in students in architecture and civil engineering in the 1990s and criticized the popular understanding of sustainability as three equal pillars (economy, social, and ecology), due to leading to inactivity and not sufficiently considering endless physical resources [157]. Not least, he became a "global networker" in research and teaching. Baccini's late understanding of sustainability is reflected in a statement from his farewell lecture [158] where he states that the morphological quality of the urban, the architect's aesthetics, physiological perceptions, and the ecological view of the natural scientist must be linked to create suitable instruments for the transformation process of urban systems. The elective course *Sustainable Building Materials Management* (original title: *Nachhaltige Baustoff-Bewirtschaftung*) was first lectured in 1993/94 (probably marking the first appearance of sustainability in the title of a course in the civil engineering curriculum of ETH) by a group of researchers around Baccini including Böhni, Professor Robert Fechtig (a full Professor at DBAUG in the 1990s for Construction Process Engineering), and Thomas Lichtensteiger [159] (a member of Baccini's group at EAWAG). In parallel, Fechtig lectured an elective course *Planning and Implementation of Maintenance and Renovation Projects* (original title: *Planung und Durchführung von Unterhalts- und Renovationsprojekten*) together with Professor Hans Rudolf Schalcher (a full Professor for Planning and Management at DBAUG). Further, Schalcher lectured *Maintenance of Buildings* (original title: *Erhaltung von Bauwerken*) and *Planning and Execution of Maintenance and Refurbishment Projects* (original title: *Planung und Ausführung von Instandsetzungs und Sanierungsprojekten*) in 1996 together with Gerhard Girmscheid [75], a Professor at the Institute for Construction Engineering and Management from 1997 to 2015. Today, the continued relevance of managing existing building infrastructure is reflected in the civil engineering Master's program with a change in the area of specializations' title from *Building Planning and Operation* (original title: *Bauplanung und Baubetrieb*) to *Construction- and Maintenance Management* (original title: *Bau- und Erhaltungsmanagement*) conducted in 2011 [160,161]. A closer look into a research project indicates Baccini's impact on architecture research. With Franz Oswald, Professor for Architecture and Design at ETH, Baccini was responsible for the research project *Sinoykos* [162]. After their long-term collaboration, the publication of the "Netzstadt" (literally "net-city") model in 2003 [162], aiming to provide a new urban design method for architects, was highly positively reviewed [163]. The model includes an early comprehensive transdisciplinary system approach to urban planning and territories.

Regarding institutional networks, 2002 marks a crucial moment for urban planning. The foundation of the Network for City and Landscape (NSL) in collaboration with a new Institute in Basel ("Studio Basel–Contemporary City Institute") as a successor of the Institute for Local, Regional and National Planning (ORL) founded in 1961, brings together urban design, urban planning, landscape architecture, and transport planning and is presented in the DARCH yearbook 2003 [162]. This institutional network was intended as an interdisciplinary research platform between architecture, civil and environmental engineering, and geomatic engineering, including five institutes and initially two Master's programs. The aim was to develop foundations for shaping the environment while considering a broad perspective on culture, sustainability, and aesthetics. However, the developments around the NSL were also criticized, prominently by Hans Georg Bächtold, because the network no longer requires core professorships in urban planning [164]. Bächtold was a researcher and lecturer at ETH in urban planning and later became the Swiss Association of Engineers and Architects (SIA) president in 2009 [165]. He contributed to courses in the MAS on Urban Planning from 2009 to 2012, among others, with Christian Gabathuler [166] In an article from 2016, Gabathuler describes his path from participating in courses on urban planning offered by Walter Custer to the ETH post-graduate program ("NDS") in urban planning in 1978 and to the foundation of Wüest & Gabathuler in 1985. After Gabathuler's employment at the public administration of the city of Zurich's *Hochbauamt*, he participated in the NDS in *Urban Planning* shortly before the first urban planning law came into force in 1979. Finally, a research project at ETH entitled "MANTO" that dealt with the possibilities and risks of telecommunication in transport and real estate would provide decisive input for the office's foundation [167]. Together with Hannes Wüest, Gabathuler's colleague within the former post-graduate program ("ND") in urban planning at the ORL, they contributed with an early analysis of the "Bauwerk Schweiz" in 1989 [101]. During the early 1970s at the ORL, headed by the deputy director and lecturer Walter Custer, the education already revolved around the draft for the first urban planning law in Switzerland (1974) and the notion of *Limits to growth* by the Club of Rome.

