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Computational earthquake management: An educational perspective

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Abstract

This article presents an educational undertaking to integrate earthquake management subjects into the curriculum, specifically in a master' s-level design studio course within an architecture faculty. The course explores the employment of challenge-based learning (CBL) and self-directed learning (SDL) principles, emphasizing computation for earthquake resilience and recovery. It is taught with a teaching team with diverse expertise, and it is formulated as an interdisciplinary learning environment that leads to the development of projects that explore know-how beyond the typical disciplinary boundaries of the students' backgrounds. The article suggests that employing the principles of CBL and SDL, emphasizing computational thinking as a transversal competence, and introducing digital technologies into the course content and teaching methods can lead to an effective interdisciplinary learning environment that improves students' motivation and agency. They can allow the students to take the initiative in extending their disciplinary knowledge and encourage their self-positioning as problem solvers. The projects formulated and developed by the students address all four phases of earthquake management through computational methods and digital technologies. Accordingly, it is suggested that computational earthquake management can be studied as an interdisciplinary research field that can address all phases of earthquake management, influencing both educational and professional domains. This article presents this course's pedagogical approach, learning methods, and outcomes. It is concluded with an evaluation of this experience, highlighting directions towards future research. It is suggested that it can give insights into the effective integration of this subject into education and influence future research and professional explorations at the intersection of computation and earthquake management within interdisciplinary learning environments.

Keywords: architecture and built environment education, challenge-based learning, self-directed learning, interdisciplinary learning, computation, earthquake management

1. Introduction

Earthquake management is among the most significant subjects relevant to the built environment. It addresses several domains, including technical, technological, societal, and economic, to name a few. All professional actors who practice within the design and production of built environments, such as architects, planners, designers, or engineers, must have a fundamental understanding of this subject. Moreover, society needs experts who can develop effective solutions to this natural phenomenon, which otherwise can cause deadly disasters. Therefore, it is necessary to develop curricula in the related study programs to support students in developing the needed fundamentals and expertise to build more resilient environments. This article presents the theoretical background, methodology, and outcomes of an educational undertaking that aims to address this need after the devastating February 2023 earthquakes in Türkiye. It focuses explicitly on earthquake resilience and recovery by addressing computational thinking and digital technologies within masters-level education at an architecture faculty. Presenting this original educational perspective can contribute to the existing literature on integrating the earthquake management theme into architecture and built environment education through interdisciplinary learning environments.

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Page | 230

1.1. The Need for Interdisciplinary Learning Environments

The primary motivation of the course design was to cover all phases of earthquake management instead of focusing on only one phase, which is the common practice in educational settings. This motivation necessitates creating an interdisciplinary learning environment, as the needed know-how and skills in different phases are significantly diverse, and they can be harvested only through collaboration between various disciplines. Therefore, the course design aimed to explore how an interdisciplinary learning environment can be created to allow and encourage the students to extend their know-how and skills beyond their previous studies.

Interdisciplinarity refers to integrating methods, knowledge and skills, theories, perspectives, and different disciplinary knowledge bodies to realize innovative solutions and advancement in uncharted problem areas (Castán Broto et al., 2009; Klaassen, 2018; Lam et al., 2012; Menken et al., 2016). Klaassen (2018) points out that pedagogical approaches that challenge students to demonstrate interdisciplinary understanding by integrating multiple sources of knowledge, methods, and perspectives from two or more disciplines to realize a problem solution or a learning outcome are limited. Van den Beemt et al. (2020) highlight the need for sound pedagogy to develop interdisciplinary skills, knowledge, and values and teaming experiences that provide students with authentic ways of engaging in interdisciplinary practice. Similarly, Moirano et al. (2020) emphasize the importance of interdisciplinary collaboration for innovation and the need for supporting pedagogical strategies.

To develop an effective pedagogical approach for creating the needed interdisciplinary learning environment, the course design presented in this article followed two hypotheses. The first hypothesis is that specific educational approaches, such as challenge-based learning (CBL) and self-directed learning (SDL), can support the creation of the needed interdisciplinary setting. The second one is that computational thinking, as a transversal competence, can encourage students to initiate projects with interdisciplinary content by enabling them to understand and apply the know-how and skills of other disciplines.

The need to integrate earthquake management into architecture education is widely discussed. However, more research is needed for a more thorough outlook and effective and sustainable results, especially to address the interdisciplinarity dimension discussed in this article. According to Laboy and Onnis-Hayden (2019), new pedagogies for design education should make evident how traditional curricular approaches are opened up to new questions and forms of input because, while interdisciplinary collaboration can begin to break down the silos in design education (architecture, engineering, urban planning, etc.) its shortcomings become more evident when well-intentioned efforts rely on self-contained modes of research, which are then brought together. Potur & Metin (2021) evaluate architects' role in disaster management and argue that while the 1999 Marmara Earthquake spurred initial improvements in architectural education and practices, these advancements have not been sustained over the past 20 years, emphasizing the need for multidimensional approaches in education and professional practice. In this line, Özdoğan and Güney (2016) emphasize the need to integrate comprehensive disaster-related education into architecture curricula to improve disaster preparedness and resilience, especially in countries that are geographically and climatically vulnerable, like Türkiye. In addition to the course contents and teaching methods, thorough explorations of effective pedagogical approaches are needed to achieve useful results. For example, Akdağ and Beyhan (2024) state that shifting earthquake education from traditional, instructor-centered methods to student-centered, experiential learning with modern technologies would enhance the quality of learning and better align with current learning habits.

