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1. Enviromental Performance of an Australian Remote Regional Health Clinic Based on Instrumental Monitoring

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Author: Van Stephan "Steve" Burroughs, pp. 1-9

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2. Reconstruction and Rebuilding of Bridges in the Czech Republic

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Author: Květoslav Rušar, Jaromír Rušar, pp. 10-27

Abstract: The article is focused on the experiences with rehabilitation of brick, concrete and steel road bridge constructions, both of the superstuctures and the supporting structures (abutments and piers). The paper discusses the entire epoch of bridge constructions from the last century to these days. In the Czech Republic, there are also historic bridges over 300 years old. Additionally, with use of examples supported by photos, all basic rehabilitation methods are described, including demolition and full replacement of the original structures in cases when all possible corrective methods are exhausted. Special approaches to objects subjected to historic preservation or cases of urgent interventions in emergency situations are detected as unusual situations.

3. The Use of Regular and Irregular Polyhedra in Architectural Design

DOI: 10.15341/mese(2470-4180)/01.02.2022/003

Author: Ana-Maria Graur, Carmen Mârza, Georgiana Corsiuc, pp. 28-36

Abstract: With the advent of the computer are dramatically influenced, both the shape and materialization of architecture, and of course the representation in architectural design. New trends, theories and styles appear in the architecture produced by digital. A new language of architectural forms, the so-called free forms, makes its presence felt in the built environment. The relationship between the shape of these free volumes and simple geometric volumes represents an evolution whose result is the change of the architectural paradigm towards a digital architecture. At the base of this new architecture is geometry, with its primary volumes. In this paper we want an inventory of buildings that use irregular and regular polyhedra as geometry. These polyhedral volumes allow modularity and repetitiveness, and this process can be extended to give rise to more complex forms such as free forms. Descriptive geometry must provide basic knowledge about the creation of space, shapes and methods by which they can be represented.

4. The Role of Organizing Routine Maintenance of Central Java Provincial Roads in Reducing Poverty and the Utilization of Android Device Technology

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Author: A. R. Hanung Triyono, Agus Supriyanto, Ury Wahyu Suprihati, Anindita Rifta Hapsari, pp. 37-44

Abstract: The article is focused on the experiences with rehabilitation of brick, concrete and steel road bridge constructions, both of the superstuctures and the supporting structures (abutments and piers). The paper discusses the entire epoch of bridge constructions from the last century to these days. In the Czech Republic, there are also historic bridges over 300 years old. Additionally, with use of examples supported by photos, all basic rehabilitation methods are described, including demolition and full replacement of the original structures in cases when all possible corrective methods are exhausted. Special approaches to objects subjected to historic preservation or cases of urgent interventions in emergency situations are detected as unusual situations.

5. Possibilities of Use of Glass Recyclate From Photovoltaic Panels for Concrete Masonry Units

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Author: Michal Stehlík, Jana Knapová, pp. 45-50

Abstract: The paper deals with the possibilities of use of glass recyclate from photovoltaic panels for concrete masonry units. It compares different recipes and its physical and mechanical properties with the focus on the compressive strength, density. It then compares the values of these recipes with the values of commonly used composite materials for masonry units without recyclates. Recycling of materials from photovoltaic panels is a highly discussed topic nowadays. The paper presents possibility for secondary use of glass from these panels in building industry, namely the substitution of aggregate in concrete with glass recyclate.

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Environmental Performance of an Australian Remote Regional Health Clinic Based on Instrumental Monitoring

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Abstract: Both environmental (e.g., energy use) and human sustainability (occupant wellbeing/productivity) need to be considered in building design and operation. The challenging climatic and socioeconomic conditions in remote regions of Australia mean that achieving sustainability is difficult and costly. Currently, the energy use patterns, thermal performance, and indoor atmospheric quality (IAQ) of remote health clinic buildings are unknown, meaning that there is an information gap in the design and operation of such buildings. This paper reports the results of an investigation into the environmental performance of a clinic in the remote clinic of Numbulwar. Climate variables, energy consumption, and IAQ variables were instrumentally monitored at the clinic from April 2017 to March 2018 at 10-minute intervals, with data uploaded to a cloud database now holding 3 million values. Analysed temporal variations in the measured variables for the clinic and the relationships between them reveal the performance of the building. The results obtained provide a basis for the formulation of strategic interventions, design guidance, and further investigation, including: (i) the range of indoor atmospheric conditions needs to be narrowed to provide more consistent occupant comfort; (ii) an occupancy profile needs to be developed to determine user behaviours with respect to energy use; (iii) the heat-exhaust/aircon systems need to be reviewed for more efficient use; (iv) the cycling of air, heat, moisture, and pollutants through the building needs to be further investigated; and (v) BIM should be undertaken using the data as input to test future design solutions.

Key words: energy consumption, thermal performance, IAQ, atmospheric conditions, design solutions, building skins/facades

1. Introduction

Sustainable building practices have made significant advances in the last two decades [1]. However, a truly sustainable building addresses not only environmental impacts but also human sustainability and well-being. Environmental sustainability is the ability to maintain the qualities of the natural environment, including the processes involved in producing energy, as well as the impact of buildings and human activity on the environment. Human sustainability involves specific strategies and methods for enhancing the well-being and productivity of building occupants/users [2].

Remote parts of Australia are defined based on the physical road distance to the nearest town or service centre. Remote Australia is home to around 500,000 people or 3% of the Australian population. The remote regions of Australia have common systemic problems including persistent social and economic disadvantage and weak infrastructure. These remote-region characteristics when combined with changing climate and different energy futures result in particular challenges faced by remote-region buildings and their occupants with respect to environmental and human sustainability compared with urban areas, including generally harsher climates with greater temperature

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extremes and much higher electricity costs (up to $5/kWh versus $0.25/kWh) [3].

Climatic conditions in the remote regions of Australia are acknowledged to be harsh, characterized by extreme temperatures, wide temperature variation, and high seasonal variation in rainfall. Such conditions pose difficulties for achieving environmentally efficient buildings [4] and for establishing high levels of IAQ for sustaining human comfort and well-being. These challenges are likely to become greater, given projections of climate change (higher temperatures and general declines in precipitation) and energy requirements (increasing demand and higher prices).

Remote Australia is still highly dependent on fossil fuels for transport and for household and public service energy needs. Energy consumption is rising, and the use of air-conditioning will increase with increasing temperatures in inland Australia, which will lead to even higher demand for energy to maintain current lifestyles and to address the changing requirements of an ageing population. Energy prices are likely to continue to rise as the cost of production of fossil fuel increases, and electricity production plants will be obliged to purchase emissions permits under legislation. Renewable energy sources have low uptake in Remote Australia, with barriers including the costs of development and maintenance in remote locations, perceptions, relatively immature technology, and the distance between energy sources and markets [, 5, 6].

Remote Australia is served by a network of health clinics and associated staff. Hospitals and clinics need to generate conditions that are conducive to medical treatment and recovery by mitigating the spread of disease and improving occupant comfort, as well as allowing staff to work productively. Indoor atmospheric quality (IAQ) provides a critical foundation for meeting this target. However, strategies to enhance human health and well-being have unfortunately played a minimal role in the evolution of building standards and practices in remote communities. Further, there is a continuing drive to reduce the environmental impact of buildings, particularly with respect to energy use, as well as to reduce operational costs. Therefore, it is imperative that human health and productivity, as well as environmental quality, take centre stage in building design, function, and operation so that buildings can perform better for both people and the environment. This can be achieved through a dedicated focus on evidence-based research and the measurable performance of sustainability metrics.

2. Research Purpose and Objectives

Climatic conditions impact significantly on a building's ability to provide the necessary conditions for occupant well-being as well as on its environmental efficiency, particularly its energy consumption. Climatic conditions have changed significantly over the last century, and predictions indicate that changes will continue to occur in the near and mid-term futures. Therefore, it is important that climatic and building performance data be available not only to assist in measuring and managing energy use and IAQ in existing health clinics, but also provide a base upon which future clinics can be planned, designed, constructed, and operated. Currently, the Northern Territory Government Department of Health (NTGDoH) has no data regarding environmental sustainability (as measured through energy use) and human sustainability (as measured through IAQ) for its remote health clinics. Such data should be a valuable tool for developing strategic interventions in existing buildings and for indicating sustainable design solutions in new buildings. This study examines the energy use, thermal performance, and IAQ of the Numbulwar health clinic building based on monitored data.

The term "environmental performance" here refers to three aspects: 1) The energy use patterns of the building with particular attention to diurnal-nocturnal and seasonal patterns as well as relationships with other variables. 2) The thermal performance of the building.

