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BUILDING … A NEW EXPERIENCE IN AFRICA

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ABSTRACT: This paper presents an interdisciplinary design-build-project for students of Civil Engineering and Architecture. The project consisted of a theoretical design phase at the university and a second, practical stage, during which the participants were given the opportunity to actually build the structure. Thus, as a special teaching method within university education this full scale project linked theoretical information on building materials, construction and sustainable technology to the practical experience of implementing them on site – while simultaneously imparting communication and collaboration skills which are essential for both engineers and architects throughout their professional careers.

KEYWORDS: interdisciplinary teaching, student project, sustainable technology, sustainable building, South Africa

1 WHY DESIGN AND BUILD?

Most educational exercises in Architecture and Civil Engineering are theoretical – due to constraints of time, money, and opportunity. An abundance of information is expected to be memorised and understood by future professionals without offering them the opportunity to link theoretical knowledge to personal experience. Building a new kindergarten for underprivileged children in South Africa became such an exceptional experience for a group of students from Munich, who first designed and then built the structure with their own hands.

2 OUTLINE OF THE STUDENT PROJECT

The layout of the new building is the outcome of an interdisciplinary design project. Such projects are a regular part of the teaching concept of the Department of Timber Construction (Faculty of Architecture) and the Chair for Timber Engineering and Building Construction (Faculty of Civil Engineering) at the Technische Universität München, as shown in the proceedings of this conference [4] .

In this case, the assignment asked for a kindergarten for up to 80 children from the families of farm labourers. In order to find solutions for the wide scope of problems included in the assignment, the students worked together in groups of one architect and two civil engineers. Similar to a real planning process, each member of these design teams had to contribute results from his or her special field to come up with a collective proposal. Inevitably, individual concepts had to be given up in favour of mutual decisions.

Figure 1: *Final presentation and jury at the university*

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In a final presentation at the end of the term, the projects were assessed by a jury of external and internal critics, who decided on the most suitable out of the 17 proposals to be realised afterwards (Figure 1).
The criteria for the jury's decision ranged from a high architectural and artistic standard, a moderate but adequate layout, a practicable concept for lighting, heating, cooling and ventilation and a realisable proposal for the construction of the building. In the second, practical stage of the project, the participants were given the opportunity to actually build the structure, an undertaking made particularly challenging by the short construction time of only nine weeks on site. Even during the design phase, decisions had to be assessed, compared to preliminary assumptions and then adapted or discarded. While this was even more the case throughout the realisation, the actual building project offered the participants the rare chance to experience and personally evaluate the consequence of their own planning decisions.
Funding for this project came mostly from private donations given by various supporters in Germany and South Africa, but there was also a grant from the Regional Government of Bavaria.

2.1 SITUATION AND SITE

The site of the new building is located next to an existing primary school in Raithby, a village near Stellenbosch in the Western Cape Region. The long and narrow piece of land with a slight slope to the South had been donated by the local Methodist Church. (Figure 2) The new building was to replace an existing kindergarten situated a few kilometres away on private farm property.
The new site, adjacent to the school the children will most probably attend afterwards, offers a great improvement of the situation of the preschool through its location alone. Only very little reliable information regarding the exact boundaries, surface topography and geological properties of the site could be obtained beforehand, which meant that the design had to be flexible enough to meet a number of diverse, potentially unknown requirements incorporate the possibility of alterations.

Figure 2: *aerial view of Raithby, building site highlighted with white line (aerial photograph: google maps)*

2.2 BUILDING DESIGN

2.2.1 Layout and building plan

The layout of the long, rectangular building, which incorporates a variety of covered indoor and outdoor spaces under a large single pitched roof was only slightly altered after the end of the studio work. The building consists of four playrooms as well as a washroom, kitchen, store room, office and generous covered outdoor spaces which are needed for a variety of outdoor activities both during the hot summers and the wet winters of the Cape Region (Figure 4). The entrance is from the village street East of the plot, while the open space West of the building site, even though not explicitly part of the donated space, was intended to be used as a vegetable garden and play area from the beginning. As the village of Raithby is a fairly safe area by South African standards, it was possible to realise a very open layout of the building, allowing free access to the outdoor spaces. The orientation and layout of walls and openings are strongly influenced by energetic considerations, as will be shown later.