The review research of Theodoropoulos (2006) shows that most architecture schools address the concepts central to seismic design across the curriculum in various courses. They mostly address subjects related to seismic design principles (Morales-Beltran et al., 2020; Morales-Beltran & Yildiz, 2020) and earthquake-resistant structural design systems (Karadag & Canakcioglu, 2023; Soyluk &

Harmankaya, 2012). Additionally, architecture schools have an extensive tradition of teaching post-earthquake or emergency shelter design (Krishnan & Liao, 2019; Mahmoud et al., 2019). Hence, the prominent interest in architecture schools focuses on the earthquake management cycle's response or recovery phases. As an alternative and original approach, the course presented in this article aimed to address all four phases of earthquake management and allow the students to explore diverse subjects, know-how, and skills needed in this broad spectrum. This objective requires an interdisciplinary learning environment that can be formulated on two levels. The first level involves a teaching team composed of experts from diverse areas of expertise who deliver lectures, workshops, and tutoring in their field. The second one considers the student teams as interdisciplinary despite having the same background. The course design presented in this article combined these two levels through a pedagogy that is new to its context and the literature.

1.2. The Influence of Digital Transformation on Earthquake Management Education

Digital transformation influences educational and professional domains in most fields, including earthquake management. Thus, computational competences and digital skills can play a significant role in developing the course contents and teaching methods on this subject. As relevant to this, Charleson (2018) argues that architecture schools should incorporate seismic design content into their curriculum, using rule-of-thumb software to enhance students' understanding and skills. Similarly, Solak (2022) states that engineering-based structural analysis programs used for earthquake-resistant building design should be integrated into the curriculum of architectural education, and the use of digital technologies within earthquake-resistant design courses is expected to enhance students' knowledge and learning. Also, Morales-Beltran and Yildiz (2020) emphasize the lack of research on teaching methods on seismic knowledge in architecture education, and they mention the possible influence of computational-aided structural design in the teaching and learning process.

The course presented in this article addresses digital transformation on two levels. On the first level, it employs computational thinking as a transversal competence, which supports achieving the targeted interdisciplinary learning environment. On the second level, the course introduces many subjects within digital technologies, provides learning activities to improve students' digital skills, and asks the students to apply these skills in their projects, exploring innovative ways of using them. In this sense, it introduces a new framework, so-called "computational earthquake management," which also points out directions for future explorations in research and professional fields. However, this article explicitly focuses on the educational setting and its implications for pedagogical perspectives.

1.3. Methods

Following the described needs, motivation, and hypotheses, this article presents the general course setup (section 2.1) and the specific theme and content implemented in the relevant semester (section 2.2). It is followed by a description of its pedagogical approach (section 2.2), referring to the literature on CBL and SDL, which are suggested as the enablers of an interdisciplinary learning environment.

The concept of earthquake management and its four phases are explained (section 3.1) as they constitute the course content. Then, how computation and digital competences can be integrated into earthquake management education is discussed (section 3.2), in line with the objectives of an interdisciplinary learning environment. An overview of the student projects is presented and analyzed (section 4) to understand how they have responded to the course setup and to what extent the interdisciplinary learning environment is achieved, as reflected in the project scopes.

By observing students' study behaviors during the course and analyzing the course evaluation surveys, the article concludes with evidence that employing CBL and SDL as pedagogical approaches and employing computational thinking as a transversal competence in education, an interdisciplinary learning environment can successfully be created, increasing students' motivation. The observations also include suggestions for more robust future implementation of such learning environments. Moreover, it proposes computational earthquake management as a novel holistic framework that needs further research.

2. The Educational Context

2.1. Course Setup

Page | 232

The course is offered as an elective in the first quarter of the second year of the Building Technology track of the Master of Science (MSc) degree in Architecture, Urbanism, and Building Sciences at Delft University of Technology (TU Delft). It takes ten weeks (a full quarter) and consists of 15 study credits based on the European Credit Transfer System (ECTS). This corresponds to a workload of 420 hours, including contact hours (e.g., lectures, studios, and workshops) and self-study times. The students do not follow any concurrent course during this quarter. After completing this course, they start their MSc graduation theses. It is an interdisciplinary studio course that integrates computational methods and digital technologies into structural and material design within building technologies. It addresses various scales within the built environment, ranging from urban to building products, by paying attention to environmental, social, cultural, and ethical aspects. The course is called CORE, an acronym for "COmputational REpertoire for Architectural Design and Engineering". One of its goals is to bridge the know-how between architecture and (building) engineering disciplines.

The course aims to help students develop computational competences, integrating computational thinking and computer programming skills, toward designing and producing built environments. Herein, computational thinking refers to a cognitive approach to formulating problems and developing solutions. Programming is introduced as a practical skill to implement computational thinking within complex problems. Thus, the course includes a "programming crash course" module, which introduces Python programming language in eight sessions in the first two weeks. Each session includes a four-hour practical workshop. The students are further guided on their programming work through weekly studio sessions until the end of the course.