This covers, in particular, the ability of the building to minimise energy consumption by reducing the need for cooling (and potentially heating, if needed) in the interior of the building. This is a function of the design of the building and the construction materials used, and the extent to which these moderate the external ambient conditions. 3) The IAQ of the building, referring to the properties of the indoor air and the associated comfort and well-being of the building's occupants with respect to these properties. In this study, this covers the temperature and humidity of the air as well as chemical and particulate pollutants. The objectives of the study are:

To establish and analyze a database of variables (indicators) measuring aspects of environmental and human sustainability by instrumental monitoring at the Numbulwar clinic;

Based on the monitoring and measurement of the chosen indicators, to inform decision-making and strategic interventions in the operation of the Numbulwar health clinic; and

To evaluate the Numbulwar clinic data with respect to understanding the operation of other existing health clinics as well as the design and construction of future health clinics.

3. Method and Data

3.1 Location

The health clinic building is located in Numbulwar in the Northern Territory (Fig. 1) and was built in early 2017. The clinic (Fig. 2) has 22 rooms in total and has a floor area of around 300 m^2, serving around 2000 people in Numbulwar. Numbulwar has a long-term average maximum temperature of 28.8°C, a dry winter season (May-September) with humidity of 20%-50% and temperature of 15-33°C, and a wet summer season (October-April) with humidity of 30%-95% and temperature of 22-35°C.

3.2 Energy Data Collection

This study involved a quantitative empirical

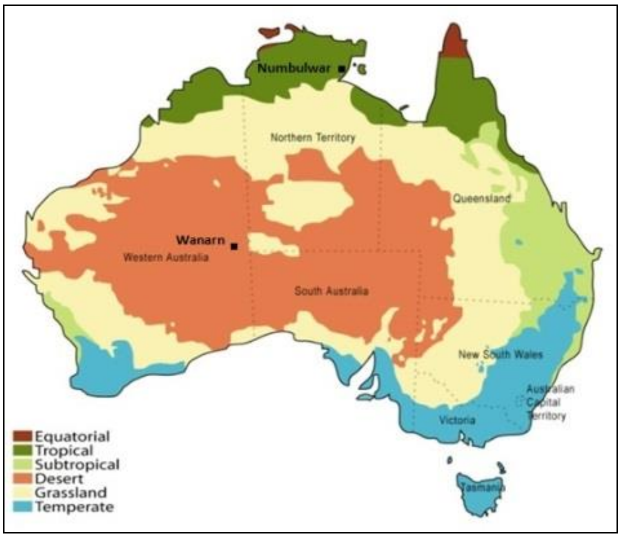

Fig. 1 Political states and climatic zones of Australia, and the location of Numbulwar.

Fig. 2 Numbulwar clinic building.

approach, with monitoring instrumentation being installed both within and outside the clinic building to continuously measure energy use, IAQ data, and external climatic data for a 12-month period. Analysis of these quantitative data provides an account of the temporal variation in the selected environmental and human sustainability indicators as well as of the relationships between the indicators.

The clinic building had been constructed by 1 April 2017 but was unoccupied and non-operational prior to mid-September 2017. In mid-September, the clinic started its operational phase with staff and equipment being used for the usual duties and functions performed by a health clinic. As the measurements made cover both the pre-occupancy and post-occupancy phases of the Numbulwar clinic building, the data from each phase contribute different insights into the environmental and human sustainability of the building, as well as indicating comparative differences between the two phases.

A suite of 24-hour electronic monitoring equipment was set up to record climatic, energy consumption, and IAQ data for the Numbulwar clinic for a period of 12 months. The monitoring equipment was installed in late March 2017. The monitoring devices were installed in various rooms/corridors inside the building as well as inside the ceiling/roof-space cavity. Devices were also installed on the eastern and northern external walls of the building. An energy consumption meter was installed on the switchboard. Once installed, data were uploaded continuously at 10-minute intervals via the Telstra network to a cloud-based platform, from which data could be accessed via a secure portal either live or as downloads. The following data were collected from April 2017 to 31 March 2018: Climate (external) variables — temperature and humidity; total building energy consumption; and IAQ variables — temperature, humidity, and airborne chemicals and particulates.

The 12-month database contains around 2,880,000 values. The database was first inspected thoroughly for data consistency and quality. A number of periods were discovered during which data were not recorded because of transmittance or other disruption (accounting for < 0.1% of the total data).

4. Selected Results and Findings

Selected graphs (with data frequency of 10 mins) are presented that summarize some of the key variables and data trends for the clinic building, with accompanying results, interpretations, and findings.

4.1 Local Climate

External temperature and humidity values reflect the tropical location of the Numbulwar clinic. Day-time temperatures generally exceeded 35°C and sometimes 40°C (Fig. 3). Maximum temperature variations were observed in April-May and December-March. Minimum (night-time) temperatures were most variable between April and September (17.5-28°C) and more stable (~25°C) between October and March. Monthly mean temperatures were lower from June to September compared with the other months, with the range being 26.7°C in June to 31.0°C in December. A typical diurnal cycle during December sees temperature starting to increase from its night-time level at about 06:00, reaching its maximum typically between 11:30 and 13:00, from which time it slowly decreases during the later afternoon, evening, and night-time to reach a short stasis period at ~05:00.

Humidity values varied from 25.9% to 97.5% during the 12-month study period (Fig. 4). Maximum humidity levels are closely controlled by temperature, with maximum humidy values of 45% at 40°C and 95% at 27°C. On a diurnal scale, humidity was highest during the night-time. In December, for example, humidity peaked at ~04:30-06:00 (e.g., 90%) and then reduced to reach a minimum at ~11:30 to 13:00 (e.g., 35%), following which it rose through the afternoon, evening, and night to reach its next peak at the same time the next morning.

4.2 Energy Consumption of the Building

On As a result of the external temperature variation, energy consumptions associated with air-conditioning are higher during the months of October to May and lower from June to September (Fig. 5). Day-time temperatures have a major influence on the energy consumption of HVAC units, with higher external temperatures causing higher energy consumptions because of the greater differential between indoor and outdoor temperature. This is shown, for example, by the higher energy consumptions recorded for higher outside temperatures in maintaining a constant indoor temperature (Fig. 6).

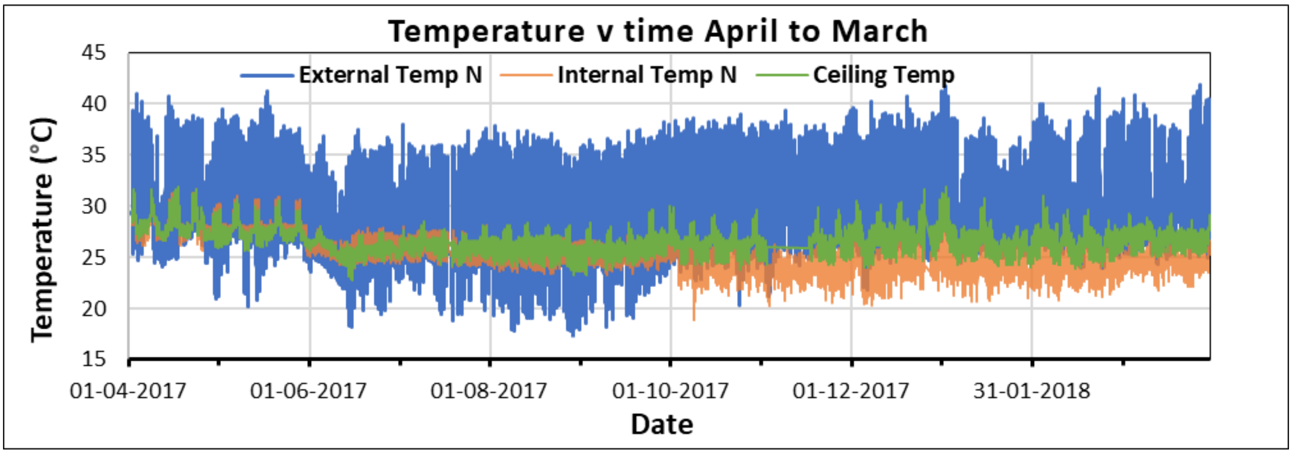

Fig. 3 **Temporal variation in external and internal temperatures (northern part of the building) and in ceiling-space temperature of the clinic from 1 April 2017 to 31 March 2018.**

