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ÍNDICE

12. **Arquitectura en formato Olimpiada: aplicación de la metodología de Proyectos a Secundaria.** ***Architecture in Olympiad format: applycation of the methodology of Projects to Secondary.*** Carcelén-González, Ricardo; García-Martín, Fernando Miguel.

13. **Relaciones desde lo individual a lo colectivo. Tres ejercicios de Composición Arquitectónica**. ***Relations from the individual to the group. Three exercises of Architecture Composition.*** Barberá-Pastor, Carlos; Díaz-García, Asunción; Gilsanz-Díaz, Ana.

14. **Dibujo y Máquina: la aplicación de lo digital en Arquitectura y Urbanismo**. ***Drawing and Machine: the application of the digital in Architecture and Urbanism.*** Castellano-Román, Manuel; Angulo-Fornos, Roque; Ferreira-Lopes, Patricia; Pinto-Puerto, Francisco.

15. **Diseño e implementación de la pauta de seguimiento del logro formativo**. ***Learning Achievement Assessment Guideline, Design and Implementation.*** Muñoz-Díaz, Cristian; Pérez-de la Cruz, Elisa; Mallea-Maturana, Grace; Noguera-Errázuriz, Cristóbal.

16. **Yes, we draw! El papel del dibujo en la pedagogía contemporánea de Arquitectura.** ***Yes, we draw! The role of drawing in contemporary Architecture teaching***. Butragueño Díaz-Guerra, Belén; Raposo Grau, Javier Francisco; Salgado de la Rosa, María Asunción.

17. **Aprendiendo a proyectar mediante el análisis de las decisiones de proyecto**. ***Learning to project through the analysis of projects decisions***. Fuentealba-Quilodrán, Jessica; Goycoolea-Prado, Roberto; Martín-Sevilla, José Julio.

18. **Espacio, Teatro, Arquitectura. El lugar del teatro en la enseñanza de la arquitectura.** ***Space, Theater, Architecture. The place of theater in the teaching of architecture.*** Ramon Graells, Antoni.

19. **Uncastillo. De la escala territorial al detalle proyectual**. ***From the territorial scale to proyectual detail***. Elia-García, Santiago; Comeras-Serrano, Ángel B.; Lorén Collado, Antonio.

20. **Drámatica del arbolado sobre la escena construida**. D***ramatic of the trees over the built scene***. Climent-Mondéjar, María José; Granados-González, Jerónimo.

21. **La Didáctica del Territorio. Un Modelo para Armar**. ***The Didactic of The Territory. A Model to Assemble***. Prado Díaz, Alberto.

22. **Conexiones culturales en los antecedentes de la obra arquitectónica**. ***Cultural connections in the background of the architectural work***. Comeras-Serrano, Angel B.

23. **Estudiantes de la UVa llevan la Arquitectura a colegios y familias de Castilla y León**. ***UVa´s students bring Architecture closer to schools and families of Castilla y León***. Ramón-Cueto, Gemma.

24. **La habitación está vacía y entra el habitante. Seminario de experimentación espacial**. ***The room is empty and the dwellwer. Experimental space workshop***. Ramos-Jular, Jorge.

25. **Taller de concursos para estudiantes de Arquitectura**. ***Workshop of contests for students of architecture***. Camino-Olea, María Soledad; Jové-Sandoval, José María; Alonso-García, Eusebio; Llorente-Álvarez, Alfredo.

26. **Aprendizaje colaborativo y multidisciplinar en el estudio del Patrimonio en Arquitectura.** ***Collaborative and cross-disciplinary learning applied to Heritage studies in Architecture.*** Almonacid Canseco, Rodrigo; Pérez Gil, Javier.

27. **Reaprender el arte del urbanismo. Estrategias docentes en la EINA (2009-2018)**. ***Relearning the art of urbanism. Teaching strategies at the EINA (2009-2018).*** Monclús, Javier.

28. **Lenguaje analógico y digital en la enseñanza del dibujo arquitectónico**. ***Analog and digital language in the teaching of architectural drawing***. Cervero Sánchez, Noelia; Agustín-Hernández, Luis; Vallespín Muniesa, Aurelio.

29. **Una introducción al urbanismo desde la forma urbana y sus implicaciones socioambientales**. ***An introduction to urbanism through urban form and its socioenvironmental dimensions***. Ruiz-Apilánez, Borja.

30. **Innovación docente a través de las Tecnologías de la Información y la Comunicación**. ***Teaching innovation through Information and Communication Technologies***. Alba-Dorado, María Isabel.