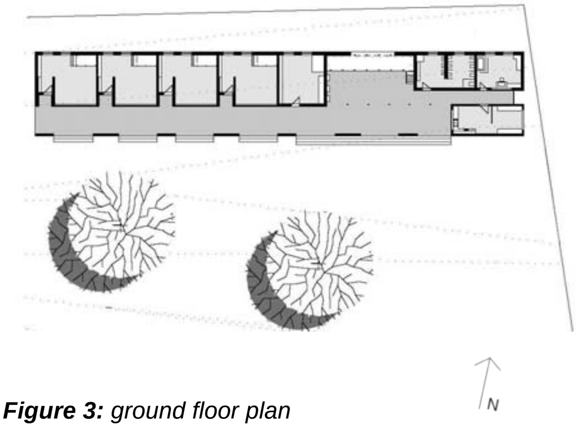

Figure 3: *ground floor plan*

2.2.2 Principal aims of the design concept

A fairly simple layout and consequently unsophisticated construction and detailing, e.g. using only limited spans for roof constructions, were a prerequisite for the intended method of building: The objective of the project was to come up with a structure made from local materials which could be built by students and local workers with only the help of simple equipment and within a short period of time. Students are in most cases not trained as craftsmen, and even local workers are usually qualified to a much lower standard than could be expected in Europe for instance. At the same time the building had to be energy efficient and use ecological materials as far as possible.
The structure of the building consists of a surrounding solid brick wall and light-weight timber framed interior and exterior walls which are protected from the weather by the large roof. For the choice of materials it was essential that they should be locally made, highly degradable, contain little or no harmful substances and have good ecological qualities, as for instance low embedded energy.

Figure 4: *view of covered outdoor space in front of the play rooms*

This led to the decision to use adobe bricks for the surrounding wall, which require almost no energy for production, and very little for transport and assembly.
For all timber constructions South African Pine from a local saw mill was used. Insulation glass for the windows and ecological paints were also supplied by local companies, the wooden frames for the windows were made from reclaimed timber.

2.3 CONSTRUCTION

2.3.1 Timber Construction

Both the roof construction and the load-bearing and partitioning walls are made of timber. Although this material is available in South Africa, its use in building construction is very limited, which is due to a large extend to the fact, that timber surfaces have an extremely short life span in the South African climate. It was therefore a prerequisite for the usage of this material to ensure that the construction should be protected both from rainfall and direct exposure to the sun.
Among the reasons for choosing timber as a material for a large portion of the construction were the advantage of prefabrication and the fact that wood can be processed with relatively little know-how and simple machines, as long as the details are well planned. The walls were prefabricated on a large worktable close to the site (Figure 5). They consist of standard-profile posts with a cladding made of 18mm plywood boards. For weight reasons, prefabricated walls were finished with one side of cladding, then transported and assembled. The timber frames were then either filled with insulation as exterior walls or with bricks as interior partitions.

Figure 5: *prefabrication and transport of timber wall*

The construction of prefabricated timber wall elements brought two main challenges: for the intended standard of insulation, it was necessary to work out details for an acceptable airtightness of the building skin. The building materials necessary for airtight joints between building components such as interior walls, windows, or doors are not available at standard building suppliers in South Africa. Thus, while it was possible to import some donated materials like special adhesive tapes, in many cases the details for joints and seams had to be developed and tested on site. A second challenge arose from the necessity to structurally link the prefabricated timber elements to the in-situ built brick wall.