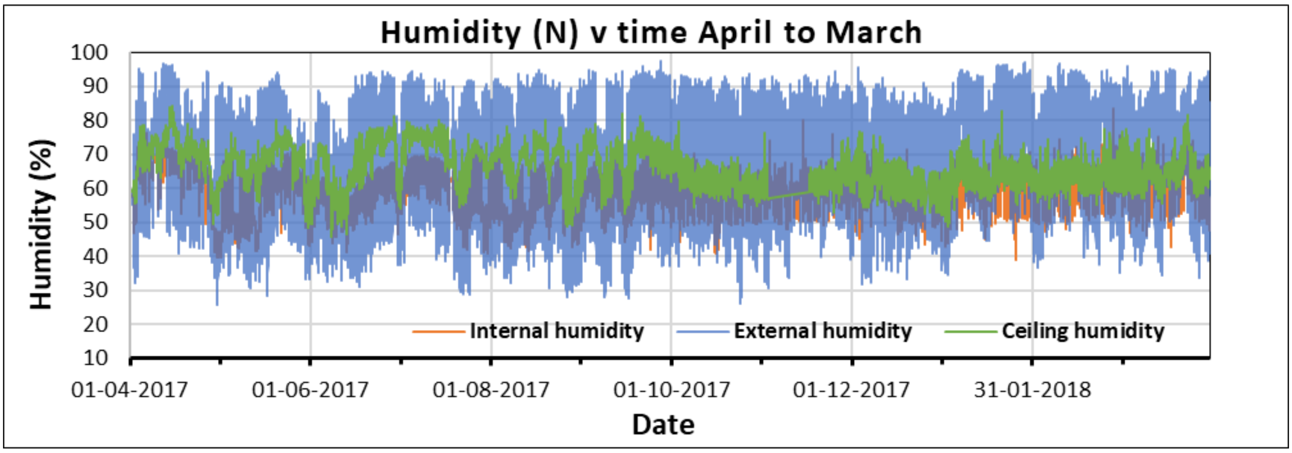

Fig. 4 **Temporal variations in external and internal humidity (northern part of the building) and ceiling/roof-space humidity for the clinic 1 April 2017 to 31 March 2018.**

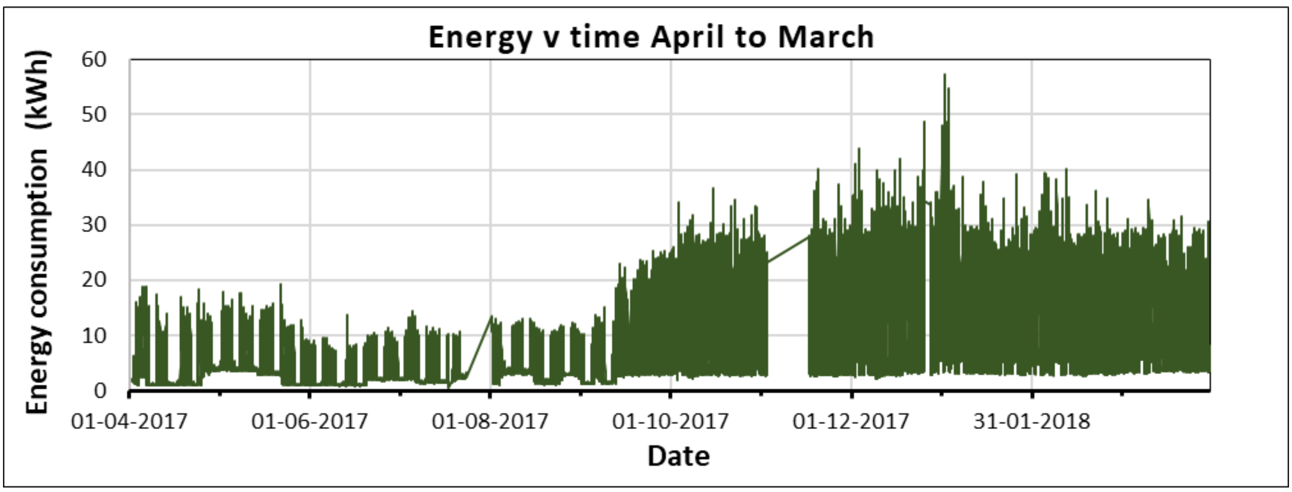

Fig. 5 **Clinic energy consumption for the period 1 April 2017 to 31 March 2018 (kWh measured over hourly intervals).**

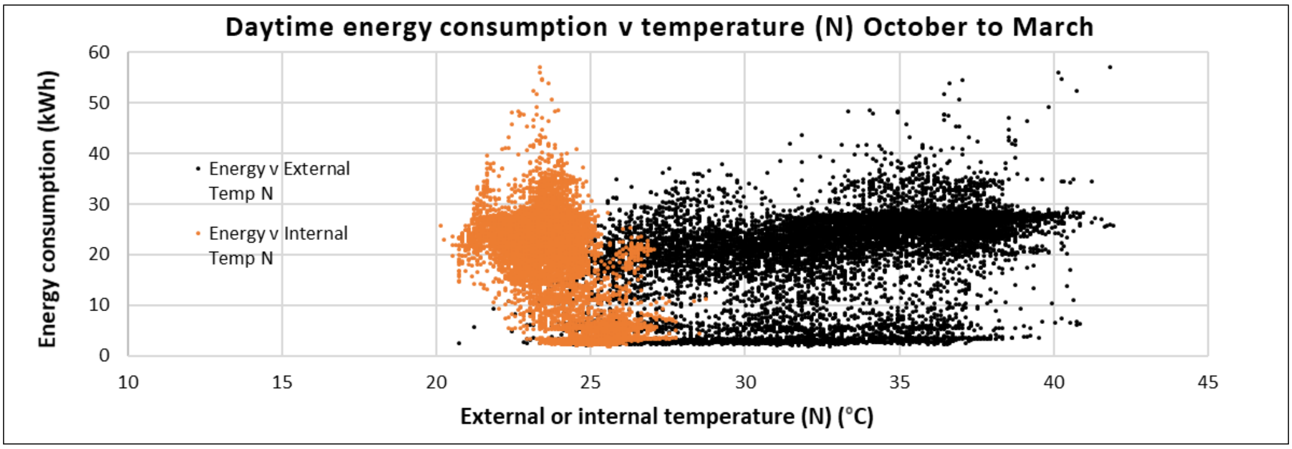

Fig. 6 Clinic energy consumption versus external and internal temperature for the northern side of the building from 1 October 2017 to 31 March 2018 (energy in kWh measured over hourly intervals).

Despite the broad relationships observed between energy consumption, external temperature, and internal temperature, there is a large amount of scatter in the data (Fig. 6). The very wide range of external temperatures associated with the corresponding internal temperature range for the same energy consumption level, and the very wide range of energy consumptions associated with maintaining the internal temperature at 21-25.5°C, suggest that there is potential for efficiencies to be made in the operation of the HVAC and heat exhaust systems of the clinic building and for an investigation to be made into human activity and behaviour in the clinic regarding the generation of heat and moisture.

From mid-September, the clinic building became occupied and operational, with total daily energy consumption increasing from that point. September was a transitional month for the clinic, marking the start of occupancy/operation and the associated adjustments in building mechanical and electrical systems, including HVAC. Therefore, the period October-March best represents normal occupancy and building use. For this period, for energy consumptions of < 8 kWh per hour (at which level it is assumed that HVAC is not running), there is a horizontal band of data for which external temperatures up to ~40°C are associated with internal temperatures of 22.5-27°C (Fig. 6). The horizontal band represents times before ~09:30 and after 15:00 during some weekends when a reasonable internal temperature range was maintained in the building without the use of HVAC. On these weekends, the clinic was open for shorter times and HVAC was being run only between ~09:30 and 15:00.

The October-March data show a positively sloped band of external temperature data, extending from energy consumptions of ~18 kWh per hour and temperatures of ~25°C to consumptions of ~28 kWh per hour and temperatures of ~40°C (Fig. 6). This band covers a range of internal temperatures from ~21 to ~27°C with most between 21 and 25.5°C. Assuming that the variation in energy consumption above 8 kWh is due mainly to HVAC operation, then for every 3°C rise in the external temperature, an additional 2 kWh per hour is needed to maintain the observed range in internal temperature.

Data scatter means that there is a very broad range of external temperatures associated with the corresponding internal temperature range for the same energy consumption level. For example, high energy consumptions of ~25 kWh per hour occur for external temperatures of between 25 and 40°C. In addition, energy consumptions of 10-55 kWh per hour are associated with maintaining the internal temperature at 21-25.5°C, although most of the data lie within the 15-35 kWh range. The scatter may be due to inefficiencies in the HVAC system or variations in occupant behaviour and equipment use.

