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Integrating Climate Responsive Principles into the Design Process: Educating the Architect of Tomorrow

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Summary

In the 20th century the world hailed a new type of construction. Following modernists' theories for minimalistic and functional buildings, a contemporary unified style based on standardization evolved into the International Style buildings.Steel, concrete, and glass-wall high rise buildings respond neither to different functional demands nor to different urban environments and climates. Such design choices influence thermal comfort and potential for natural ventilation negatively. Compensation with AC leads to higher energy cosumption.

In times of vigorous debate about rapid climate change this architectural style threatens the ecological equilibrium. Nowadays, the architect's role should be to design energy efficient buildings embedded in sustainable urban environments. Therefore, the need for corresponding principles and strategies must be included in an academic curriculum to shape conscious architects.The paper reports about experiences from a university course. It starts with an analysis comparing an International Style office room and an optimized one at 14 locations worldwide covering all main different climates. The used different tools combining energy and design aspects are presented as well as results and conclusions for the design process. Furthermore, the desire and fitting time for using climate responsive principles and the manageability of the multiple stages of design were tested through surveys distributed to students in construction-related disciplines.

Keywords: Climate responsive architecture, energy demand, architectural education, design strategies, international style buildings

3. Introduction

Buildings account almost one third of the total global energy use and contribute by one third to energy related greenhouse gas emissions [8].Currently, there is a growing demand for environmentally sustainable building solutions due to climate change and the environmental impact associated with the use of fossil fuels [9]. Additionally, the depletion of fossil fuels and the need for energy security increase the interest towards the reduction of energy consumption and the use of renewable resources.

For the years followed the first modernists' theories for minimalistic and functional buildings, same characteristic buildings regarding form, materials, type of construction appeared in many areas globally despite the differences in climate, character and geomorphology of the surroundings.The last decades the building sector is witnessing a growing trend towards adaptive and hybrid buildings [1], where the climate responsive architectural design and the application of technology for benefiting from renewable resources create a comfort, pleasant, environmental friendly and energy efficient building environment. The term adaptive presupposes a building which reaches comfort levels with only passive measures whereas a hybrid building is partly, during some months of the year, mechanically heated or cooled.

Nowadays the professional market expects from architects and planners to have theoretical and technical knowledge on how to propose creative and environmentally responsive solutions [1]. Climate Responsive Design and Planning is one of the methods for achieving sustainability in architecture [4] by adjusting the design of the building and incorporating passive strategies that benefit from the local climate and weather conditions as well as the availability of local and renewable resources. It is a necessary answer for the construction sector to climate change mitigation, depletion of finite resources (oil, gas etc.) and ecosystem agitation [1].The market demand, climate mitigation efforts and the complexity of Climate Responsive Design Principles (CRDP) themselves suggest that the departments of architecture and others related to building environment should play a decisive role in shaping the architect and planner of tomorrow.

Climate Responsive Architecture and Planning is a 5 credit points, master's level interdisciplinary course of the Resource Efficiency in Architecture and Planning (REAP) program at the HafenCity University of Hamburg [5]. It should be noted that the majority of the participants are architects, followed by a number of urban designers and planners, civil engineers and other disciplines. The course equips students with skills on how to create adaptive or hybrid buildings and renders the necessity of being aware and understand the special nature of a place and its weather conditions, principles that define a sustainable proposal.

The course is carried out through a series of lectures and assessments. It addresses the problematic nature of International Style buildings (see ch.2) regarding their energy consumption and artificial comfort they create with the help of technology. It challenges as well the students to optimize an International Style office room to the point it becomes part of a Zero Energy Building (ZEB). During the course participants realized the necessity of CRDP and the commitment it requires from the beginning of a project to its completion. Even though most of the participants were familiar with some of the principles (such as building orientation, shading, natural ventilation strategies, window placement related to openness/closeness of a place) by the end of the course many reported that the experience changed the way they create architecture.

In order to test the level of understanding, interest and perception of CRDP and whether these are currently a part of all students' academic curriculum and not only of a small percentage such as REAP students, who receive special education on matters of climate responsiveness and sustainability, a questionnaire was administered to students of all disciplines and all levels of study at the HafenCity University of Hamburg.

2. Introduction to International Style in Architecture

In the 20th century a new period begins for architecture and construction. After years of experimentation on new technologies, materials and theories, the world was mature enough to celebrate the arrival of a new epoch in architecture, in which "the palaces and houses of the future will be flooded with air and light [6]. The predominance of volume over mass, which the traditional construction techniques and forms commanded, constituted one of the main principles of the new modern movement in architecture. A branch of this new movement was the "International Style".