31. **Una aproximación a la cooperación desde el Grado en Fundamentos de la Arquitectura**. ***An approach to cooperation from the Degree in Fundamentals of Architecture***. Ruiz-Pardo, Marcelo; Barbero-Barrera, Maria del Mar; Gesto-Barroso, Belén.

32. ***Consideration of Climate Change Effects in Architectural Education.*** Pesic, Nikola.

33. **Un itinerario docente entre la Aljafería y la Alhambra.** ***A learning path between the Aljafería and the Alhambra.*** Estepa Rubio, Antonio; García Píriz, Tomás.

34. **La experiencia del Aprendizaje-Servicio en el diseño de espacios públicos bioclimáticos**. ***The Learning- Service experience in the design of bioclimatic public spaces***. Román López, Emilia; Córdoba Hernández, Rafael.

47. **Introducción al taller de diseño a partir del perfil de ingreso del estudiante**. ***Introduction to design workshop based on student´s admission profile.*** Pérez-de la Cruz, Elisa; Caralt Robles, David; Escobar-Contreras, Patricio.

48. **Pan, amor y fantasía. Ideas para 'actualizar' la enseñanza de la Composición Arquitectónica**. ***Bread, Love and Dreams. Some ideas to 'update' Architectural Composition's Teaching***. Díez Medina, Carmen.

49. **Investigación sobre *El Modelo***. ***Investigation on Model***. Soriano-Pelaez, Federico; Gil-Lopesino, Eva; Castillo-Vinuesa, Eduardo.

50. **Aproximación al territorio turístico desde la innovación docente en Arquitectura**. ***The touristic territory, an approach from teaching innovation in Architecture***. Jiménez-Morales, Eduardo; Vargas-Díaz, Ingrid Carolina; Joyanes-Díaz, María Dolores; Ruiz Jaramillo, Jonathan.

51. **"Emotional Structures", Facing material limitation.** ***"Emotional Structures", Enfrentando la limitación material***. Mendoza-Ramírez, Héctor; Partida Muñoz, Mara Gabriela.

52. **Aprendiendo del paisaje: El tiempo como factor de renaturalización de la ciudad**. ***Learning from landscape: Time as an element of renaturalization of the city***. Psegiannaki, Katerina; García-Triviño, Francisco; García-García, Miriam.

53. **Taller experimental TRA-NE: transferencias entre investigación, aprendizaje y profesión.** ***Experimental studio TRA-NE: transfers between research, learning and professional practice.*** Zaragoza-de Pedro, Isabel; Mendoza-Ramírez, Héctor.

54. **Lecciones entre aprendices. La estructura vertical en las enseñanzas de arquitectura**. ***Lessons between apprentices. Vertical structure in the architectural education***. Alarcón-González, Luisa; Montero-Fernandez, Francisco.

55. **La maqueta como herramienta de proyecto**. ***The model as a Design tool***. Solans Ibañez, Indíbil; Fernández Zapata, Cristóbal; Frediani-Sarfati, Arturo; Sardà Ferran, Jordi.

56. **Influencia de la perspectiva evolucionista en las asignaturas troncales de arquitectura**. ***Influence of the evolutionary perspective on the architectural core subjects***. Frediani-Sarfati, Arturo.

57. **Nuevas tecnologías y Mapping como herramienta para promover un urbanismo interdisciplinar**. ***New Technologies and Mapping as a Tool to Promote an Interdisciplinary Urbanism***. Mayorga Cárdenas, Miguel Y.

***JIDA'18**. V Jornadas de Innovación Docente en Arquitectura*
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Consideration of Climate Change Effects in Architectural Education

Pesic, Nikola
Department of Architectural Technology (TA), Barcelona School of Architecture (ETSAB), Polytechnic University of Catalonia (UPC), Spain, nikola.pesic@upc.edu

Abstract
As the concerns for the environment and energy-efficiency (EE) emerged on the world scale, teaching in the field of anthropogenic world climate change (CC) effects became one of the key-components in contemporary educational programs. This paper presents an architectural course, based on the building physics and technology that applies two proposed techniques: climate change survey (CCS), which is founded on managing weather data (WD) and identifying CC effects, and the climate change response (CCR), which is a synthesis tool for the building performance simulation (BPS) modelling process. Regarding the pedagogical concept, the consideration should be given to the application of the proposed advanced active teaching model (AATM), which incorporates the problem-based learning (PBL), think-pair-share (TPS) and critical thinking (CT) methods. Using an active teaching approach, the aim of the course is to build among students a coherent multidisciplinary knowledge basis for use of CC analytical techniques in architectural design (AD) process.