4.3 Thermal Performance of the Building

Inferences about the thermal performance of the building and the effectiveness of the building skin can be made by investigating temperature characteristics when the building is unoccupied, the HVAC system is not running, and the weather is hot and sunny. The energy use pattern during the operational period from mid-September onwards indicates that the HVAC system was running every day during the daytime. However, the period prior to mid-September, while the building was unoccupied and non-operational, contained several weekends where HVAC was clearly not running. For one such weekend in June (Fig. 7), the 24-hour variation in external temperature of ~10°C is reflected by a variation in ceiling/roof-space temperature of ~1°C (with the peak temperature lagged by ~3.5 hours) and by a variation in indoor temperature of ~2°C (peak temperature lagged by ~4 hours). For a similar period in early September, the variation in external temperature is ~16°C, in ceiling/roof-space temperature is ~3.5°C, and in internal room temperature is ~2.5°C. The peak temperature lag time is the same as the June data, ~3.5-4 hours for both ceiling/roof-space temperature and internal room temperature.

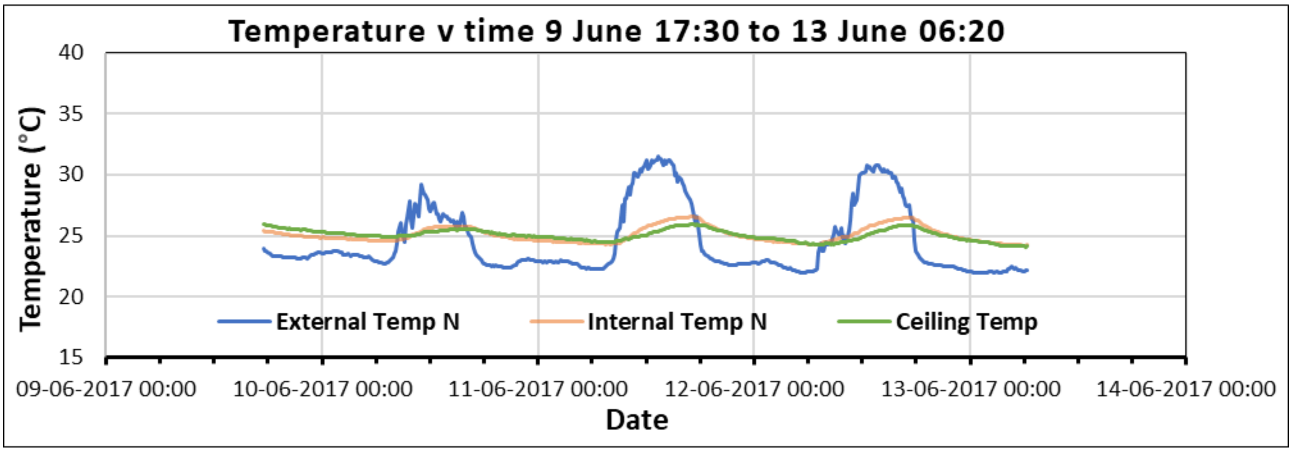

Fig. 7 Variation in external and internal temperature (northern part of building) and in ceiling/roof-space temperature for the clinic for 9-13 June, during which the building was unoccupied and no air-conditioning or other mechanical/electrical systems were operating (apart from fridges/freezers and night lighting).

On the above basis, the building skin and thermal envelope of the Numbulwar clinic seem effective at dampening solar gain and conduction of heat into the building from the outside. The ceiling/roof-space performs particularly well, given that it is the part of the building that is most exposed to direct sunlight. The daily increase in external temperature from its night-time value is typically ~15°C for most of the year, and the typical rise in building indoor temperature (unoccupied, no HVAC) during the daytime is determined to be ~2°C and the rise in ceiling/roof-space temperature ~2.5-3.5°C.

4.4 Indoor Atmospheric Quality of the Building

4.4.1 Internal Temperature

The internal (indoor) temperature in the northern part of the building shows three distinct periods between April 2017 and March 2018 (Fig. 3). During April and May, the temperature was quite variable, ranging between 26 and 32°C with a mean of 28.0°C. This is interpreted as representing testing of the HVAC system or minor works occurring in the building. At the beginning of June, the internal temperature dropped, probably as a result of a manual adjustment to the air-conditioning thermostat. From 3 October, the internal temperature dropped and became more variable, ranging between 19 and 28°C from then until the end of March, although more generally between

20.5 and 26.5°C, and with a mean of 24.2°C. This drop is presumed to be an adjustment to the thermostat control of the air-conditioning system at the beginning of the occupied/operational period of the clinic.

Consistent temperature differences exist between indoor locations through the operational months of October–March. In March, for example, the day-time temperatures in the waiting room were ~2°C cooler than those in the northern consulting room, which in turn were ~2.5°C cooler than the corridor area in the central-west part of the building. This may indicate variable airflows, variable distances from HVAC vents, and/or zoned control of air conditioning throughout the building.

The indoor air temperature range that meets ASHRAE 55:2013 "Thermal Environmental Conditions for Human Occupancy" standards is 21.0 to 24.9°C (the range in which 90% of occupants feel fairly comfortable). For daytime (06:00 to 18:00) hours, the clinic's internal temperature for October–March varied between 20.1 and 28.7°C but more usually between 21.0 and 26.5°C, with a mean of 23.4°C. The minimum and mean temperatures appear to be acceptable, but ~10% of the data exceed 24.9°C.

4.4.2 Internal Humidity

The internal humidity in the northern part of the building varied from 39% to 83% between April 2017 and March 2018 (Fig. 4). The humidity behaviour from late September to the end of March (building occupied) is characterized by high shorter-term variability but with fairly stable moving-mean-value trends. Day-time data for October-March (Fig. 8) show that internal temperatures of ~21°C are associated with humidity values of ~65% to 70%. The range in humidity for a particular temperature increases with increasing temperature until a temperature of ~23°C is reached, with the lower bound for humidity decreasing from ~65% to ~40% as temperature increases from ~21°C to ~25°C. Temperatures of 22-26°C are associated with a wide humidity range, from 40% to 75%. Day-time humidity for October–March ranged mainly from 45% to 75% (mean 59.9%).

Temperature and humidity are important IAQ metrics of a building as they largely determine the physical comfort of an occupant. It is generally regarded that the optimum humidity range for human comfort is 35%-65%, which, if applied to the Numbulwar clinic, would mean that around 15% of the day-time humidity values are too high. ASHRAE thermal environmental conditions for human occupancy show that if the humidity is 60%, then a suitable temperature range is 23-25.5°C and if it is 30% then a suitable temperature range is 24.5-28°C. The clinic's temperature–humidity value distribution includes this former value range (Fig. 8) but has considerable amounts of data outside it.

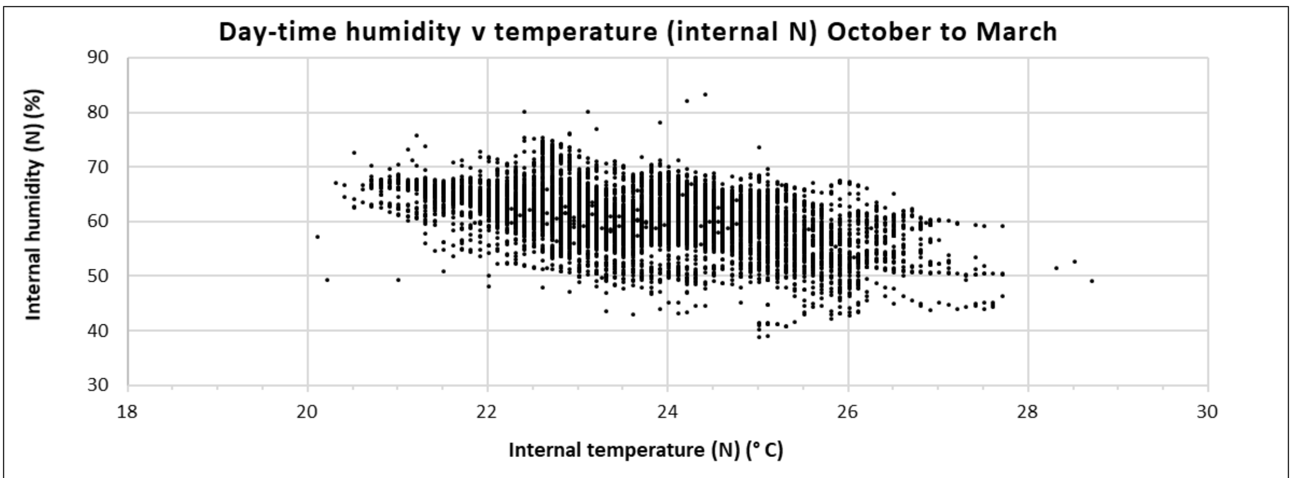

Fig. 8 Internal humidity versus internal temperature during the day-time for 1 October 2017 to 31 March 2018.