The principles of this style influenced many architects of the past century and played a decisive role on forming the image of many metropolitan cities around the world. The use of metal and reinforced concrete with metal bars provided the possibility of larger openings between the bearing elements of the building. This technological advanced freed walls from the main structure allowing for larger openings and a continuity in the façade creating a grill effect [6].The standardisation dictated by the construction, the economic prudency as the buildings were free from any arbitrary decoration and the theories of a mass production helped the spread of the style worldwide which is evident in many architects' decisions even nowadays.This resulted in steel, concrete, and glass-wall high rise buildings that do not respond neither to different functional demands nor to different urban environments and climates. Basic design choices frequently omitted in this type of buildings such as natural ventilation or passive solar heating can provide thermal comfort and reduction in energy consumption by benefiting from local climatic conditions.

3. Analysis of the Course “Climate Responsive Architecture and Planning”

The objective of the course was to determine similarities in architectural design solutions that responded to comparable climates and to start a dialogue on what it means to optimise an International Style room and later building, in different climates, so as to reach a desired comfort level, a zero energy demand and an acceptable human urban situation. The program succeeded to combine the theoretical background of physical laws and their practical application through a series of assessments. For the initial recommendations on passive strategies for building design in relation to climate type, the digital tool Climate Consultant [10] was used. Additionally, for assisting the learning process and testing the feasibility of the proposals we benefited from case studies, rules of thumb and the empirical knowledge of students.

The theoretical content of the course was taught in the form of a written script together with lectures that contained the following information:

- Analysis of Energy Demand
- Comfort Levels (indoor and urban spaces)
- Natural Ventilation
- Sun Protection (shading, glazing)
- Passive Solar Optimization
- Passive Cooling Methods (heat pumps, free evaporative cooling etc.)
- Photovoltaics
- Aspects of Urban Planning
- Analysis of Climate
- Compensating Measures (renewable energy)

Assessments were developed in groups of 3 to 4 students and were divided into 3 parts. Each group was assigned a city from different continents with a choice between Dar Es Salaam, Tanzania / Addis Ababa, Ethiopia / Cairo, Egypt / Chicago, USA / Mexico City, Mexico / Santo Domingo, Dominican Republic /Beijing, China / Delhi, India / Singapore, Singapore / Oslo, Norway / Hamburg, Germany / Reykjavik, Iceland /Jakarta, Indonesia / Sydney, Australia.

The subsequent steps consisted in a more in depth analysis of each city's climate provided a set of design strategies and rules to optimise at first the office room and later the building. Following this approach, each team proposed an improved building which is adapted to each climate. The optimized building was then tested for energy demand, comfort levels and energy production on-site or off-site as well as its arrangement in a real urban situation.

4. Analysis of the Assessments

As starting point a standard office room was defined with an area of use of 168 m2 (12 x 14 m) for 12 persons; with a suggested north-south orientation. The energy demand in terms of ventilation, artificial light, heating and cooling was presimulated for all locations and given to the groups.

The use of a self developed excel tool allowed the investigation of two different ways to reach a ZEB, a purist one which produces all energy on-site and an extended one where it is allowed to bring a part of the (renewable) energy from off-site (ZEB with compensating measures like wood pellets, wind turbines etc.). Thermal energy production on-site was assumed with a geothermal system (heat exchangers in the ground and heat pump), power production with PV modules on the building's roof.

The calculation of the purist ZEB ends with a maximum number of stories (limited by the capacity of PV which has to cover power demand of the whole area of use) and a minimal size of estate (limited by geothermal system which has to cover heating and cooling demand). The resulting urban situation can be discussed and compared with the real one.

The alternate scenario starts with a given (real) urban situation with more site-appropriate building height and distance. With the resulting size of geothermal system and PV modules it is possible to cover a defined part of the energy demand but maybe not all. To reach an extended ZEB the remaining part must be covered by renewable energy gained off-site. The resulting need of off-site land for such compensating measures was finally determined and discussed.

The outcome showed under which possibilities a ZEB could be reached with the chosen conditions and if the proposed urban arrangement meets the city's current situation and contributes to a sustainable and livable urban environment.

4.1 Assessment 1 – International Style building

The first task focused on a preliminary analysis of the climate on each location according to Koppen-Geiger system [7] and an investigation on local resources such as water availability and potential for energy generation and supply. The primary energy demand of the office room and the allocation of the energy required for the buildings' various needs indicated the focus point of the optimisation measures.