Since 1990, architecture and civil engineering Professors at ETH Zurich have increasingly engaged in projects in the Asian construction industry, leading to the foundation of the Singapore-ETH Centre for Global Environmental Sustainability (SEC) in 2011, described by Schmitt [168]. Schmitt lists the three main objectives of the center: contributions to a discussion on "city science", curriculum development in Asia, and development of new participatory methods and instruments for city planning and management. Although the impact of the center's efforts on curricular changes in Asian higher education institutions needs further investigation, the research modules in the early phase indicate the conception of the center as an internationally operating network of ETH professors focusing on a transfer of technology and research on a wide variety of aspects, as described by Schmitt. Considering the entanglements in the 1990s and 2000s across disciplines of construction management, architectural design, urban planning, professional networks, and industry, it becomes clear that personal and institutional networks enabled a range of teaching efforts and research projects partly based on collaborations in academic networks. The extent of courses offered indicates the potential of partnerships within educational networks for high-quality education. However, the most critical drawback of personal actor-based networks is that they can quickly vanish after key actors retire or terminate collaborations. Further research would be needed if the investigated case of a network leveraged its full potential via a decentralized structure and "multiple nodes of interconnected influence" rather than being characterized by a "centralized pattern of operation" [52] and simple pathways of communication that extend a small central core of particular actors with strong influence.

4. Conclusions

This study addresses the transition of architecture curricula in mediating a sustainable built environment (SBE) as an objective in architecture education. Therefore, crucial factors representing trends in curricular changes for architecture education (1990–2022) are derived for the case study of ETH Zurich using a new approach based on curriculum mapping. Applying the proposed research strategy results in seven influential factors already described in the abstract. These influential socio-technical factors reflect a tendency on an SBE since the early 1990s parallel to a more frequently reported strand on new construction. More generic variations in the identified factors can be found across disciplines and countries in the literature. Therefore, the results might not be limited to the Swiss context or the architecture field.

This study demonstrates that focusing on linkages beyond the institution is necessary. Increasingly involving reflective practitioners in courses could support meaningful collaborations between academia and practice. In turn, more efforts on inquiry-based learning concepts in architecture education could prove valuable in educating reflective practitioners who especially leverage the potential of digital tools.

Since many courses as experiments in niches could quickly disappear due to specific circumstances, debates around long-term knowledge management in teaching remain pertinent (e.g., the "sustainability of knowledge" [47]). The quality of education could be improved by collaborative efforts that truly facilitate the formation of valuable networks in teaching beyond disciplinary silos. Horizontal and vertical alignment of disciplinary and interdisciplinary approaches, new courses, and re-configurations of existing courses may result in overlaps and need transition monitoring concepts to handle potential conflicts, synergies, and dynamic interventions.

Debates are required to locate distinct viewpoints on sustainability in different fields of architecture. Adopting a sustainability viewpoint in a specific field can be challenging for the scientific staff regarding necessary competencies and time resources, especially when budgets for teaching are scarce anyway. Committed actors and staff need to have institutional support. Existing funding schemes (such as ETH's *Innovedum* program) for novel teaching projects are seen as crucial instruments for the early phases of educational novelties. Long-term (re)locations benefit from formalized foundations. Otherwise, courses are in danger of disappearing quickly. However, even theoretically well-founded teaching projects are not exempt from the threat of being lost over more extended periods, especially in combination with the retirements of key actors.

This work argues that the hierarchical structure of the curriculum allows to mediate the necessary knowledge for architects. However, the habits of practitioners may reveal an absence of scientific approaches that are supposed to be applied [12]. This might be because knowledge in reflective practice is applied within a different structure, illustrated by Maier and Rechtin as "systems architecting" [11]. In addition, the temporal extension of system limits—central to sustainability efforts—has been formalized in various frameworks [43]. To conduct quality assessments of the curriculum's content, these non-hierarchical approaches should be in focus.

Defining clear reduction pathways to a climate-neutral Swiss built environment by quantifying carbon budgets has currently been conducted [169]. Implementing reduction pathways in practice could not only be beneficial for a transformation of the construction industry, but also to further anchor an SBE in teaching.

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Abbreviations

The following abbreviations are used in this manuscript:

CAD	Computer-Aided Design
DARCH	Department of Architecture (ETH Zurich)
DBAUG	Departement of Civil, Environmental, and Geomatic Engineering (ETH Zurich)
DUSYS	Department of Environmental Systems Science (ETH Zurich)
Eawag	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz
EMPA	Swiss Federal Laboratories for Material Science and Technology
ETH	Swiss Federal Institute of Technology (ETH Zurich)
FCL	Future Cities Lab (FCL) Global
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MAS	Master of Advanced Studies
MLP	Multiple-Level Perspective
ND(S)	Nachdiplom(studium) (post-graduate studies)
NDS	Nachdiplomstudium
NSL	Network City and Landscape (ETH Zurich)
ORL	Institute for Local, Regional and National Planning (ETH Zurich)
SBE	Sustainable Built Environment
TM	Transition Management

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