5. Conclusion

This study monitored external climate variables, energy consumption, and IAQ variables for a health clinic building in the remote community of Numbulwar, producing ~2.9 million data over a 12-month period. It is the first case where a suite of sustainability variables has been measured over such a time-frame for a healthcare facility in Australia.

An analysis of temporal variations in the monitored data, including at the diurnal and seasonal scales, as well as differences between the non-operational and operational phases of the clinic, has allowed inferences to be made regarding building energy use patterns, thermal performance, and IAQ. Relationships between climatic variables, energy consumption, and IAQ metrics highlight where interventions might be made to optimise the building systems as well as showing where further investigation would be most beneficial.

Strategic interventions and further investigation include: (i) the range of indoor atmospheric conditions needs to be narrowed to provide more consistent occupant comfort; (ii) an occupancy profile needs to be developed to determine user behaviours with respect to energy use and other aspects [7]; (iii) the heat exhaust and air conditioning systems need to be reviewed for more efficient use; (iv) the cycling of air, heat, moisture, and possible pollutants through the building needs to be further investigated; and (v) BIM should be undertaken using the data as input to test design solutions and discover which design features of the current clinic are contributing most to building performance [8]. As part of a wider ongoing investigation, these results will help to develop key clinic building performance indicators, inform improvements in the energy-use efficiency, thermal performance, and IAQ of remote clinics, and optimize future building design solutions buildings via BIM simulations to optimize sustainability with respect to climate, environmental performance, and occupant well-being.

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Reconstruction and Rebuilding of Bridges in the Czech Republic

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Abstract: The article is focused on the experiences with rehabilitation of brick, concrete and steel road bridge constructions, both of the superstuctures and the supporting structures (abutments and piers). The paper discusses the entire epoch of bridge constructions from the last century to these days. In the Czech Republic, there are also historic bridges over 300 years old. Additionally, with use of examples supported by photos, all basic rehabilitation methods are described, including demolition and full replacement of the original structures in cases when all possible corrective methods are exhausted. Special approaches to objects subjected to historic preservation or cases of urgent interventions in emergency situations are detected as unusual situations.

Key words: repair, injection, prestressing, external reinforcement, masonry, reinforced and prestressed concrete and steel

1. Introduction

The bridge object is a part of a road, railway or any line generally in conflict with a natural or artificial obstacle, with which it is not possible to level contact, crossing, ford, etc. According to valid standards and regulations (EN, ČSN EN, ČSN ISO, TKP, TP, VL4), bridges are designed to ensure their required load-bearing capacity, serviceability and service life. It all depends on the structural design of the bridge and the details, the materials used and their quality, protection in aggressive environments and maintenance. Changes in the method of use (size and repetition of loads) also have an effect. The service life of individual parts of the bridge and the materials used varies according to the method of stress and the influence of the environment. In the periods of life (durability) of the materials used, it is necessary to plan their reconstruction, repair or rebuilding in a broader sense, including total demolition and construction of a new structure. Statistics of the Ministry of Transport of the Czech Republic and regions state warning numbers of bridges, the condition of which is classified as poor to emergency, their usability of road safety and pedestrian safety is reduced, or they are obsolete due to their spatial arrangement. A brief overview of methods and possibilities in reconstructions is the subject of this paper. It will be road bridges. Due to the real length of the written part in this poster, we tried to balance the scope of the textual and pictorial part. Even so, there was an effort to cover the full range of types of structures.

2. Stone Substructures

These structures were established in the 19th century until about the 1920s, and this gives an insight into their construction. It is therefore a quarry stone or burnt bricks built on a mortar of hydraulic lime. The back was mostly provided with only clay insulation. Over time, the insulation and mortar of the joints were washed away. Historically, 2 new load-bearing structures were then built on these abutments, so that it is not necessary to demolish the entire bridge structure regarding the bridge as a whole (see Figs. 1, 2). One of the repair options appears to be the injection of

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masonry with cement-modified mortar, supplemented by a gel waterproofing system of thickness up to 20 mm. Cement grouting is done with a pressure of up to 0.4 MPa after drilling the masonry to a depth of about 2/3. Both the masonry and part of the backfill are then injected. Gel injection is expensive, so it is done secondarily. After a year or two, it can be restored locally in places of possible leaks (it is expected that it is a part of the technology because no one can see on the back of the support). Grouting is an effective and often the only method enabling the remediation of failures of stone structures with a vision of their preservation. However, it is always necessary to choose a suitable grouting technology and material so that the conditions of compatibility with existing materials of stone construction are met. Fig. 3 is an example of a stone abutment during (after) grouting with an example of grouting packers.

Fig. 1 Stone abutment, reinforced concrete beam.

Fig. 2 Stone abutment, slab superstructure.

Fig. 3 Grouted support, grouting packers.

3. Brick Vaults

These structures were also set up in the years mentioned above. The reason for their preservation may be, among other things, historical value. Repair methods may vary. In case of not backfilling the backfill (it is compacted, the damage is removed, it has become a part of the structure for years), it is possible to perform grouting, see above. When expanding, it is possible to lay the reinforced concrete slab, placed on the front walls and backfill. The board, its waterproofing system, as well as the bridge superstructure and safety devices are the same as on the bridge with the new deck. Such a bridge then meets the width parameters, proportional to the importance of the road (see Figs. 4-6).

Another method of remediation of the vault consists in excavation of the embankment, execution of the composite reinforced concrete shell, its insulation including the back of the front walls with classic

Fig. 4 Grouting and jointing of the vault.

Fig. 5 Cantilever shape of the unloding slab, extending the bridge.

Fig. 6 View of the extended bridge.

cardboard or sprayed waterproofing membrane, extension of the vault including the concrete wall in the face of the front walls and prestressing with transverse cables of Monostrand type. Such a remediation method has been tried many times and successfully applied (Figs. 7-9).

Fig. 7 Bridge before reconstruction

Fig. 8 Transverse prestressing cables.

Fig. 9 Bridge after reconstruction.

A separate chapter is listed bridges, where it is necessary to make a compromise between a purely technocratic solution, based more or less on departmental regulations (standards, TKP…) and the conditions of conservationists who want to repair the bridge so that its final appearance best copies the original historical form. Example - bridge ev.č. 19-079 in the village Olešná. It was allowed to widen the bridge, but in such a way that the front motif, including the marked arches, had to be preserved. A bituminous roadway was allowed, but the sidewalks, including the railings, and the statues had to be original (Figs. 10-12).

The bridge of registration number 37-048 Žďár nad Sázavou. The bridge was hit by long-term leakage into superstructure, degradation of the upper parties, including handrails and curbs, the front walls of the wings were very inclined. Grouting was carried out, the bridge superstructure was replaced, including stonemasonly designed new front walls and railings made by an artistic blacksmith. The curbs and cornice is made of stone. The carriage on the 1st class road was allowed as a classic bitumen. Details are illustrated in Figs. 13-15.

The bridge of registration number 351-011 in front of the town of Polná. It is a brick vault. The aim of the repair was to restore waterproofing system of the bridge, restore the original lime plaster and sidewalks paved with a small stone cube. The bitumen carriageway was restored on the bridge. The

Fig. 10 Bridge before repair.

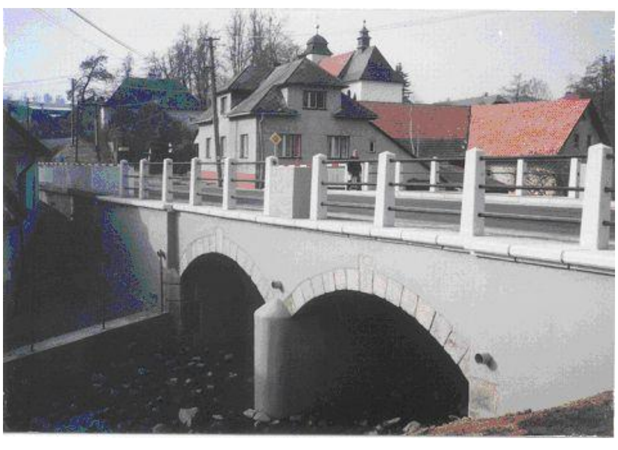

Fig. 11 View of the forehead after repair.

Fig. 12 View after rebuilding.

Fig. 13 Detail of the bridge upper before repair.

Fig. 14 New railing.