International Style buildings respond to a standardisation of design but are not climate responsive. Therefore, as starting point for the analysis, a standard International Style office room was selected in order to test how it behaves in diverse climates. Some typical assumptions were taken related to constructions and equipment. The room was assumed with fully glazed facades, an internal shading system, light internal construction and suspended ceilings. Air-conditioning works with 20°C for heating, 26°C for cooling, artificial light is switched on during time of use.

The investigation ends for most of the locations with unsatisfying results, Hamburg would allow for a ZEB urban arrangement of only 2.6 stories with a building distance of 34m which is out of any urban situation. During this first task students realised that in order to create a ZEB with International Style characteristics and simultaneously having an acceptable dense urban situation while diminishing the demand of the considerable amount of land necessary for the application of the compensating measures is not enough.This observation came as a result of the considerable size of land necessary for the application of PV and geothermal systems which contradicts with the density of most urban environments and an increasing request for densification. Therefore alterations and an optimal design of the room and building are required.

4.2 Assessment 2 – analysis of climate, traditional architecture, best practice examples

Designing and planning climate responsively requires knowledge and skills for analysing climate conditions and predict how these might affect the performance of buildings. For this purpose several programs are at the disposal of architects and planners. Climate Consultant [10] as one of these programs provides a detailed analysis of climatic conditions of a site and suggests passive design strategies for creating more adaptive buildings. Nevertheless, as its name suggests the tool becomes more a consultant to the user in which not all provided suggestions are adequate for all climates and locations. The right choice is defined consciously by the user. The provided by the tool design strategies, the acquired theoretical background during lecture and own research on the vernacular architecture as well as the investigation of best case studies of contemporary architecture on every location, shaped students' final design proposals.

4.3 Assessment 3 – optimized building and urban arrangement

The proposals contained the most relevant strategies which could have an impact on energy consumption and comfort levels (Adaptive Comfort Model) [2] [3]. The optimised building was examined for energy demand. A graph provided by the course, demonstrated an expected reduction in primary energy demand in an optimised climate responsive building as seen Fig. 1. Given the energy demand each month during the whole year the mode of building could be chosen to be partly or fully adaptive (natural ventilation cooling, passive heating) or partly or fully non-adaptive (air-conditioned). Effects of increased power demand for artificial light because of shadowing of opposite buildings are included as well as the possibility to use evaporative cooling or to replace partly the geothermal system by standard chiller (decreasing need of estate for geothermal system but increasing power demand). Through the excel tool, the dimensions of the standard room (width and depth) could be changed but total area of use had to be preserved.

The outcome showed under which possibilities a purist ZEB could be reached with the chosen conditions and if the proposed urban arrangement meets the city's current situation and contributes to a sustainable and livable urban environment. On the other hand, the ZEB with compensating measures is a result of own proposed building heights and distances which meets a more realistic urban scenario.

5. Results of the Course

The students were encouraged to experiment in possible design strategies that improved the thermal and visual performance and reduced the energy consumption of the office building. The final design choices for each group included proposals regarding optimal building orientation, window size and placement, need of shading systems, a natural ventilation strategy based on the on-site analysis of prevailing winds, construction type (light/heavy) and appropriate use of colors and materials. In some cases the local climate favors the implementation of exterior design strategies that affect the overall performance of the building such as vegetation and water bodies. Moreover, as mentioned in the previous chapter groups were puzzled as to how the building should be designed taking into account the site urban relationships. The results of all group assignments showed a great diversity in the design strategies and passive and technical measures as seen in Fig. 2. However, locations with similar climate indicated similar patterns. For example cities within Tropical Megathermal and Arid/Semiarid Climates tend to avoid exposure to east and west sunlight thus orienting the building north-south with some exceptions to catch prevailing winds. Constructions are lighter in tropical regions as opposed to Arid Climates. Ventilation strategies are often combined between natural ventilation and ceiling fans to improve the indoor effective temperature given the high levels of humidity but evaporative cooling functions better in dessert areas.In addition Tropical Climates allow the use of overhangs while for Arid Climates internal shading is more suitable.