***Keywords:** climate change, impact assessment, building performance simulation, pedagogical methods, active teaching model.*

***Bloque temático:** 1. Metodologías activas (MA)*

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Introduction

Energy-efficiency (EE) grew into one of the key-components in contemporary building design requirements, regarding that the world building sector should emit as less as possible carbon-dioxide (CO_2), reduce gross energy demands and expand the use of renewable energy resources. The architectural profession today is facing new design challenges, among which one is to efficiently withstand negative climate change (CC) effects by applying adequate contemporary bioclimatic strategies. New rising requirements that define architectural design (AD) approach should be complied properly regarding, among other things, the evaluation of current and future estimated building performances.

One of the objectives of educational programs' orientation towards sustainable development is to provide also an in-depth knowledge about CC mechanisms and the application of EE strategies in AD. In practice, one of the first phases during an AD process is to perform a climate analysis of a specific geographical location (GL).

Against this background, the paper presents an architectural course that is based on analyses of predicted CC impacts, which determine the overall potential of building energy savings and an implementation of AD strategies that could respond adequately to such estimated future weather effects.

1. Course Objectives

It is an imperative that today's architects and architectural designers should be familiar with basic principles of CC effects and how building's EE would perform in the future. In view of this, the objective of the architectural course that is presented is to build among students a multidisciplinary theoretical knowledge in the field of CC response regarding AD, with the focus on the WD management and BPS modelling processes.

In comparison with the majority of present-day courses that are related to CC effects from different fields of science (e.g. geography, environment, CC policy, land-use etc.), this course is based on the building physics and technology and is oriented towards students with an architectural background. The course systematizes AD process with proposed analytical procedures that are mainly focused on relation between building energy demands and EE aspects. Such generated datasets serve for analyses of building energy performance in order that the particular bioclimatic strategies could be applied for coping efficiently with previously identified CC threats.

The course is focused to establish a clear designer-developer workflow, i.e. initiative and responsibility through different areas of AD analyses. The highlight of the program is in two proposed analytical techniques: the climate change survey (CCS) (Section 3.1) and the climate change response (CCR) (Section 3.2), which are developed in Barcelona School of Architecture (ETSAB) during previous researches (Pesic et al., 2018a, 2018b) and as well currently conducted analysis.

The objective of the course content is to strength students' conceptual, analytical and problem solving skills while establishing also a personal critical approach. During individual and group-based tasks, students perceive CC principles, gather, analyse and process WD, conduct AD processes by applying proposed analytical techniques, implement bioclimatic strategies to respond to CC effects and in the end, during group-works and round-table discussions, share end evaluate their key-findings and results with other participants.

2. Course Program

The proposed program is a postgraduate or continuing curse type of one-year duration. A large part of teaching methodology is based on the face-to-face classroom concept while more demanding course content is oriented towards work in groups or pairs.

The course knowledge transfer is conceived of class lectures, group-work sessions, round-table discussions, work presentations and collaborative and self-guided learning methods. A round-table class discussion is organized at the end of each course block as a recapitulation point of previously apprehended content. A concept of an active teaching and dynamic program structure enables students to achieve objectives and to demonstrate the applicability of apprehended course content.

2.1. Course Scheme

The course program is systematized in three course blocks (B1–B3) and each block is sequenced in three core modules—in total, nine modules (M1–M9) (Table 1). The evaluation phases (E1–E3) are planned at the end of each block and are based on a different assessment method. The end of the course is summarized with the final evaluation (FE).

Table 1. Course organizational scheme

Block	Module			Evaluation	Evaluation method
B1	M1	M2	M3	E1	Exam
B2	M4	M5	M6	E2	Case study, discussion
B3	M7	M8	M9	E3	Synthesis project design
Final evaluation				FE	

2.2. Course Program Structure

2.2.1. Block Structure

The program in conceived in three following blocks:

Block 1 (B1): Energy-Efficiency Aspects

Block 2 (B2): Weather Data Management and Adaptability to Climate Change

Block 3 (B3): Architectural Design Process

2.2.2. Module Structure

B1: Energy-Efficiency Aspects

The course block provides a closer look to CC mechanisms and building sector EE aspects, following with the world climate classification and an overview of the current human thermal comfort (TC) normatives.

M1: Introduction to energy-efficiency

Human influence on the climate system:

- Principal effects; perturbation of atmospheric composition: CO_2, NO, NO_2; greenhouse effect; land-use change etc.