Fig. 15 Restored forehead without statues.

function of the railing is formed by parapet walls. Their small, abnormal height was maintained. The top of the walls was provided with the original stone slabs or their replicas (Figs. 16-18).

4. Delay of the Heel of the Brick Vault After Its Partial Destruction

The bridge has one field, the supperstructure is a brick elliptical arch, which in the lower part passes into a short stone support and foundation. The thickness of the brick part is 750 mm, the bricks are fired, lined with lime mortar. The carriageway is bituminous, its thickness, including the embankment in the upper part of the vault, is 720 mm. In a period of weeks, there was a fatal defect at the foot of the brick part, where water flowed down the back of the front wall (mortar leaching) and due to frost cycles, the front wall moved with the vaulted belt lower. It was at this place that the cavern appeared, in view of the length of 1.8 and the height of 1.50 m, it stretched in the transverse direction to a distance of about 1 m, where the related fault of 0.9×0.7 m appeared, this time only up to 2/3 of the vault thickness. As a result, there was a local collapse of the front wall (see Fig. 19). Apparently the activation of the arched effect of the wall strip above the cavern did not destroy the entire vault. It was necessary to immediately support the vault in place of the cavern by using hydraulic jacks (to replace the effect of the missing strutting effect of heel of the vault. Then the cavern was concreted with self-compacting concrete and the front of the vault was repaired so that the original defect is almost invisible (see Fig. 20).

Fig. 16 Front view before repair.

Fig. 17 Forehead with new plaster.

Fig. 18 View of the carriageway.

5. Provisional Solution to the Emergency Condition of the Brick Vault

The original bridge was to be removed and a new bridge was designed, but this one has not yet been built

Fig. 19 View of the inlet after the accident.

Fig. 20 The same place after repair.

due to obstructions during the issuance of a building permit, affected by a sudden fatal accident. Within two days, part of the front wall of the vault was destroyed, creating a cavern in the roadway. The bridge is on a heavily congested road II. class. The bridge was partially closed for several days, formwork was made for a concrete seal, which extends to the level of the road. The formwork was made of wood and is pulled together in the transverse direction by steel rods, guided under the vault and in the grooves of the bituminous roadway. This temporary condition was supposed to last a maximum of months, but it lasted several years!!

Fig. 21 View of the cavern before the repair.

Fig. 22 Same place after repair.

Fig. 23 View of the anchorage on the opposite (transverse) side of the bridge.

Fig. 24 Detail of the drawbar.

6. Repairs of Bridges by Inserting A Flexible Steel Corrugated Pipe of the Multi-Plate Type

Within a day, a bridge with stone abutments and a reinforced concrete girder collapsed. Behind the nicely paired faces of the abutments was a discontinuous mixture of sand, clay, and the original stones of the abutment. Before the accident, the worker performing the main inspections of bridges (in the Czech Republic it is a relatively advanced system of regular inspections) would mark the condition of the bridge as good - III (there are seven levels of bridge condition, I is perfect, VII emergency condition). Immediately, the formwork and wooden temporary supports were spread, which replaced the support under the superstructure of the bridge. A temporary bridge and corresponding traffic signs were installed on the road across the crashed part. It was decided to mount a flexible steel corrugated pipe of the Multi-plate type in the axis of the bridge between the temporary stabilized abutments. After the installation of the culvert, the upper structure and side walls were demolished. The bottom of the stream in the pipe of the bridge was paved and the stone paving was finished with transverse concrete thresholds (when inspecting bridges, we often witness the water flowing under the culvert under the tube). The bridge is registered as an overflowing structure. The condition after the accident, during assembly and the finished bridge are shown in Figs. 25-28.

Fig. 25 View of the abutment after the accident.

Fig. 26 Temporary steel bridge of span 11 m.

Fig. 27 Inserting the flexible tube into the bridge opening.

Fig. 28 Completed bridge.

In the case of a very overfilled brick bridge with emergency wings and a bad brick vault, the vault was left, the Multi-plate tube was inserted into it, the top of the side walls was partially demolished. The gap between the original and the new steel corrugated tube was blown with fly ash concrete. See Figs. 29, 30 for the original and current shape.

Fig. 29 Original condition of the bridge before reconstruction.

Fig. 30 Completed bridge.

7. Reconstruction of the Retaining Wall, Its Replacement by a Gabion Wall

The road passes through a mountain valley with classic line elements such as railway, river, road in the walls, there is even the drive of a small hydroelectric power plant. The existing wall is in a state of disrepair, it has been soaked for years with water from a leaky drive and sloping terrain above it. Any previously described repair and rescue scenario would be futile here. The construction of the wall is new from gabion anchored baskets. Here, in contrast to the classic gabions, the net is welded, hot-dip galvanized, 50/100 mm mesh, the face is not classically folded, the aggregates of a smaller fraction (utility model of the Algon company) are compacted in baskets.

Fig. 31 Original condition of the retaining walls.

Fig. 32 Completed structure.

8. Rehabilitation of Concrete Substructure or Retaining Wall With Shotcrete

These are buildings where demolition is difficult or almost impossible due to bypasses, it is not possible to install a temporary bridge next to it. Concrete supports or walls are usually over 1 m thick, and although they are corroded on the surface, they will certainly not cause the collapse of the bridge or wall as a whole. They are made of concrete of the former brand B 105, 135, 170, today classes C 8/10 to C 12/15 (according to current regulations inadmissible for statically loaded concrete structures of bridges and walls). Nevertheless, they can be rehabilitated. However, not with conventional remediation materials applied immediately to the face, because there is no required adhesion of 0.8-1.5 MP, but with shotcrete. After blasting with a high-pressure water jet-VVP (do not go above 1500 bar), the surfaces are saturated with water for about 2 days, so that a crystallization mass of the XYPEX type can be applied, which penetrates the concrete, reacts face against the attack of water from the back. Then the surface is removed from the helmet, the KARI net is anchored and the min. 80 mm layer of shotcrete. In the case of additional layers of shotcrete, the KARI-net must be Φ 6 100/100 mm for every 50 mm of sprayed layer. ¨The contractor company can level the surface with masonry trowels soon after application, any unevenness can be levelled with a final trowel. This is followed by a protective color-toned coating of concrete, preferably with a color close to the natural appearance of the concrete. See Figs. 33-36 for an example of such remediation.

9. Rehabilitation of Concrete Bridges With Classic Renovation Mortars

These are bridges where the substructure is made of plain concrete or reinforced concrete, the superstructure is made of reinforced concrete or prestressed concrete (there must be a functional and durable prestress confirmed by diagnostics), where tear

Fig. 33 Surface after water jet blasting.

Fig. 34 View of the 1st layer of shotcrete.

Fig. 35 Condition of the bridge before rehabilitation.

Fig. 36 After repair.

tests confirm that it is possible to provide concrete structures. For statically inactive parts, the min. tension strength 0.8-1.0 MPa, for load-bearing parts 1.5 MPa. The concrete is blasted with a water jet of high pressure min. 1500 bar, for prestressed concrete beams C 30/37 and higher 2300 bar. This is followed by anti-corrosion coating on protruding reinforcing steel inserts, a connecting bridge, renovation mortar th. 10-40 mm, final trowel and unifying protective coating (color close to the original concrete). The bridge deck and waterproofing are removed to the surface of the superstructure. Coupling elements are fitted in the case of a composite slab or connecting mandrels of the slope concrete. They are equipped with classic waterproofing system, drainage system and expansion joints. The surface of the board is machined, cleaned, a sealing layer of epoxi resin is applied, anchor-impregnation or just penetrating paint (according to the importance and load of the road), insulation from fused strips of cardboard or sprayed insulation, new cornices made of concrete resistant to frost cycles are laid, it is laid insulation protection and top carriage layer. A bridge handrail, a safety fence or both are installed on the cornices. Of course, such repairs are also landscaping under the bridge — the establishment of stone paving, footings, reclamation interventions, grass sowing, etc. — see Figs. 37-44). In the event that it is necessary to replace the bearings, it is necessary to raise the superstructure, remove the existing ones and install new bearings, start the structure so that all bearings are "in action".

Figs. 45-50 document the different types of lifting of the superstructures.

Fig. 37 Condition of the bridge before repair.

Fig. 38 Coupling elements, KARI nets reinforcement (repair of bridge ½).

Fig. 39 Concreting the composite slab.

Fig. 40 Installation of the expansion joint structure.

Fig. 41 Drainage plastic concrete.

10. Rehabilitation of Bridges in Order to Increase the Load-Bearing Capacity of the Existing Superstructure

This is a complete reconstruction described in the previous point. The difference, however, is that the

Fig. 42 Application of protective coating.