On the other hand, Temperate and Continental Climates rely their orientation mainly on daylight and solar heat gains for winter while catching prevailing winds for summer cooling. Construction type is heavy for higher thermal mass and cross ventilation along with Thermo Active Building Systems (TABS) are enough to completely avoid the energy demand for AC in the summer as seen in Fig. 2. Window size is usually less than 50% of the total facade area to prevent heat losses during winter but in Tropical Climates window size tends to be larger for natural ventilation. In some areas with harsh weather conditions real ZEB with no mechanical support are not feasible, having in mind that they are embedded in a dense urban environment as seen in Fig. 2 for Tropical cities where air conditioning cannot be fully avoided.

The different design strategies and methodologies applied for creating a building with zero net energy consumption showed that there is no such “recipe” for one building in all climates and locations. Instead climate, environmental and spatial data significantly influence the design decisions and shapes the final solutions.

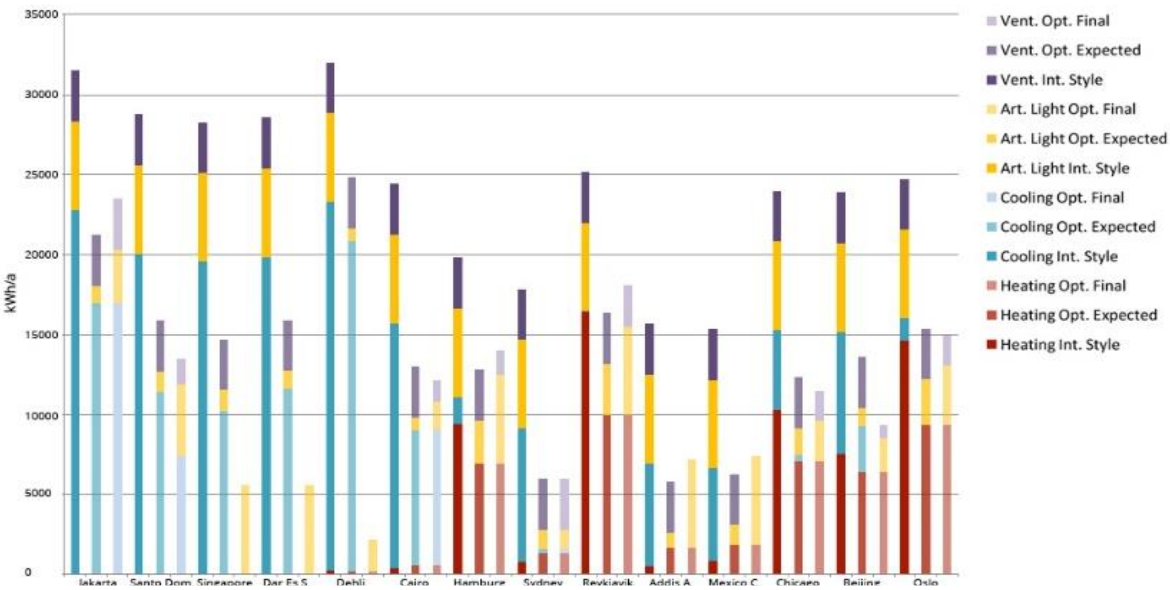

Fig. 1 Comparison of the energy demand (ventilation, artificial light, cooling and heating) expected in an International Style room, an optimised room and the students own optimised final proposal.