Figure 6: *raising of the rafters of the roof construction*

Special steel ties, developed on site, link the posts and walls of the timber structure to the wall in a way similar to traditional masonry anchors. In this way, the necessary support of the 50 m long free standing brick wall could be ensured, at the same time using the wall for bracing the timber structure.
The single pitched roof consists of purlins and rafters spanning the width of the classrooms and of the open veranda along the South side of the rooms. The three rows of purlins running the whole length of the building are supported either on single posts or timber walls (Figure 6). Only standard South African timber profiles with a maximum width of 56 mm were used. In order to span the playroom width of 5.60 m the maximum profile size of 56x280mm proofed to weak. Therefore, simple composite beams made of two rectangular profiles were used. The roof and principal load bearing parts of the building were conceived as a free-standing construction which was to be erected independently of the brickwork. This strategy seemed necessary during the planning

phase, as the rate of completion of the bricklaying could not be calculated beforehand.

2.3.2 Adobe Bricks

The use of clay for the walls of buildings has a long tradition in the Cape Region. The raw material, clay soil, is available almost everywhere at a very low cost. Even in the village of Raithby, some traditional dwellings from the mid-20th century with clay brick walls still survived. Some years ago, in a nearby settlement of farm workers the newly established Sustainability Institute started to revive the traditional technique of making and drying bricks. They were then used for building simple but comfortable houses for the underprivileged inhabitants of the village in a self-help programme for the owners of the houses. Owing to a visit at the Sustainability Institute early in the preparation of the Raithby project, the idea to use this traditional building material was considered for the first time. The bricks used for the kindergarten in Raithby were locally made on a neighbouring farm by unemployed workers from the nearby townships. The soil for the clay mortar used in the walls came from excavation works on another a farm in the area. Since the method of mixing the clay can be described as archaic, the total fossil energy used for the adobe wall comes down to not much more than the fuel for several truckloads of bricks and soil.

Figure 7: *mixing the clay mortar*

The bricks used for this project had a size of approximately 250x380x100 mm. Each brick had a weight of about 20 kg, which made handling them rather challenging. The students worked together with a team of local bricklayers, who helped with plumbing the corners and gave instructions on laying out the bond (Figure 8). As the clay bricks are very sensitive to permanent moisture, two rows of regular fired bricks with two layers of damp course were laid out on the concrete slab as a base for the adobe wall.

Another special detail of the adobe wall is the use of wooden reinforcement boxes integrated into the bond of the brickwork (Figure 9). The construction makes use of the fact, that wood and clay have similar shrinking and swelling behaviour when exposed to a similar moisture content. This fact was also utilised in traditional building, e.g. when using clay as wall infill for historic timber-framed houses. The boxes serve as a substructure for fixing windows, connecting timber framed walls or other components, which otherwise could not be fastened to the clay bricks.

Figure 8: *students working on clay brick wall*

Again, this technique is similar to a traditional brickwork detail, where wooden pegs or dowels were driven into the brick wall in order to fasten other building parts. The detailing of the adobe wall therefore featured a number of good examples of low-tech solutions replacing complicated and expensive industrialised products.

2.4 SUSTAINABLE ENERGY CONCEPT

2.4.1 Situation and general objectives

The Western Cape Region of South Africa can be described as having a mild, mediterranean climate. Daytime temperatures in winter will usually be around 5°–10°C, but there may be a chance of lower temperatures during the night. On the other hand, the winter months are usually a season of heavy rainfalls, limiting the expected solar gains to sometimes only a few sunny days per month. Temperatures in summer can sometimes rise up to 40°C, and although there is usually natural ventilation due to the vicinity to the coast, measures to ensure comfortable indoor temperatures have to be taken. The normal standard of building in South Africa incorporates single glazing for windows, insulation of exterior walls and ceilings are extremely rare.