Fig. 43 Condition of the bridge deck surfacing.

Fig. 44 Side and soffit after repair.

superatructure is able to achieve a long service life after rehabilitation, but the bridge is not very load-bearing. These are either bridges built before 1945, dimensioned for 22 t of a machine, or part of the

Fig. 45 Lifting from the scaffolding.

Fig. 46 New bering.

Fig. 47 Lifting from the face of the abutment.

Fig. 48 PERI liftingbridge.

Fig. 49 Firesta liftingbridge.

Fig. 50 Single stroke lever system.

concrete or prestressing reinforcement is surface-attacked by corrosion, but the load-bearing structure can be strengthened to meet the load-bearing capacity requirements of current traffic needs. It was already mentioned in the previous point that in case of replacement of the bridge superstructure it is statically advantageous that the slope concrete is made in th. min. 100 mm in order to be able to be coupled to the original superstructure and the structure thus strengthened continues to transmit both dead load (formerly other permanent loads) and traffic loads. Other methods are 1. Installation of steel passive external reinforcement (steel sheets) (see Figs. 51, 52). Reinforcement of the bridge with glued high-strength carbon lamellas (can also be prestressed) (Figs. 53, 54). Prestressing, introduced through free prestressing cables or rods in Figs. 55-58. A separate chapter is steel bridges, which can be relatively easily strengthened by welding steel sheets in places of maximum stress, these then cover the tensile, compressive stresses, usually associated

Fig. 51 Reinforcement of the plate with external sheets.

Fig. 52 External steel reinforcement on beam.

Fig. 53 Carbon glued lamellas on the concrete beam.

Fig. 54 Prestressed carbon lamellas.

Fig. 55 External prestressing of beam structure.

Fig. 56 Loose cables — box girder repair.

Fig. 57 Increasing the load capacity — external prestressing bars.

with stability problems (buckling, flexural-torsional beam buckling, local buckling of the walls of beams).

11. Rehabilitation of Pillars and Abutments, New Superstructure

These are bridges where the substructure is

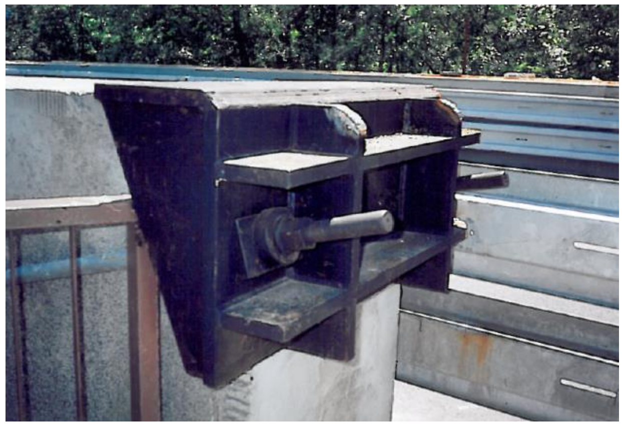

Fig. 58 Anchoring of bars at the front of the U-shaped girder.

removable, it is uneconomical or impossible to demolish in terms of transport. It is therefore remediated by the methods described above. The superstructure is then demolished and set up as completely new. Thus, bridges are currently being reconstructed from prefabricated prestressed beams from 1950-1990, in which part of the reinforcement is uninjected, prestressed patented wires are broken due to corrosion, so there is a risk of loss of load-bearing capacity. An accident can occur very suddenly (in the order of minutes), because the beams are fully prestressed, there is almost no longitudinal concrete reinforcement, so they are broken by the so-called brittle rupture. The new superstructure can be made of cast-in-place partially prestressed concrete (concreting on a falsework), prestressed precast concrete with a composite reinforced concrete slab or the previous, but with a superstructure made of welded steel beams. The upper part of the bridge is completely new according to the valid departmental regulations as with the bridge. Below are presented 3 new load-bearing structures, placed on a reprofiled substructure (Figs. 59-63).

12. Total Reconstruction — Demolition of the Bridge and a Completely New Bridge Structure

If it is uneconomical to rehabilitate the bridge, it is not possible for technical reasons, the service life would be extended only for a short time (10-20 years),

Fig. 59 Beams type KA-61- interrupted prestressing wires.

Fig. 60 New superstructure — prestressed continuous concrete slab.

Fig. 61 Ceiling of wetted corroding beams KA type.

the bridge is narrow or directionally so that it is a local defect of the connecting road, the bridge is torn down and a new structure will be built in its place, built according to the currently valid departmental regulations and standards. During these reconstructions, there may also be a need for support in the catalog of recommended types of bridges, issued by the Directorate of Roads and Motorways or the Ministry

Fig. 62 New superstructure-prestressed precast girders + composite reinforced concrete slab.

Fig. 63 Instead of MPD beams new composite structure.

Fig. 64 Detail of main steel beam, cross beam and composite slab. In this case, it is a continuous beam with 2 spans, integrated with the middle pier.

of Transport Czech Republic and made available on the organisation’s website. Here, the types of bridges are recommended for different spans and types of bridged obstacles, including an estimate of material consumption and the price for this bridge (m^2 of the bridge). However, when considering the type of bridge, it is mostly based on the designer's own experience, on current trends in structure of bridges, following scientific and technical progress in the field. For

Fig. 65 Wet, slab bridge.

Fig. 66 New reinforced concrete frames of the “Beneš” type.

Fig. 67 View of the road.

bridges with a span of 2-15 m, in addition to the previously mentioned steel flexible structures of the Multi-plate or Supercore type, concrete cast-in-place or precast closed frames or arches and open reinforced concrete frames. Frame structures above this range must already be prestressed. From 10 to 35 m, in addition to prefabricated or steel beams, composite

Fig. 68 Strong corrosion of steel girders.

Fig. 69 New parabolic haunched frame.

Fig. 70 View in the direction of the road.

with a reinforced concrete slab, it is also possible to design a cast-in-place prestressed structure, built on a falsework. Bridges with larger spans and the number of fields (viaducts, flyovers…) are designed with special

Fig. 71 **Parapet long-lived bridge.**

Fig. 72 **New H-shaped beam with pavement console.**

Fig. 73 **View in the direction of the road.**

Fig. 74 **Steel “Langer beam”.**

Fig. 75 **New reinforced concrete “Langer”.**

Fig. 76 **View in the direction of the road.**

Fig. 77 **Narrow surviving 2 arch bridge.**

Fig. 78 **Concrete Langer’s beam.**

Fig. 79 View on the road.

Fig. 80 Arch with lower deck.

Fig. 81 True copy (wishes of conservationists).

Fig. 82 View of the road.

Fig. 83 Corroded bridge of small road radius.

Fig. 84 New reinforced concrete slab.

Fig. 85 View of the road.

Fig. 86 Narrow, outdated, demaged reinforced concrete overpass.

Fig. 87 New steel truss girders composited with a reinforced concrete slab.

Fig. 88 View — ascent to the bridge.

technologies such as cantilever concreting, erection, concreting on the retractable or fixed scaffolding, sliding out, turning. Cable stayed bridges (straight ropes, are economical with field spans over 100 m, the largest world record is 890 m) or suspension bridges (supporting cables in the shape of a catenarian curve, the bridge deck is suspended by a system of vertical suspensions — the largest world record is 1991 m). I intentionally omit wooden structures because they require constant care, periodic preservation and achieve a short service life (up to 30 years — if they are not covered by a roof). The following are examples of the bridges described above, always for comparison with the original-new bridge.

13. Conclusion

On the previous pages, we tried to discuss very briefly all the basic types and methods of reconstruction and rebuilding of bridges. Each of the types can be described and specified in more detail in the scope of the usual 20 pages of the Specifications of the PD of the bridge object. Although the symposia in the forefront of interest are mainly new bridges (for example Czech Symposium BRIDGES, etc.), on new roads and highways, a project of repair, reconstruction, rehabilitation or reconstruction requires more skill and experience, because it is not possible to use a universal model, one-each structure is another, unique, so-called “tailor-made”. That is why this activity is more interesting from our point of view, because it is possible to escape from strict “prefabricated templates” with ever-increasing volumes of various regulations, recommendations, restrictions, prohibitions, orders, etc. (unfortunately, this unfortunate syndrome accompanies other fields). The same creative spirit is inherent in subjects engaged in diagnostics or inspections of bridges.