During the first two to three weeks, several lectures and relevant debates are organized to help students understand the theme's various dimensions and develop a personal reflection. Their contents are tailored based on the theme, which alters every year. After these sessions, the students identify a research question and develop a design brief. Accordingly, they build teams and work on their projects, receiving tutor feedback. During project development, they receive formative (ungraded) feedback in studio meetings, workshops, and presentations. The only summative (graded) feedback is given upon submitting and presenting the finalized project.

In the 2023-2024 academic year, 46 students enrolled in the course. They hold bachelor's degrees in architecture from different universities in 14 countries. This results in an extensively diverse group in terms of their prior experience. In their second quarter, they followed another course on computational design, which gave them a fundamental understanding of computational thinking and practical skills in visual programming using the Grasshopper (GH) software. Later, some followed other electives and deepened their knowledge of this subject. In this MSc program, no other courses explicitly teach programming with Python. Some students start this course with some experience in Python programming based on their individual ventures, whereas others start it with no experience. Moreover, also concerning altering course themes, there is extensive diversity in the students' prior experiences.

2.2. Course Theme and Content

The course explores a different theme every year, addressing significant societal topics. Following the devastating February 2023 earthquakes in Türkiye, the theme was defined as "Computation for Earthquake Resilience and Recovery" for the 2023-2024 academic year. This response aimed to contribute to worldwide endeavors to solve this crucial challenge through an academic perspective and reflect on our roles as architects, designers, planners, and engineers in light of it.

Following a thorough evaluation of the scientific and professional needs of the Architecture, Engineering, and Construction (AEC) industry, the scope of the theme was defined to address all phases of earthquake management, including mitigation, preparedness, response, and recovery. Even though it increases the complexity of the challenge, the scope could be complete only when all of these phases are covered and the needs associated with each are studied. Therefore, the course theme aimed to introduce the students to the challenges of all four phases and to raise awareness of their professional roles in recovering the built environments from earthquake damage and ensuring their future resilience.

Concerning the course objectives, the solutions to the problems identified in all phases were meant to be solved using computational methods and digital technologies. This could mean the advanced utilization of existing methods, tools, and technologies or the creation of new ones to develop the solutions. Eventually, both the scope of the theme and the approach to explore it required a high level of divergence, which could only be undertaken with an interdisciplinary approach. The fact that the course was taught by the involvement of three scientific chairs (Design Informatics, Structural Design & Mechanics, and Design of Construction) made it possible to appoint staff from different disciplines and form a teaching team with diverse expertise. Moreover, several guest tutors contributed to the content through (online or in-campus) lectures and workshops, significantly improving the course's interdisciplinary nature.

In the first three weeks, several sessions were organized as lectures or workshops to elaborate on several subjects concerning the theme and approach. They covered subjects such as the aftermath of the February 2023 earthquakes, urban and disaster resilience, humanitarian engineering, geographic information systems and machine learning for disaster management, seismic performance of structural and non-structural building elements, material-related problems in earthquakes, energy dissipation in buildings, seismic fragility, performance-based earthquake engineering, seismic simulation, finite element analysis, earthquake-resistant architectural design, facade design and retrofitting, low-damage technologies, earthquake early warning systems, robotics for search and rescue operations, emergency shelter design, participatory reconstruction, layout optimization, and community empowerment through digital technologies. The core teaching team and the guest lecturers elaborated on these subjects in 27 sessions through lectures and workshops. Additionally, a field trip was organized to observe an existing retrofitting solution on a historical building affected by an earthquake and to implement hands-on structural design experiments on a shake table.

The total workload of these planned activities could exceed the maximum allowed contact hours. Therefore, the students were allowed to select the course activities they wanted to participate in within the allowed limit. They were informed about the content of each activity through the course book and enrolled in the ones they were interested in at the beginning of the course. Similarly, each programming crash-course session was offered as a free-to-choose activity, allowing the students to tailor their schedules and decide on the activities they wanted to follow based on their prior experience and interests. This method was suggested to keep the workload per student within the allowed limits and further enhance the group's diversity of know-how and approaches.

During the first two weeks, a few brainstorming sessions were organized where students discussed the possible problems and formulated methodologies to solve them in the moderation of the tutors. An interactive online mind map was kept active throughout this process, allowing the students to read and edit their ideas at any time. Through these sessions, each student focused on a specific problem that was collectively developed. Moreover, they found their teammates who shared similar interests with them. This method was proposed to let the students identify their own interests and define the project they want to work on. Moreover, it helped the team formation by making it a more informed decision. Accordingly, they identified their research and design objectives, methodology, deliverables, and learning resources through the guidance of the tutors. Over ten weeks, they developed projects through teamwork that addressed different phases within computational earthquake management.

2.3. Pedagogical Approach

Page | 234

The studio employs primarily two pedagogical approaches: challenge-based learning (CBL) and self-directed learning (SDL). According to Malmqvist et al. (2015), CBL is a multidisciplinary learning experience that takes place through the identification, analysis, and design of a solution to a socio-technical problem, aiming to find a collaboratively developed solution, which is environmentally, socially and economically sustainable. Gallagher and Savage (2020) state that CBL fosters student transversal competencies, knowledge of socio-technical problems, and collaboration with industry and community actors. Doulougeri et al. (2024) emphasize that CBL centers learning around open-ended global socio-technical challenges, often involving external stakeholders in self-directed and collaborative learning.