Figure 9: *black wooden boxes later used for fixing window frames*

Altogether, indoor temperatures in winter are generally lower than adequate for residential buildings, much less for day-care facilities for small children, making additional heating necessary for all habitable rooms. Heating systems using fossil fuels are more or less unknown in South Africa, the use of regenerative sources of energy has only recently become a matter attracting some attention on a domestic scale. The standard source of energy for space heating is electricity, generated in often out-dated coal-firing or nuclear power plants. Considering the fact, that electrical space heating has an efficiency factor of 30% or less, for a similar indoor comfort this system of electrical heating has a higher carbon footprint than space heating with fossil fuels in the cold regions of Northern Europe. At the same time, electrical heating creates a need for new nuclear powers plants, because the consumption of electrical power exceeds the capacity of the existing power stations, leading to frequent breakdowns. Nevertheless, conservation of electrical energy through thermal insulation of buildings is as yet considered dispensable. However, a growing awareness for the need to conserve energy is noticeable.

2.4.2 Integrated energy concept of the building

Even during the design process, special attention was given to an economical and considerate utilisation of natural resources and energy both for the construction of the building and for its later use and operation.

Two strategies were pursued in an attempt to make this project a prototype for similar buildings of its kind in the Cape Region: The first was to make use of the abundant supply of solar radiation available in the region for a sustainable system of space heating, laid out to service the four play rooms mainly used by the children during the day. This system and its components will be described in the subsequent chapter.

An active room heating system can only be energy efficient within a building having sufficiently insulated peripheral walls and roof. The second strategy, therefore, included both the layout and orientation of the building, size and location of openings and the design of a well insulated outer building skin. These integrated measures aim at ensuring comfortable indoor conditions during the summer and winter months.

Figure 10: *exterior timber framed wall with insulation*

The surrounding surfaces of all rooms serviced by the central heating system consist of the concrete floor slab, the adobe wall, timber framed partitions and exterior walls, and the roof construction.

The surrounding clay wall with a thickness of 250 mm and an inner and outer layer of lime plaster was calculated to have the U-value of about 1.90 W/m^2K (the clay bricks have a density of about 1900 kg/m^3 and a λ= 0,5-1,4 depending on the raw material used). This solid wall is the least insulated surface of the rooms, but makes up only about a quarter of the surrounding wall area. It runs along the North side of these rooms (which in the Southern hemisphere is exposed to direct radiation from the sun). Therefore, while also taking into account the technological difficulties associated with composite external insulation systems, it was decided to leave the brick walls free of insulation even though it offers much lower U-values than could perhaps be desirable.

Figure 11: *roof during construction with insulation and permeable under-tile membrane*

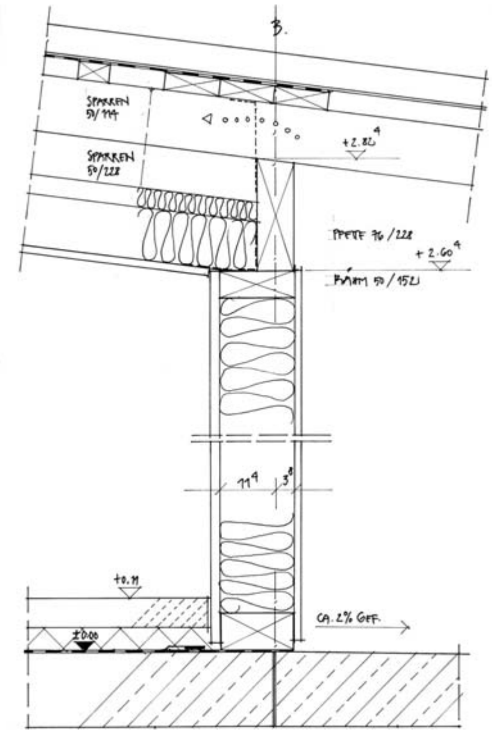

Figure 12: *section through timber wall and roof construction*

Figure 13: *show-case window with low set casement in the South facade (photograph: M.Hall, Cape Town))*

As a compensation, all other exterior walls were insulated at a much higher standard than is usual in South Africa. Mineral wool, chosen for the fact that it is incombustible, with a thickness of 140mm was used as filling for the timber walls as well as between the rafters of the roof construction (Figure 10,11). The roof was planned as a ventilated construction, both to ensure the evacuation of humidity from the insulation layer, and to reduce overheating of the construction during the summer. The 7° pitch and the orientation toward the prevailing wind direction facilitate a natural airflow underneath the roof sheeting of corrugated fibre cement.