Building sector energy-efficiency aspects:

- Transformations from “passive” to “active” AD concepts; energy consumption; building CO_2 emission; space heating and cooling (HC) loads etc.;
- European Union’s energy transition process: objectives for year 2020, 2030, 2050.

M2: World climate classification

- Köppen–Geiger climate classification system; climate types; examples of major world cities and their GL; comparison with other systems, e.g. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) weather classification.

M3: Human thermal comfort

- Basic conditions and parameters for human TC; boundary conditions: temperature, relative humidity, air-flow speed, radiant temperature, activity, clothing etc.; standards and normatives, e.g. ASHRAE standard 2017–55, CEN (Comité Européen de Normalisation) Standard ISO 15251:2006, etc.

B2: Weather Data Management and Adaptability to Climate Change

The block presents the principal course content and is oriented towards analytical tools and methods for WD processing and building design CC response.

M4: Adaptability to climate change effects in architectural design

Contemporary tools, techniques and strategies:

- Bioclimatic design strategies: passive solar systems, natural ventilation, thermic inertia, sun protection, insulation, etc.; examples of reference built projects around the world.

The city of the future:

- City models; towards sustainable city; natural resources usage; reference city models; technology and integrated approaches on the city scale etc.

M5: Climate change survey (CCS)

Weather data management:

- Introduction to WD parameters;
- Generating present-day climate data and projecting and morphing them by applying CC scenarios for the future “time slices”: year 2020, 2050, 2080.

Comparison between present-day and future climate data:

- Comparison methods and presentation of results: heat-maps, charts, tables etc.

M6: Case study

- Comparison analysis in a particular climate zone between reference examples of vernacular architecture and contemporary built projects;
- Presentation of case studies regarding the aspects of world climate types related to applied bioclimatic building strategies.

B3: Architectural Design Process

The course block establishes a correlation between AD processes and BPS modelling, in order to demonstrate a response model to the previously identified CC effects.

M7: Architectural design practice today

- Architect's position: individual vs. team-work; relation and interaction with other professions (urbanism, ecology, façade design, environmentalism etc.);
- Diagrams and schemes of activities during an AD process.

M8: Building performance simulation (BPS)

- BPS modelling in DesignBuilder software program with building EE calculations;
- Applying present-day and generated estimated CC model WD; results comparison.

M9: Climate change response (CCR)

- AD process methodology and applying the proposed CCR technique;
- Synthesis project design process.

3. Specific Course Content

3.1. Climate Change Survey (CCS)

The course core module 5 (M5) consists of teaching the use of the CCS technique, which is a WD-based analytical method designed to observe key-aspects between present-day and future estimated CC conditions for a particular GL.

The CCS is conceived in four steps (S1–S4) (Figure 1). The S1, or "data handling", systemizes present-day and CC model WD. The S2, or "risk identification", displays in its first part "WD comparison", which is an overview of present-day and calculated future weather conditions. In the following second part, "CC impact model" displays a list of estimated CC effects. The next S3, or the "adaptation" phase, represents an early-stage climate impact assessment from the aspects of "sensitivity", "exposure" and "resilience" (adopted from: Lyth and de Chastel, 2007). In that manner structured dataset of estimated CC impact is then processed in the final S4, or the "survey" phase, for defining the "analytical model" that propose a set of general bioclimatic building strategies.

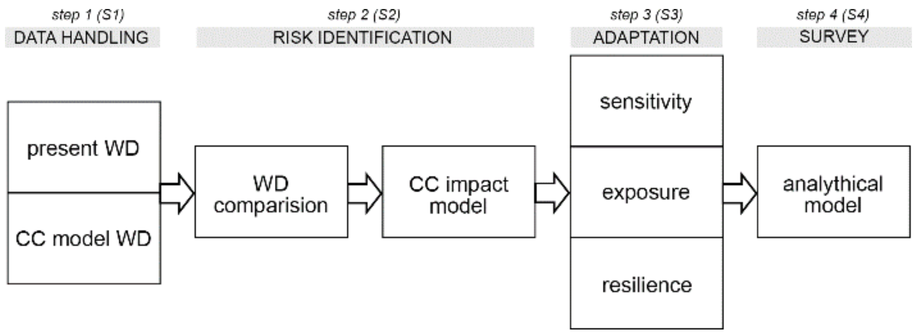

Fig. 1 Climate change survey (CCS) process. Source: by author (2018)

3.1.1. Detailed Climate Change Survey (CCS) Process

Step 1 (S1): Data handling

Present-day weather data:

- Typical meteorological year (TMY) files list hourly values of WD for a specific GL;
- "EnergyPlus weather data" web-site provides WD files in EnergyPlus weather format (EPW) for the large part of major world cities according to the selected weather station;
- For the specific weather stations that are not included in the "EnergyPlus weather data" web-site (e.g. nearby GL, multiple weather stations in the same area etc.), data can be accessed with "Meteonorm" software program;
- The previously acquired WD files are further managed with "Climate Consultant" software program for conversion, sorting and filtering of selected parameters.