In this course, the principles of CBL were implemented by formulating the course scope as a response to a recent major earthquake. This challenge was evident at the faculty, observable through several initiatives of the different student groups and other stakeholders seeking ways to support the earthquake region by different means. Thus, the students readily perceived the course theme as an authentic and actual subject, reflected by the high enrolment numbers. Also, involving people who brought in observations and experiences directly from the region and shared them with the students through lectures or discussions further improved the authenticity of the challenge.

Loeng (2020) describes SDL as a process by which individuals take the initiative in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes, and emphasizes that when teachers are involved in SDL, they should be facilitators of learning, not transmitters. Avsec and Jagiełło-Kowalczyk (2021) explore the interactions between design thinking and SDL in architecture students, and they conclude that design thinking can provide metacognitive insights such as interpersonal skills, creativity, and digital skills that can support SDL. Thus, one may state that architecture students must typically be competent in SDL, as design thinking is a fundamental cognitive procedure in architecture education.

In this course, the implementation of the principles of SDL is evident on several levels. First, the flexibility offered to the students to customize their schedule and course activities allows them to diagnose and act on their learning needs and styles. Allowing them to identify their project objectives, methodology, and deliverables further strengthens this approach. Based on the needs of each project, the students had to identify the learning resources, reaching out to people and institutions who could provide them with the needed expertise, information, or data. In the meantime, the tutors facilitate the environment needed to explore various open-ended questions, acting as students' collaborators instead of traditional instructors.

A search was implemented on Web of Science (WOS) and Scopus databases to understand how CBL and SDL are explored in architecture (and related fields) education. It aimed to identify the articles which have "Challenge-Based Learning", "Self-Directed Learning", "Architecture / Architectural Education", "Design Education", "Planning / City Planning / Urbanism / Urban Planning Education" and "Engineering Education" terms in titles, keywords, and abstracts. Table 1 presents the number of articles found with each search query. Accordingly, it can be argued that the scientific literature that explores CBL and SDL, specifically within architecture, planning, and design education (which are commonly considered closely related study programs), is very limited. Meanwhile, research on CBL and SDL within engineering education is fairly extensive. More research is needed to develop pedagogical approaches to integrate CBL and SDL in architecture (and related study programs) education and to evaluate their effectiveness.

Table 1 The Number of Articles in WOS and Scopus on CBL and SDL

Search Query	WOS	Scopus
"Challenge-Based Learning"	304	519
("Challenge-Based Learning") AND ("Architecture Education" OR Architectural Education")	1	1
("Challenge-Based Learning") AND ("Design Education")	2	4
("Challenge Based Learning") AND ("Planning / City Planning / Urbanism / Urban Planning Education")	1	1
("Challenge-Based Learning") AND ("Engineering Education")	47	187
"Self-Directed Learning"	4738	6769
("Self-Directed Learning") AND ("Architecture Education" OR Architectural Education")	3	6
("Self-Directed Learning") AND ("Design Education")	9	17
("Self-Directed Learning") AND ("Planning / City Planning / Urbanism / Urban Planning Education")	0	0
("Self-Directed Learning") AND ("Engineering Education")	62	345

3. Interdisciplinary Learning on Computational Earthquake Management

3.1. Disaster Management Phases

United Nations Office for Disaster Risk Reduction (UNDRR) defines a disaster as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts. According to the same resource, disaster management refers to the organization, planning, and application of measures preparing for, responding to, and recovering from disasters (UNDRR, 2017).

According to Percy et al. (2011), disaster management conventionally considers four distinct phases: mitigation, preparedness, response, and recovery. They define these four phases as follows:

1. Mitigation: The activities or perceptions relating to reducing the risks of disasters.
2. Preparedness: Considering, rehearsing, and preparing what to do in the event of a disaster, for example, by conducting drills, exercises, and simulations.
3. Response: The activities and experiences of tackling immediate danger when a disaster occurs.
4. Recovery: Activities and experiences associated with longer-term relief once immediate risk to life has passed.

Similarly, Edrissi et al. (2013) define these phases as follows:

1. Mitigation includes strategic measures taken to reduce or eliminate the disaster impacts.
2. Preparedness aims to lessen or avoid disaster consequences by preparing the community for hazards.
3. Response includes acting according to emergency plans to preserve lives, properties, the environment, and the community's social, economic, and political structures.
4. Recovery involves long-term actions that will restore normalcy to the affected areas.

Preparedness and mitigation are pre-disaster activities, while response and recovery are considered as during (disaster) and post-disaster activities, respectively, although there is increasing recognition that these activities considerably overlap (Nyimbili & Erden, 2017). These four phases form a cyclic cycle rather than a linear process, and success within one phase depends on the proper administration of all phases. Therefore, the course scope aimed to cover all four phases, encouraging the students to understand the importance of each and see the relationships between them.