On the concrete slab, screed floors were laid on a layer of EPS as thermal insulation for the under floor heating. Nevertheless, the screed with a thickness of 70 mm serves as thermal mass during the summer. By filling the interior partitions with adobe bricks, additional thermal mass was brought to the light-weight structure, helping to balance the indoor climate during the summer months.

Decisions on window size, as well as their orientation and position, were also made deliberately to reduce solar gains and to avoid complicated sun-screens, as it has been found in previous projects that users rarely use adjustable shading devices.

Each playroom has two high windows in the North façade, large enough to give natural light, but limited in their size by the amount of solar radiation which was calculated to be tolerable during the summer. In addition, each room has a large showcase window facing the veranda in the South, and shaded by the roof. On this side, the generous size of the opening permits visual contact between the room and its fore-zone (Figure 13).

Additional sunscreens are not necessary. The shape of the respective window types allowed for a casement low above the ground in the South and an opening above head height in the North wall. This arrangement, together with the sloping ceiling of the rooms and prevailing winds from the South or South East, ensures an effective night ventilation of the rooms during the summer months. The glazing of the windows of heated rooms is a locally manufactured insulation glass. The panes have a U-value of 2,7 W/m^2K (according to the manufacturer's specification). Although glazing of a higher quality may have been available, this would have been an imported product. It was, however, one of the stated goals of the project to show that a building skin of comparatively high quality can be achieved using only local standard building parts.

2.4.3 Solar Heating System

As a special feature the building was equipped with a solar heating system. It consist of solar panels on the North wall (Figure 14), which heat water in a large storage tank. The tank is a standard 5000l water tank which was well insulated to serve as a seasonal store. Four separate heating circuits supply each of the four playrooms with under floor heating. The whole system is laid out with as few components as possible to minimise the risk of technical failures and to make it easy to operate and control. Expected solar gains, the energy demand of the rooms, and the materialisation of the building skin were calculated and adjusted in a simulation process accompanying the building design.

The large area of the playroom floors was found to be the most suitable surface for heating the rooms, as it allowed for very low flow temperatures, fully utilising the heat available in the storage tank. The floors are also frequently used for playing or sleeping by the children,

Figure 14: *solar panels on North facade*

who will benefit from the comfortable surface temperature of the heated floors, even if the system does not yield enough energy to substantially increase the air temperature on certain days. These advantages outweighed some disadvantages of the underfloor system, like the limited accessibility of the pipes for maintenance or repair.

In order to verify predictions made concerning the operation of the system as a whole, as well as temperatures and humidity in the rooms, several data loggers have been installed. The first results for evaluation are expected by midyear of 2010.

Figure 15: *interior of one of the play rooms (photograph: M.Hall, Cape Town)*

3 RELEVANCE FOR UNIVERSITY EDUCATION

3.1 INTERDISCIPLINARITY

3.1.1 The students' starting position

Over the past few years, interdisciplinary design projects have become a particularity in the choice of studio projects offered at the Faculty of Architecture at the Technische Universität München. Students of Civil Engineering can chose to work on these projects as an elective in their final year. When they first start working together, the students have acquired a reasonable amount of professional knowledge and are trained to solve complicated assignments from their own field. Most of them, however, have not had an opportunity to put their capability and knowledge to the test by discussing them within a planning process.

3.1.2 An approach similar to professional reality

In their professional careers, both architects and civil engineers have a constant need to communicate with other professionals. This requires not only an ability to use correct technical terminology, but also to put one's own consideration into the greater context of the overall planning process. Working in a group requires a high degree of collaboration but also the ability to come to individual decisions and act independently and without instruction. Individual results become prerequisites for the work of others, the outcome of the team's planning efforts has to be presented as a common solution.