Climate change (CC) model weather data:

- Present-day WD are converted with "Climate change world weather file generator" ("CCWorldWeatherGen") by applying the CC scenarios for years 2020, 2050, 2080, which are developed by Intergovernmental Panel on Climate Change (IPCC);
- Managing WD: conversion, sorting, filtering and organizing of datasets.

Step 2 (S2): Risk identification

WD comparision:

- Comparison of generated present-day and applied CC model WD using various display methods for an overview of similarities and dissimilarities: charts, tables, heat-maps etc.

CC impact model:

- Identifying CC key-findings in a comparison process regarding WD parameters: dry-bulb temperature, relative humitidy, wind direction, wind speed, solar irradiation etc.

Step 3 (S3): Adaptation

Sensitivity:

- Defining a "sensitivity profile"—liable level to be affected by CC; human comfort needs; estimated level of building sensitivity.

Exposure:

- Determination of potential risks; state of level without protection; mitigate CC impacts: estimated level of building exposure and potential vulnerability.

Resilience:

- Available bioclimatic AD techniques and strategies for the specific region; preparedness level for the future estimated CC treats; estimated level of building resilience.

Step 4 (S4): Survey

- How identified CC key-aspects for a particular GL could affect an AD?; survey of positive and negative identified CC impact factors;
- Applying general bioclimatic AD strategies according to regional, climate and technological possibilities.

3.2. Climate Change Response (CCR)

The core module 9 (M9) includes the CCR technique, which is an AD process tool based on a BPS of a hypothetical building model calculated under estimated CC effects. The focus of the analysis is on calculations of building HC energy loads and CO_2 emission.

The proposed analytical tool summarizes a larger part of the program content so that is also considered as a final course synthesis project design, which consists in six steps (S1–S6) (Figure 2). The CCR technique applies a set of bioclimatic AD strategies in a hypothetical building model that is designed to efficiently cope with estimated future CC conditions in a particular GL.

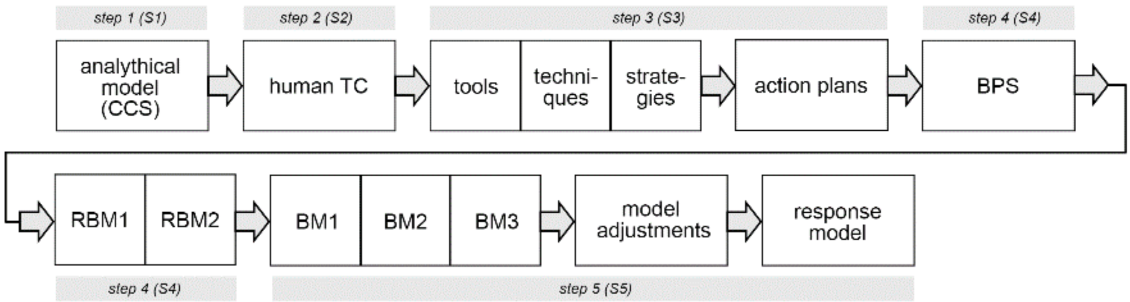

Fig. 2 Climate change response (CCR) process. Source: by author (2018)

3.2.1. Detailed Climate Change Response (CCR) Process

Step 1 (S1):

The first step is “analytical model”—an initial input which has been defined in the previous CCS process (see Section 3.1).

Step 2 (S2):

This part applies a selected human TC standard and a chosen model of acceptability range (according to e.g. ASHRAE standard 2017-55, CEN Standard ISO 15251:2006 etc.)

Step 3 (S3):

The first part of S3 includes an application of bioclimatic building tools, techniques and strategies (on a more detailed level than in the CCS process). In such a way, analysed data serve for defining “action plans” in the second part of this step, which include a set of building components that could be incorporated in a BPS model.

Step 4 (S4):

This segment is based on a BPS of a hypothetical building model using DesignBuilder software program. A performance simulation includes two models: the reference building model no. 1 (RBM1) and the reference building model no. 2 (RBM2)—the same building model analysed under two different weather conditions, i.e. present-day and applied CC conditions.