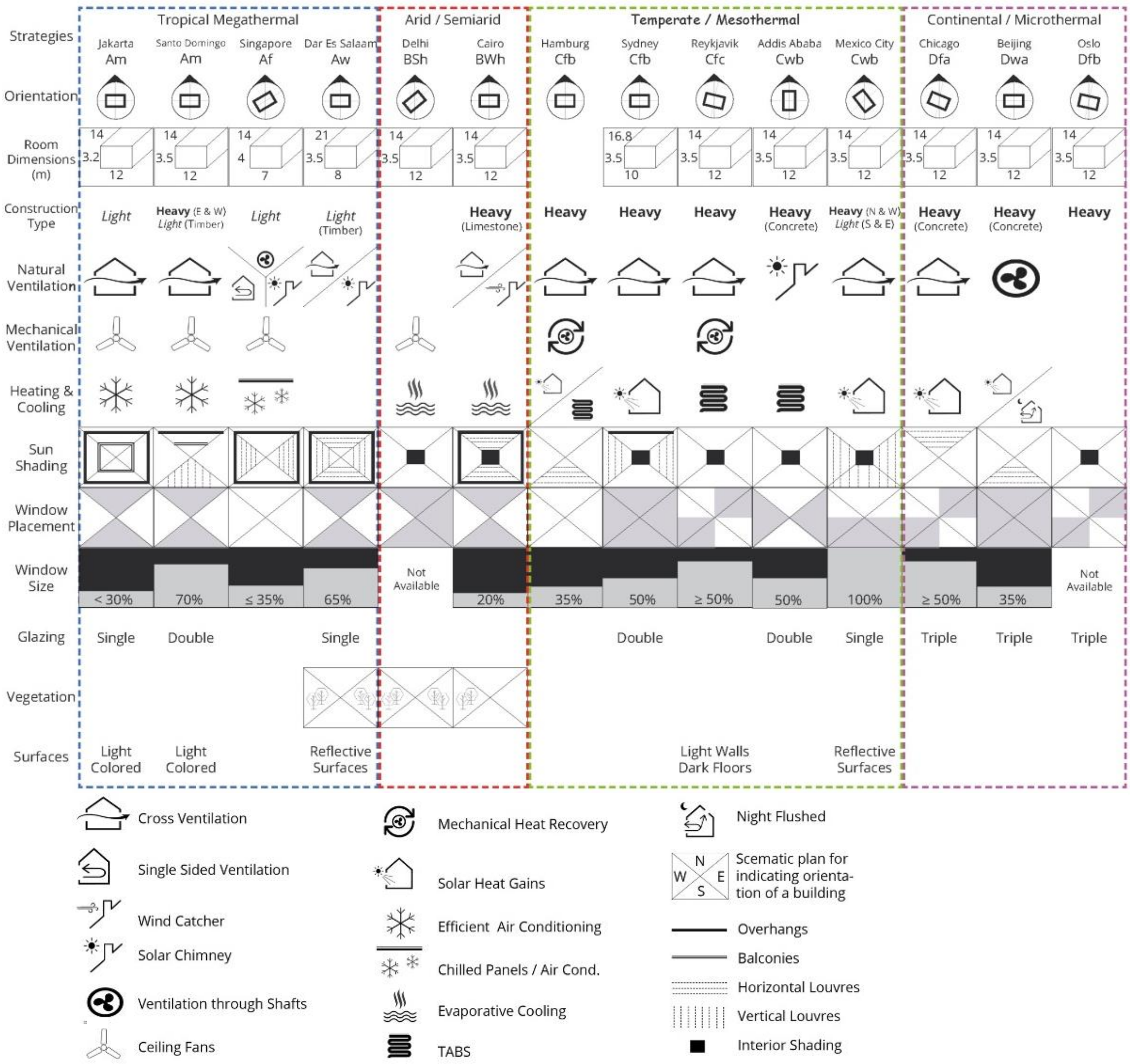

Fig. 2 Design strategies and passive and technical measures for all studied climates

The result is an adaptive and unique to each location building, with pleasant interior spaces (appropriately cooled/heated, with fresh air, well shaded) and prudent energy consumption. Particularly, in each case the reduction of energy demand between typical and optimised International Style buildings is significant. In almost all cases as shown on Fig. 1 a climate responsive design (adaptive/hybrid) and planning strategy proposed by the students (see Assessment 3) aiming to a real ZEB shows a further reduction to the energy demand of buildings from the optimised values.

The course provided a series of steps and tools on how to create more climate responsive architecture embedded into sustainable urban environments. Almost all participants' background is related to architecture and/or urban planning. Therefore, for many participants, the course made a correlation between ideas and principles already taught and followed empirically in architectural design and planning.

6. Survey and Assessment of the Course

By the end of the Climate Responsive in Architecture and Planning course participants were asked whether the information and knowledge they acquired as well as their experimentation on CRDP changed the way they understand the complex role of today's architect and urban planner and the process of conceiving a building or an urban formation. The positive response from the participants of the course was a triggering point for the last part of this research, which seeks to further investigate the level of knowledge, understanding and interest of students. The survey aimed as well to identify whether CRDP and strategies are part of the academic curriculum of all disciplines in HafenCity University and where the possible acquired knowledge stands in the conceptual design.

The research evaluates the results of 36 students, who carried out the survey. More than half of the students who took part were from the Master of Science REAP program. The students who participate to the program have a particular interest to sustainability matters and thus in the field of climate responsiveness. This possibly explains why 80% of the participants replied that they have been exposed to CRDP during their studies. This might obscure the true purpose of this research which is to investigate the thoughts of students in architecture and urban planning (bachelor and master), as typically taught, and other construction related fields regarding CRDP principles. However the results of the survey are worthy discussion and show some interesting facts.