3.2. Computation and Earthquake Management Education

Page | 236

One of the primary objectives of the course was to help students develop competences in computation. There are vast definitions and discussions on what the term computation refers to. Additionally, the term may gain different meanings in different contexts. Knight and Vardouli (2015) interpret the term broadly as the use of formal, mathematical systems, theories, and methods, as well as tools and technologies developed on the basis of such systems, and they state that computation may include, but is not limited to, the use of digital computers. Therefore, the term may contain two related processes: computational thinking as a cognitive skill and using computer systems as a practical skill.

According to Aho (2012), computational thinking refers to the thought processes involved in formulating problems so their solutions can be represented as computational steps and algorithms. Wing (2006) argues that, it relates to thinking at multiple levels of abstraction, and it is a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use.

Computational thinking is a transversal competence. Sá and Serpa (2018) define transversal competences as a set of competences that can be applied in any professional situation or task, regardless of where they were attained. Cruz et al. (2019) emphasize the importance of integrating transversal competences in education curricula to prepare students for the labour market. Similarly, Belchior-Rocha et al. (2022) argue that the acquisition of transversal competences, especially in a labour market that is affected by social, economic, technological and political changes, is increasingly essential. Granado-Alcón et al. (2020) highlight that transversal competences allow students to engage constructively and responsibly with today's world. Moreover, transversal competences can encourage and support individuals' self-positioning as a problem solver within or outside any disciplinary context.

Even though computational thinking does not necessarily require the use of computers, formulating and solving complex problems necessitates the use of contemporary computer applications and digital technologies. Therefore, the ideal educational curricula, which aims to address a complex socio-technical problem like earthquake management, need to intertwine computational thinking with expertise in computer programming. The scope and methodology of the course which is discussed in this article is developed following this argument. It is suggested that its outcomes can provide insights into how computation can support earthquake management, contributing to both educational and professional contexts.

Even though there is a wide range of applications in which distinct digital technologies are used to solve specific challenges within disaster management, the definition of a holistic framework is scarce. One of the existing definitions is presented by Van Hentenryck (2013), who views computational disaster management as a system that integrates various layers such as; (i) the geospatial modeling layer mapping of a region; (ii) the sensing and monitoring layer collecting information via sensors, social media analyses, crowdsourcing, and hyperspectral imaging; (iii) the data layer managing information; (iv) the behavioral layer synthesizing individual and group behaviors during emergencies; (v) the simulation and forecasting layer generating potential scenarios; (vi) the optimization layer providing decision support; and (vii) the visualization layer offering unprecedented awareness via 3D and information visualizations. Also, Eslamian and Maleki (2021) explore computational methods to address the complexity of disaster management, and they propose a conceptual design framework that integrates a computation core involving simulation modeling algorithms, optimization algorithms, cost-benefit analysis, and verification.

In this course, each project utilized a specific approach for defining the research and design problems and developing solutions. The emphasis on computational thinking facilitated a cognitive approach by which students formulated problems and solutions through procedural steps, algorithms, and abstractions on multiple levels. This approach was further supported by using computer programming methods and digital technologies. Eventually, each project delivered a tool, toolset, or workflow that can practically be used to solve complex problems. Moreover, these methods and technologies enhanced integrated problem-solving, which supported the needed interdisciplinary learning environment. The course's emphasis on computational competences, the presentation of various digital technologies, and the introduction of practical computer programming skills led to 17 distinct projects. They were distributed over various subjects within earthquake management, eventually covering all four phases. Due to the interdisciplinary explorations the students pursued, they brought together know-how from different fields.

4. Results: An Overview and Analysis of the Projects

The course resulted in 17 projects, each studied in a team of 2 to 4 students. Each project is distinct in its problem statement, which students identified through the guidance of the tutors. The project subjects are as follows:

1- Large-scale seismic risk assessment of aged hydraulic structures: It aims to develop a computational tool that can identify the risk level of dams and visualize the potential flood hazards around them. The computational model uses data related to dam type, construction material, construction year, soil type, and water level to define the risk factor of a dam. It also visualizes the effects of a possible flood caused by failure after an earthquake to help predict the damage in the dam's surrounding region. The project utilizes Python, Rhino, Grasshopper, and SOFiSTiK for mapping, structural modeling, analysis, and simulation.

2- Enhancing seismic resilience in mid-rise buildings with visco-elastic dampers in Antakya: It aims to provide rapid feedback on the effects of seismic bracing in the early design stages of architectural structures. It uses a machine learning algorithm to calculate and simulate the seismic behavior of dampers, providing input to the architect by generating optimized bracing configurations. The project utilizes Python, Rhino, Grasshopper, and Karamba3D for programming, numerical simulation, and visualization.

3- Shear wall generator for housing typologies in Antakya: It aims to develop a computational tool that can provide optimum shear wall placement based on the spatial layout of the building. The tool specifically considers the common housing typologies in Antakya, ensuring seismic performance in the early architectural design phase. The project utilizes Python, Rhino, and Grasshopper for static analysis, optimization, and visualization.

4- Architectural guide for site-specific designs of new earthquake-resistant buildings and structures: It aims to develop an Interactive analysis tool that allows architects to visually and qualitatively understand how their building design will respond to earthquakes. It provides feedback to illustrate potentially problematic building qualities based on the user's inputs. The project utilizes Python, Rhino, Grasshopper, and Karamba3D for structural modeling, analysis, and visualization.