Step 5 (S5):

The final step includes a proposed number of building models with the purpose to analyse and improve the overall EE. A set of building models (three models in this case: BM1–BM3) are proposed as a response to CC effects with a variation of applied strategies. S5 is summarized by displaying comparative charts and tables of generated output for all models. A model that shows an advantageous EE performance is selected for the next phase—“model adjustments”, which also incorporates possible favourable components from the previous BM1–BM3. In that manner is defined a “response model”, as the final output of the applied CCR technique, which represents a preliminary proposed reference building form which responds, with the calculated level, to the previously estimated CC effects.

4. Specific Teaching Methods—Advanced Active Teaching Model (AATM)

This paper proposes the advanced active teaching model (AATM), which is structured as a three-by-three form, i.e. a horizontally divided three-level process model is further divided vertically with a three-level[1] teaching model (Figure 3). The entire AATM is divided horizontally in three general process phases: perception, analysis and application, while vertically are incorporated the problem-based learning (PBL), think-pair-share (TPS) and critical thinking (CT) teaching methods. The model’s vertical axis occupies the CT, as an individual-based pedagogical strategy, which is interconnected at the particular stages with PBL and TPS group-based approaches (see more Section 4.4 Advanced Active Teaching Model Interconnections).

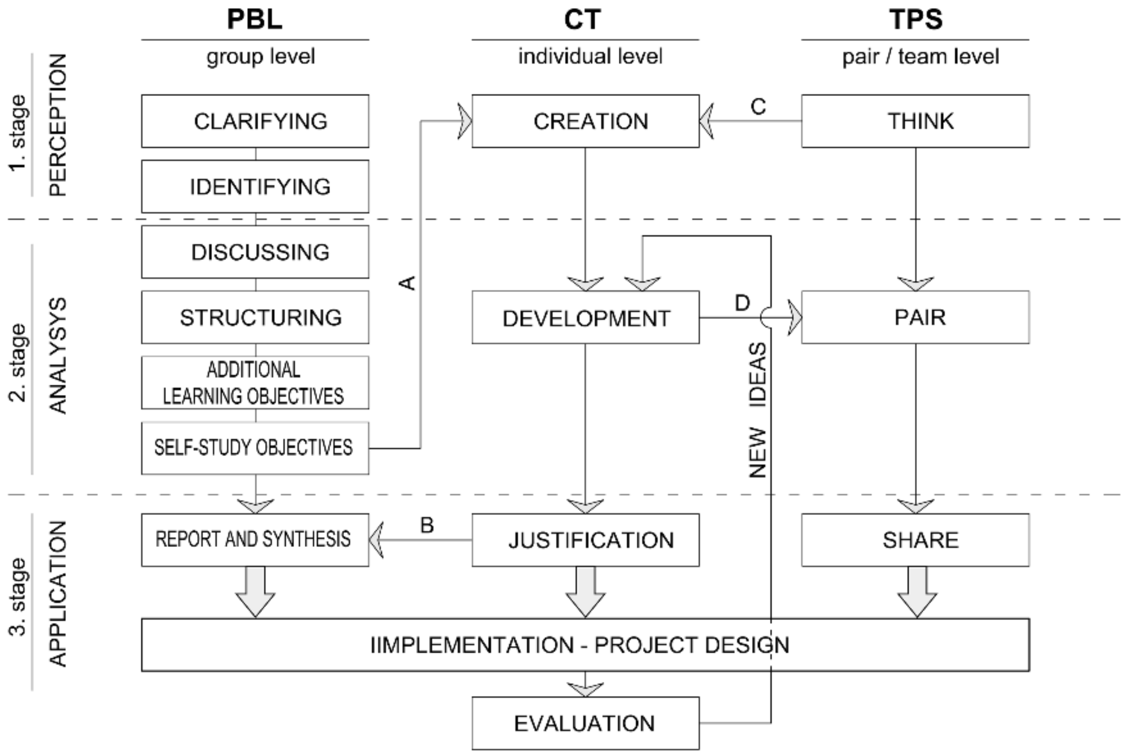

Fig. 3 Advanced active teaching model (AATM): interconnections between problem-based learning (PBL), critical thinking (CT) and think-pair-share (TPS) teaching methods. Source: by author (2018)

The teaching model that is presented proposes a simplistic approach to the PBL, TPS and CT methods. With respect that exist numerous variations and subtypes according to relevant references and literature, a more detailed level of analysis would certainly require an extensive form of presentation.