3.2 SPECIAL CASE OF DESIGN AND BUILD

3.2.1 Outline and procedure of design-build-projects

Design-and-build projects incorporate a limitation to the size and the level of sophistication of the structures which will be their outcome. On condition that the same group of students should be involved in the planning and the construction of the building, there can only be an overall schedule of not more than one year for the whole project from university studio to realisation on site. In some cases, as in the project shown here, this schedule is even tighter. In addition, the voluntary construction time of the students is limited to a few weeks, their practical skills usually restricted to basic procedures.

A spontaneous planning process, taking place while construction is already under way, is part of the concept followed in this kind project. It is necessary to allow for some uncertainties like the quality and availability of building materials, delivery times, unpredictable weather conditions and so on. While these problems tend to put a serious strain on everyone in the team, they are nevertheless very similar to the challenges of a real planning and building process, where it is an essential part of the engineers work to find solutions to unpredicted questions. So called full-scale projects include the substance of theoretical research and practical experiment in a field, where both are otherwise difficult to bring together.

3.2.2 Connecting virtual planning to actual results

It may be argued, that architects and engineers do not need to be trained as craftsmen in order to understand the theoretical principles of sophisticated calculations and planning processes. However, both architects and civil engineers work in a field where, even today, manufacturing and assembling of components require manual labour and craftsmanship. An understanding of the effort necessary to put together a building from raw materials will be a helpful experience for future planning. Unlike in an industrial placement where a supervisor or instructor takes responsibility, in this project they had to rely on their own judgement.

Figure 16: *students discussing the building plan*

One of the general attitudes in the building sector today is the idea, that industry offers a solution to almost every technical problem imaginable.

The creative skill of designing the necessary details for joining together the parts of a building, according to ones own artistic intention but without neglecting the technical and physical necessities, is one of the essential abilities of the planning profession. Therefore, design-build-projects, working with an extremely reduced availability of industrial products, will support this skill of individual detailing.

3.3 THE IMPORTANCE OF COOPERATION

The success of the whole project depended on cooperation: cooperation within the design teams, within the student group on site, but also cooperation with the responsible authorities, with the neighbours in the village and definitely with the local workers.
For a student project, a cooperation with the local universities was indispensable. Through the support of lecturers from two of the large universities in the area, it was possible to present the project both at the Civil Engineering Department at the University of Stellenbosch, and at the School of Architecture of the University of Cape Town. Students from Stellenbosch came for a site visit to Raithby (Figure 17), students from Munich went on a day trip to see the future site of a UCT project in a township near Cape Town. South African Universities were found to have a great interest in this kind of project, which have an even greater social relevance for the local students than for their colleagues from Europe.

Figure 17: *students from the University of Stellenbosch visiting the site in Raithby*

4 CONCLUSIONS

Design-build projects provide a lot of practical knowledge on building materials and the significance of construction and detailing. Decisions made during the earlier design process can be evaluated in the making of the building. These projects provide a much deeper understanding of a number of relevant issues than the purely theoretical approach of conventional university education can offer. But even as the responsibility of planners reaches beyond finding technical solutions, in underprivileged regions these projects include a consideration of the social and humanitarian needs of users and try to give an example of a reproducible approach to sustainable architecture.

Figure 18: *children take possession of the finished building (photograph: M.Hall, Cape Town)*

The projects are therefore not so much an act of development aid. Their aim is rather to create a win-win situation on both sides: While the future users receive an urgently needed new structure, students and teachers benefit greatly from the project work by their gain of exceptional and valuable experience of spending time in a foreign cultural context The great effort necessary for the preparation and realisation of such projects is therefore justified by an equally important and extraordinary objective: Teaching architects and engineers responsibility for the built environment and a sustainable development.

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