5- Holistic site-specific hazard assessment: It aims to improve accessibility to probabilistic seismic hazard assessment by providing a site-specific prediction of primary impact direction. It outputs a tool that provides hazard assessment and predictive models based on the location and directionality concept using data from publicly available databases. The project utilizes Python, Rhino, and Grasshopper for data extraction and processing, statistical modeling, and visualization.

6- Active stabilization systems for critical infrastructures: It aims to provide a retrofitting solution for the power transmission towers to sustain power after the earthquake. It includes devices mounted on the tower arms, equipped with sensors that detect seismic forces, and actuators that

Page | 238

apply customized forces to the cables. The project utilizes Python, Rhino, Grasshopper, and Alpaca4D for earthquake simulations, seismic data analysis, and decision-making.

7- A tool for finding the shortest route for rescue after the earthquake: It aims to develop a computational tool that can identify the safe areas and routes to guide the rescue teams in transferring people from assembly hubs to shelter locations after the earthquake. The project uses QGIS and QuickOSM to obtain geospatial data. It suggests using LiDAR Drones and Ground Penetrating Radars to assess the conditions of the possible transfer routes. It uses a program made in Python to process the data and the DIJKSTRA algorithm to find the optimum transfer route. The project outputs a visual user interface that can be used by the search and rescue teams and decision-makers.

8- An information-driven framework to increase efficiency in site-specific shelter decision-making process: It aims to facilitate the timely deployment of appropriate shelters to areas in need. The project includes an analysis of the existing shelter types to better match the needs and supply, considering structural integrity, comfort, and cultural relevance. The project uses Pandas, Rasterio, and Matplotlib libraries in Python to obtain and visualize geospatial data. It utilizes data related to shelter designs derived from the documentation of the IFRC (International Federation of Red Cross) and the UNHCR (United Nations Refugee Agency). The project outputs an interactive interface on a browser to help the decision-making process.

9- Rapid estimation of disaster consequences: It aims to reduce the time needed for damage assessment immediately after the earthquake. It develops a simulation tool to forecast risk zones based on a database of building types and real-time seismic data. The project utilizes Python, Rhino, Grasshopper, and Karamba3D for data processing, structural modeling and analysis, and visualization. It outputs a map that visualizes the vulnerability assessment.

10- Active mass damper activation tool and analysis on structural seismic vulnerability: It aims to explore the potential benefits of Active Mass Damper (AMD) systems to reduce earthquake damage to buildings. The project uses QGIS to gather geospatial data, SAP2000 to perform structural analysis, and a program made in Python to integrate the automated workflow. The project output is a digital platform that integrates several software and outputs feedback towards AMD integration in a building and information on its post-earthquake condition.

11- Enhancing earthquake preparedness through building vulnerability assessment: It aims to develop a framework for building vulnerability analysis in seismic scenarios. It uses data related to building dimensions and construction materials to implement statistical analysis for assessing building vulnerability. It uses Alpaca4d, Grasshopper, and a Python program using the Pandas library for statistical analysis and machine learning for structural performance predictions. It outputs a visual interface that assesses vulnerability and identifies safe areas to help decision-makers make informed decisions.

12- Custom emergency shelter based on Japanese wood joints: It aims to support self-help for communities that need emergency shelters. The project outputs an interactive environment that can be used by people to design a custom shelter based on needs and preferences. The system optimizes the design for structural performance, provides solutions for the digital fabrication of the shelter components, and gives instructions for DIY assembly. The project utilizes Python, Rhino, and Grasshopper, and it outputs a web-based interactive interface that can be used by citizens who need shelters.

13- Identifying collapsed buildings and assessing vulnerable types with satellite image segmentation: It aims to develop and train a deep learning model to perform image segmentation and object classification on satellite images after the earthquake. The model identifies the collapsed buildings and correlates between damage and building typologies to support decision-making processes by providing quick feedback on damage assessment on the buildings after the earthquake.

14- A decision support system for search & rescue resource allocation in response to an earthquake: It aims to develop a decision support system for more efficient management of search and rescue resources. It estimates possible injuries based on building size, construction type, function, and occupancy. The project develops a Python-based application that implements fragility assessment based on available geospatial data and statistical predictive models and provides feedback for search and rescue resource allocation.

15- Earthquake damage detection with drones: It aims to develop a workflow for using consumer drones to asses damages to buildings after an earthquake. The project develops a machine learning model to analyze the drone footage and identify the buildings' safety factors based on the detected damage to structural components. It utilizes a Python-based application that uses images and videos collected by consumer drones to generate 3D models, detect the damages on the buildings, and determine the effect of the damages on structural integrity.

16- A tool for designing with reusable reinforced concrete elements: It aims to develop a workflow to support the reuse of reinforced concrete beams rescued from earthquake demolition waste in new buildings. The workflow includes strategies for harvesting and assessing the usable elements in the demolition waste. It uses a program developed in Python and integrated in Rhino and Grasshopper to suggest new design variations that use the available beams.

17- Identifying suitable locations for material hubs: It aims to develop a system that provides optimal routes after a disaster and identifies suitable locations for emergency hubs for temporary housing. The project develops a computational tool that generates networks that are updated in real-time to help identify safety routes after the earthquake. The project utilizes OpenStreetMap and Python programming for real-time mapping and providing feedback to support logistical operations in the earthquake region.