[1] Term “level” is in the context of teaching methods: group, individual and pair or team level

4.1. Problem-Based Learning (PBL) Method

The principal part of the course consists of core modules M5 and M9 whose content is focused on the application of the CCS and CCR techniques. As this segment requires an in-depth analytical approach in solving of complex tasks, therefore is applied the PBL method, which additionally shifts a teaching setting from a formal classroom lecture to a discussion-based group-work.

During the PBL process, students apprehend “through the experience of problem solving” (Walldén and Mäkinen, 2014). An educator facilitates the group-work by supervising and supporting the learning process with the role of “student among students”, ensuring that learning objectives are focused, achievable and comprehensive (Albanese, 2013). As complex learning tasks require high working memory loads, in comparison with student’s individual capacity, group-work shows an elevated level of processing abilities for relating information elements. Consequently, the obtained information elements are shared among group members, by relating them to each other and constructing a more complex conceptual framework (Kirschner et al., 2009). Applying such an active teaching method, certain negative effects are also avoided, e.g. during formal lecture-based teaching, students could become passive and uncritical with feelings of boredom etc. (Roberts, 2007). Generally, the PBL method stimulates students to actively participate in an educational content in a critical and explorative manner, while adopting along the course a comprehensive and thorough approach to the learning process.

The group-work process is systemized by applying the Maastricht “seven jump” process (Wood, 2003; Albanese and Dust, 2014), which consists in the following stages (Figure 3):

1. **Clarifying problems**: case discussion and understanding the problem.
2. **Identifying problems:** identifying key-questions that need to be answered.
3. **Discussing problems:** brainstorming—discussing about group current knowledge and identifying potential solutions.
4. **Structuring results:** the outcome from the previous brainstorming session.
5. **Additional learning objectives:** formulating objectives for the information and knowledge that are still missing for problem solving.
6. **Self-study objectives**: independent study, individual or in smaller groups, collecting necessary additional information.
7. **Report and synthesis:** round-table discussion of key-findings, summarizing the issues.

The students are exploring complex problems in a newly established PBL environment that may produce intense loads on students’ analysing process capacities because of their lack of proper mechanisms to interconnect new information with their previous knowledge (Kirschner et al., 2006). Therefore, the use of questioning should be practiced with the purpose to facilitate the discussion process and solving of key-issues (Zhang et al., 2010). A consideration should be also given to the use of prepared scenarios with identified discussion objectives in a form of check-lists or step-by-step guides adjusted to the level of the students’ apprehension capacity. Also, a particular “trigger” teaching material should be included (e.g. video presentations, on-line datasets, articles etc.) in order to stimulate the group work-flow. Nevertheless, the end of the PBL session sets a scene for subsequent activities, e.g. for further students’ self-directed learning activities which may include also the application of the CT method (see more Section 4.3).

4.2. Think-Pair-Share (TPS) Method

The TPS method is a collaborative-based teaching approach, and the consideration should be given to its application during round-table discussions at the end of each course block. The method helps students to form ideas on an individual level, and then to share and discuss them with other participants. The TPS is an active teaching concept that principally switches a setting from the formal classroom lecture-based teaching to an open discussion environment where all students became involved in a dialogue. The TPS method is conceived in the following three stages (Figure 3):

1. **"Think"**—an educator poses a question to students, allowing a certain time for students to think independently of a response.
2. **"Pair"**—students are instructed to pair or form a team, and then to share and discuss previously formed individual responses. The objective is to reach a consensus among pair or team members and to form one response.
3. **"Share"**—paired or grouped students are called to share their collaborative answers in a discussion, which is supervised by educator. The other participants evaluate the presented opinions and share their proper information and viewpoints.

The educator supports the discussion with a set of questions, lesson-guides and additional in-depth comments about the teaching content. During a discussion, the applied TPS method assists students in information processing and also pushes them from the current knowledge and comprehension area to a more engaged level of problem resolving skills (Fitzgerald, 2013). Another advantage is that TPS concept increases the interaction among students especially regarding the types of passive or isolated students who might not otherwise interact with other participants (Emerson et al., 2016).

Another benefit in this particular course is that TPS method allows the further interconnection of students on a sub-group or pair level, regarding previously formed larger work-groups during the PBL approach (see Section 4.1). In that manner, previous key-findings could be disaggregated and discussed further among participants from now multiplied viewpoints.