The majority of the participants were master's students and only 28% in bachelor level. Furthermore 72% of the participants have working experience outside of the university environment which can influence their knowledge and interest towards CRDP.

The conducted survey showed that even though there is a great interest on CRDP the education on the matter is not enough. The majority reported to understand CRDP pretty well but close to 90% of participants want to be better informed and three quarters believe CRDP will have an important role in the future. Nevertheless, further improvement of the academic curriculum is required considering that more than one third of the students do not agree that their current studies include enough courses related to CRDP but fully agree that they should be included.

Additionally, to demonstrate great interest, students showed commitment to implementing CRDP into their design solutions. Opposed to what some may believe, CRDP do not hinder the creative process nor do they oppose to the traditional way of designing. Instead they are considered to be an important part in the early stages of design, have a generative (a) and corrective (b) purpose (Fig. 3), contribute to a strong design solution and are normally included in the final proposal. It should be noted that some CRDP are considered more influential for the design such as buildings orientation, day-lighting, natural ventilation and materials (Fig. 4). This probably occurs as architects use some rules of thumb and empirical knowledge taught in most universities in the first years of the architect's education.

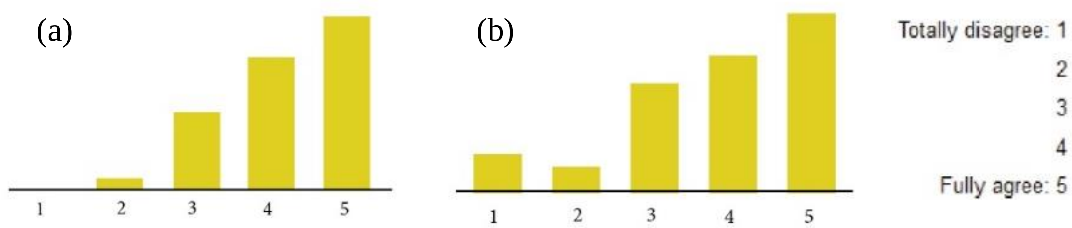

Fig. 3 CRDP have a generative (a) and corrective (b) purpose to my design

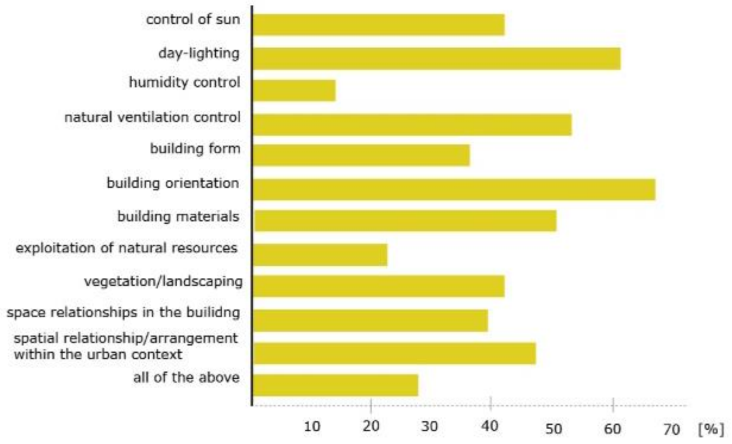

Fig. 4 Most influential CRDP factors while designing

However, there is a discrepancy on whether it is the responsibility of the architect to implement such techniques as well as a gap between the theoretical and practical knowledge. The majority of the students feel capable to apply CRDP in small scale projects but not in larger projects. For instance, larger scale projects are considered to need a team of experts and specialized consultants.

7. Conclusions

The global concerns about climate change as well as for energy security have changed the market's expectations of architects and planners and made them realize that they should take an active role on creating more energy efficient and sustainable buildings and design in harmony with the surroundings, climate and weather conditions. Many departments of architecture have realized the necessity of nurturing architects and planners with environmental related competences and are taking steps in implementing relevant courses to the curriculum, such as the Climate Responsive in Architecture and Planning course.

The different design strategies and approaches regarding building engineering that emerged during the course provide a hint of how many different and unique solutions arise from the study of climate, landscape and utilization of local resources. Participants reported that even though they had a basic knowledge of some of the CRDP the input they received during the course changed the way they might design in the future. The conducted survey highlighted the interest in CRDP from the majority of the HafenCity University students and that there should be more input on this topic. Suggestions include that the learning process of CRDP can be fostered through small scale projects and through a better integration of technical courses of the curriculum into practical and designing studios.

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