Table 2 presents the distribution of the projects in the different phases of earthquake management (as evaluated by the author). The complex nature of the projects sometimes makes it challenging to identify the specific phase the project addresses. Moreover, some projects address more than one phase, aligning with the arguments of Nyimbili and Erden (2017). Therefore, this identification can be subjective to some extent. The first column of the table refers to the project number listed above. The other four columns refer to the phases. The primary phase a project addresses is identified with A, and the secondary phase is identified with B.

Table 2 The Distribution of the Projects on Earthquake Management Phases

	Mitigation	Preparedness	Response	Recovery
1	A	B		
2	A			B
3	B			A
4	B			A
5	B			A
6	A			B
7			A	
8		B	A	
9		B	A	
10	A			B
11		A		
12			A	
13			A	
14		B	A	
15				A
16				A
17		B	A	

Figure 1 illustrates the distribution of the projects among the four phases through stacked columns. The blue color indicates primary (A), and the orange color indicates secondary (B) link between a project and a phase, similar to Table 2. As seen in this figure, the distribution of the projects among the four phases is fairly even. In total, six projects address preparedness, seven address mitigation and response, and eight address the recovery phase. This distribution confirms that the scope of the projects covers the broad spectrum of earthquake management instead of focusing on only one phase. An important aspect is that only the blue color is represented in the response phase. This aspect can be explained by the fact that the students holding bachelor's education in architecture are more trained to work on this phase (as explained with references earlier), so they can relate to this phase more easily than the others. Still, the fairly even distribution among the phases supports the hypotheses. Suggestions to improve this distribution are discussed in the conclusion section.

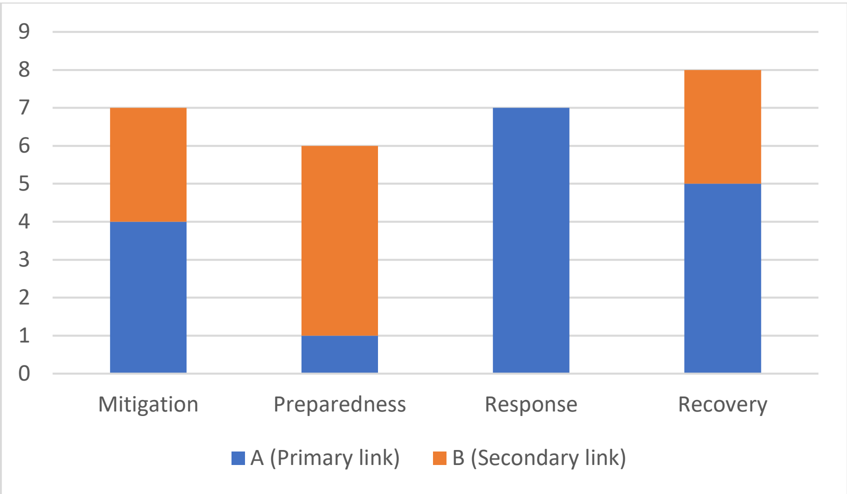

Figure 1 The distribution of the projects among the four phases through stacked columns

Another takeaway from this analysis is that computation and digital technologies can help us define a holistic framework for earthquake management by providing tools and methods to address solutions in all phases. Therefore, it confirms the abovementioned arguments of Van Hentenryck

(2013) and Eslamian and Maleki (2021). More research is needed to define this proposed framework as a professional domain, which is outside the scope of this article.

For a better understanding of the interdisciplinary scope of the projects, Table 3 presents an overview of which scientific discipline each project addresses. The relevant scientific disciplines are retrieved from The Dutch Research Council's classification of research fields (NWO, 2024) and listed in the table's first column. The following columns refer to the projects listed above with project numbers. The disciplines that a project addresses are marked with an X in the cells of the corresponding columns and rows. The bottom row indicates how many disciplines each project addresses. The right side column indicates how many projects address each discipline.

Table 3 The Distribution of the Scientific Disciplines the Projects Address

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	
Software, algorithms, control systems	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	*17*
Artificial intelligence, expert systems		X	X	X	X	X	X		X	X		X	X	X	X		X	*13*
Civil engineering	X	X	X	X	X	X	X		X	X	X	X			X	X		*13*
Information systems, databases	X				X		X	X	X		X		X	X	X	X	X	*11*
Urban studies	X				X		X	X			X		X	X			X	*8*
User interfaces, multimedia	X							X			X	X		X		X		*6*
Architecture		X	X	X								X				X		*5*
Geotechnics	X			X	X	X	X											*5*
Computer graphics		X								X		X						*3*
Design sciences			X									X				X		*3*
Mechanical engineering		X				X				X								*3*
Materials technology							X									X		*2*
	6	*6*	*5*	*5*	*6*	*5*	*7*	*4*	*4*	*5*	*5*	*7*	*4*	*5*	*4*	*7*	*4*	