4.3. Critical Thinking (CT) Method

While applying the PBL and TPS methods at a students' group or pair-level, a parallel integration of the individual-based CT approach is also considered in this course. Although exist numerous approaches to the CT method throughout the history, including that the CT is one of the "major unsolved problems of pedagogy" (Kuhn and Dean, 2004), however, for the purpose of this paper it may be considered that "the CT is a purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference, as well as explanations of the considerations on which that judgment is based" (Abrami et al., 2015). According to the relevant studies, the CT model enables student to acquire and create knowledge and skills with a more structured approach while critiquing and optimising a personal design solution with a previously formed individual opinion. The specific CT model adapted to building design process is conceived in the following five stages (Allison and Pan, 2010) (Figure 3):

1. **Creation**
2. **Development**
3. **Justification**
4. **Implementation**
5. **Evaluation**

During the course, students progressively develop and apply the method, particularly when the CT is interrelated with the PBL, which establishes an active process between self-directed and group-based reasoning that improves the overall students' understanding in relation to the structure of considered tasks (Allison and Pan, 2011). It should be underlined that a pedagogical effort is not necessarily directed towards teaching students a range of pre-determined CT skills, but it is more oriented to encourage them to become flexible and adaptable thinkers with an ability to use a broad range of developed individual-based critical proficiencies (Moore, 2011). Generally, once apprehended, CT skills can be practiced, applied and demonstrated in a wide variety of contexts.

4.4. Advanced Active Teaching Model (AATM) Interconnections

Regarding the proposed AATM (see Section 4.1, Figure 3), during the PBL group-based work process before proceeding from "self-study objectives" to the "report and synthesis" stage, the model provides an access (link "A") to the parallel CT "development" stage which allows a structured individual analysis whose outcome from the "justification" stage could contribute in the PBL "report and synthesis" phase (link "B"). On the other side, during the application of the TPS method, and while progressing from "think" to "pair" stage (i.e. before switching from individual to pair-based analysis), the CT approach can be applied (link "C") in order to define a more structured self-oriented opinion that can be further shared and discussed with other member(s) in the "pair" stage (link "D").

5. General Course Outcomes

5.1. Knowledge and Comprehension

- Phenomena of human-induced CC effects—causes and consequences;
- Physical mechanisms of CC effects on different timescales;
- Managing WD and applying CC scenarios for weather predictability;
- Correlation of CC effects and EE in AD approach;
- Applying strategies, tools and techniques for an adequate CC response;
- Critical and responsible approach in AD process;
- Design thinking and applying of proposed AD techniques;
- Team-work design process: discussing and sharing of information and viewpoints.

5.2. Individual Skills

- Use of software programs to acquire and generate specific WD and results;
- Methods to analyse and present results for a specific task related to CC;
- Able to critically examine CC impact and to formulate reasoned opinions;
- Coherent theoretical base in managing AD process related to CC effects;
- Creating an integrated AD concept and evaluating proposed solutions;
- Planning and organising both time and resources during an analysis task;
- Improved communication and debating skills;
- Improved team-work and autonomous problem-solving abilities.

5.3. Professional Competence

- Clear vision of architect's role in AD process;
- Adaptive and responsive individual approach;
- Valuable obtained course program curriculum;
- Course content is applicable further in a professional or academic work.

6. Conclusions

The consideration of CC effects in architectural education has been presented in a form which incorporates the proposed AATM, whose aim is to maximize the comprehension and knowledge transfer process. Regarding that today's educational programs are subject to a constant change and updates, the course that has been displayed could contribute to the current trend of implementation of EE fundamentals in architectural education. In this context, the consideration could be given to a phased course or methodology implementation in an actual program structure. This kind of approach would certainly open new directions for related case studies, i.e. to monitor, review and evaluate step changes during a process of putting such a model (or a selected part) into effect in a learning environment of a specific educational institution.

7. Abbreviations

AD	architecture design
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AATM	advanced active teaching model
B1	(course) block 1
BM1	building model no. 1
BPS	building performance simulation
CC	climate change
CCS	climate change survey
CCR	climate change response
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CO_2	carbon-dioxide
CT	critical thinking
EE	energy-efficiency
EPW	EnergyPlus weather, computer file format
ETSAB	Escuela Técnica Superior de Arquitectura de Barcelona (Barcelona School of Architecture)
GL	geographical location
HC	heating and cooling
IPCC	Intergovernmental Panel on Climate Change
M1	(course) module 1
MA	metodologías activas (active methodologies)
PBL	problem-based learning
RBM1	reference building model no. 1
TC	thermal comfort
TMY	typical meteorological year
TPS	think-pair-share
WD	weather data

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