This analysis may be somewhat subjective, similar to the abovementioned analysis regarding the relationships between the projects and the earthquake management phases. The complex nature of the projects makes it difficult to identify the related disciplines precisely, and the methods and know-how of disciplines often overlap. This analysis sought strong integration of distinct know-how and methods of a discipline to be considered addressed. Eventually, it demonstrates that each project integrates know-how and methods from multiple disciplines. Software, algorithms, and control systems discipline is strongly relevant to all projects, as computational thinking and programming are introduced as core competences to be gained in this course. It is followed by artificial intelligence and expert systems, which strongly correspond to the course's learning objectives and are beneficial for developing state-of-the-art solutions to complex problems. Civil engineering is another prominent discipline, as earthquake-related subjects are traditionally studied in this field, especially within earthquake-resistant structural design. The fact that information systems and databases are also highly addressed highlights the profound need for data, especially in the mitigation and preparedness phases. The low number of projects directly addressing architecture (in its typical understanding) confirms that students have widely explored new areas of expertise beyond their previous studies.

As seen in this overview, the scope of most projects is beyond what would typically be expected from a student with a bachelor's degree in architecture to work on. The course's pedagogical approach that employed the principles of CBL and SDL must have encouraged the students to go beyond the disciplinary boundaries of their field and explore other domains. The interdisciplinary nature of the course setup and the tutor team is seen as an encouraging factor towards this exploration. Moreover, the fact that computational workflows enable, encourage, and require the integration of know-how from other fields empowers the students to develop their work in an interdisciplinary manner. In this case, the interdisciplinary setup relies on something other than a situation where the students in a team come from different disciplines. Instead, they reach out to different domains while sharing similar backgrounds in this setup, which can hypothetically be called a *discipline-fluid* learning environment.

5. Conclusions

Page | 242

This article presented an educational intervention to provide an original perspective for integrating earthquake management into architecture and built environment education through an interdisciplinary learning environment. Through a course that serves as a context for observational research, it evaluated the study behaviors and outcomes, confirming that an educational perspective that employs CBL, SDL, and computational thinking enables interdisciplinary learning. Analyzing the project contents demonstrated how this perspective encourages the students to extend their disciplinary boundaries and integrate know-how and skills from different disciplines to develop solutions that relate to all phases of earthquake management. This educational perspective can provide insights into the effective integration of earthquake management into architecture and built environment curricula and stimulate future research in this direction. It is also suggested that this case serves as a basis for future research on a holistic framework for computational earthquake management, potentially leading to professional implications.

Integrating the principles of CBL strongly improves students’ motivation. This can be achieved by focusing on authentic case studies and involving stakeholders who can bring insights from actual experiences into education. The principles of SDL further improve motivation, allowing the students to identify what and how they want to learn. It supports students’ self-positioning and encourages them to explore the expertise they want to develop. Moreover, creating space for flexibility in learning is necessary to explore open-ended questions. This can be done by allowing the students to customize the learning activities they want to participate in throughout the course instead of planning a fixed program that is compulsory for all students to attend. Also, by allowing customization, the workload becomes more manageable for the students while all subjects can still be integrated into the course as the students bring all learning experiences into the course and share them with others through collaborative work. In addition, employing computational thinking as a transversal competence in curricula complements interdisciplinarity and gives students the fundamental skills to master state-of-the-art digital technologies.

The course evaluation survey confirms the observations and reveals helpful student feedback that supports the two hypotheses defined at the beginning. Also, it points out directions for improvement toward a more robust interdisciplinary learning environment. The students evaluated the course considerably high (on average, 4.8 out of 5.0) in terms of the learning experience, indicating that they learned a lot throughout the course. One of the main takeaways is that their evaluation was relatively low (on average, 3.5 out of 5.0) regarding how the previous semesters have prepared them for this course. Thus, exploring ways to integrate this specific teaching methodology with the courses from earlier semesters is necessary.

According to the survey results, the main aspects that are evaluated as the best are the degree of challenge (86%), teaching methods (86%), academic level (76%), and lectures (76%). This evaluation confirms that the students highly welcome the CBL and SDL approaches and the interdisciplinary learning environment. Clarity about what is expected (62%) and connection to prior knowledge and skills (29%) emerge as the most prominent aspects that need improvement. This evaluation confirms the need for better integration between the semesters. Moreover, a more precise definition of the expected results seems requested. Here, the challenge in front of the teacher must be sustaining the freedom in the process while helping the students feel more secure by defining the possible results concerning the particularities of each project.

According to students' qualitative feedback, the most important point for improvement is the need for more specific instructions, tasks, restrictions, and clear evaluation criteria. This feedback underlines the tutors' role as guides and facilitators. Also, a student pointed out the possible benefits of working in teams that involve students from different disciplines. This would require a different course setup that welcomes students of other disciplines to enroll, an aspect certainly worth exploring.

Also, the most common positive feedback include the following:

- The possibility of using the project outcomes to help actual disaster areas motivated the students to go further than usual and explore new challenges. It resulted in many students going out of the box to learn something new and broaden their perspectives.
- The assignment's freedom is a good feature.
- The diversity and broad spectrum of the lectures and their multi-faceted content are beneficial in defining the scope of the projects.
- Learning programming while applying it in a case provides an effective learning experience.
- The diversity and broad spectrum of the lectures are beneficial in defining the scope of the projects.

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Page | 244

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Resume

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