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The Use of Regular and Irregular Polyhedra in Architectural Design

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Abstract: With the advent of the computer are dramatically influenced, both the shape and materialization of architecture, and of course the representation in architectural design. New trends, theories and styles appear in the architecture produced by digital. A new language of architectural forms, the so-called free forms, makes its presence felt in the built environment. The relationship between the shape of these free volumes and simple geometric volumes represents an evolution whose result is the change of the architectural paradigm towards a digital architecture. At the base of this new architecture is geometry, with its primary volumes. In this paper we want an inventory of buildings that use irregular and regular polyhedra as geometry. These polyhedral volumes allow modularity and repetitiveness, and this process can be extended to give rise to more complex forms such as free forms. Descriptive geometry must provide basic knowledge about the creation of space, shapes and methods by which they can be represented.

Key words: regular polyhedrons, irregular polyhedrons, architectural design, descriptive geometry, applied geometry

1. Introduction

Over the course of time, from antiquity to the present, the relationship between geometry and architecture has been intensively studied and theorized, but only since the 16th century, starting with architect Andrea Palladio (1508-1580), geometry becomes the basis of all architectural rules and typologies. As well noted by Galileo Galilei (1564-1642), also during that period: [The universe] cannot be read until we have learnt the language and become familiar with the characters in which it is written. It is written in mathematical language, and the letters are triangles, circles and other geometrical figures, without which means it is humanly impossible to comprehend a single word.

Later, in 1784, Étienne-Louis Boulléems (1728-1799), the visionary french neoclassical architect, has developed a distinctive architecture based on pure geometrical forms, characterized by the removal of all unnecessary ornamentation and inflating geometric shapes to a huge scale. At the beginning of the 20th century, the Formalism, as its name suggests, emphasizes the form, and the architect becomes interested in the visual relationship between the parts of the architectural object and the object as a whole. The shape, often on a monumental scale, is the center of attention, which is dominated by rigid geometric lines and shapes. In the same direction, the Bauhaus style and modernism are oriented, which through the visual vocabulary of straight, curved and diagonal lines of Friedrich Wilhelm August Fröbel (1782-1852), were oriented towards a purist image of geometry. A number of common features can be identified from the analysis of these examples: the use of simple and primary geometries, capable of symbolizing by themselves monumentality.

But with the advent of the computer, architecture began to operate with increasingly complex geometries, abandoning traditional Platonic forms in favor of

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formal complexity. The new technology is dramatically changing our approach to design; it also allows us to work with a vector geometry which marks the end of the rule of the Euclidean geometry. This breaking off involves our conceptual and designing potentials as much as their implementation. We could say that, somehow, this also increases our designing abstraction skills. Increased production, reduced designing costs, improved communication of the executive building choices, and a new conception of the architectural space are just some of the major consequences of the use of new technology in architectural design [1].

In this paper we want to show that complex shapes can be obtained precisely by using simple geometric volumes. Firstly, we will represent through descriptive geometry irregular and regular volumes of polyhedral, and later, we will present some examples of buildings that use these polyhedral as an epicentre in the design of the architectural form. This exercise gives students in architecture faculties a starting point in thinking about the space and the design of the architectural form, helping them to imagine and control the increasingly complex forms of contemporary architecture.

2. Material and Methods

At the beginning of any project there is an idea that materializes by drawing, and the shape catches volume with the help of descriptive geometry by searching for geometric schemes that synthesize the complex form of architecture. The student sees drawing as instrument of conceptual control and communication of the architectural process. Along with drawing, models take a significant place in student practice, the realization of models at small scale and makes them understand better the process. However, at the core of his practice are the drawings, from earliest conception right through the realization of project. To design the architecture under its various forms, a student in architecture needs to know the geometry of these volumes, which can be composed of regular and irregular polyhedral. The main mission of descriptive geometry, as a discipline in architectural education, is the development of three-dimensional thinking, the formation of a precise and logical spatial vision and implicitly the development of strategies for effective solutions to various problems. Once this knowledge is obtained, we can more easily control complex shapes with the help of the computer, in this case Archicad 24 — GRAPHISOFT was used. Practical examples with architectural projects motivate the students to actively participate in the realization of models at small scale and makes them understand better the space and form.

3. Irregular Polyhedrons

Throughout history, architects and builders have sought to perfect the shapes of buildings, but the built environment is mainly composed of primary volumes, polyhedra. A polyhedron is the natural generalization of the polygon from two-dimensional space to three-dimensional space:

It is a region of space whose boundary is composed of a finite number of polygonal surfaces, any two polygonal surfaces are disjoint or have common edges and vertices. The polyhedra can be convex or concave, (Fig. 1). Convex polyhedra are those polyhedra that cannot be sectioned by the planes of their faces.

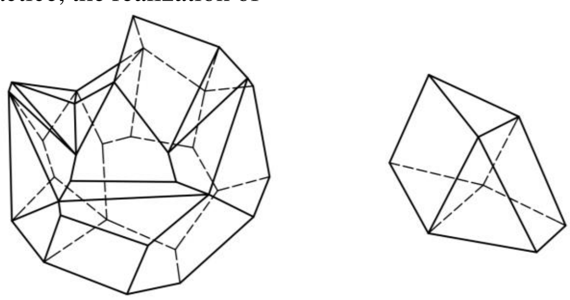

Fig. 1 (a) concave polyhedra, and (b) convex polyhedr.

3.1 The Graphical/Descriptive Representation of the Irregular Polyhedrons

An irregular polyhedron is that polyhedron that does not meet the conditions of the regular one. It is a geometric volume bordered by flat faces, various polygons. His faces can be polygons with a certain number of sides. The sides of these polygons determine the edges of the polyhedron and result from the intersection of two adjacent faces of the polyhedron (Fig. 2). Several edges of a polyhedron are competing in a polyhedron vertex, which is also common for at least three faces of the polyhedron.

3.2 Achievements in the Field of Architecture

In nature we can rarely see order and symmetry, the elements of nature are in a relationship of asymmetry, implicitly, dynamism. Extrapolating we can say that the built environment adapted to nature will approach a complex, asymmetrical volume. It will allow the planimetry a greater freedom, than in the case of using the symmetry. Each architectural volume will be able to develop freely, presenting different images depending on the facade we are looking at. The building is much better adapted to the site where it is located and will be able to respect the requirement of the architectural theme. This image is also presented by Futuroscope, theme park in Poitiers, Poitou-Charentes Region, France, opened on May 31, 1987, which uses as a formal design, the prism (Fig. 3a). Architect Denis Laming led the design of the pavilions, which include buildings shaped like spaceships, crystals formations emerging from the ground, and triangular wedges. What we study are the crystals formations that seem to come out of the site, giving the feeling of a continuous dynamic. Irregular polyhedral surfaces are most often found in the materialization of complex architectural forms due to flat faces (Fig. 3b). One such case is the folded facade that can generate free forms. It has the advantage of generating more visual directions by the different inclination of the various planes, it can be molded on an already existing structure or it can take over the load-bearing structure by its own shape. Folded plate geometries cand take a varieety of patterns, such as saw-tooth or polyhedral facets [2]. As we see multiplication of irregular prismatic volumes can generate a complex architecture.

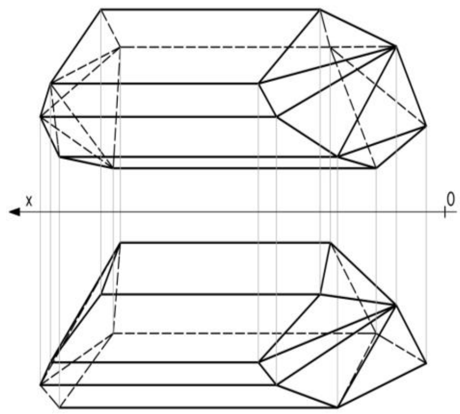

Fig. 2 Irregular polyhedron.

Fig. 3 (a) Futuroscope Theme Park, Poitiers, France, [3], (b)Basque Health Department Headquarters, Bilbao, Spain [4].

4. Regular Polyhedrons

These polyhedra have been studied for hundreds of years. The Greeks made the first attempt to "mathematize harmony", that is, to express the harmony in numerical and geometric form. In his works, Plato develops the Pythagorean doctrine, especially emphasizing the cosmic significance of harmony. He is firmly convinced that the harmony of the world can be expressed in numerical proportions [5]. The regular polyhedrons (platonic) have the faces formed by regular polygons with the same number of sides, and all dihedral and polyhedral angles are equal. We can say that this concept of regularity is related to the repetition of the chosen geometric elements (equilateral triangle, square, pentagon) that generates a symmetry, both in the geometric figure and in the regular volume. The regular polyhedra are inscribed to a sphere and are circumscribed to a sphere of the same center. In three-dimensional space there are five regular polyhedra (Fig. 4), namely: regular tetrahedron (4 equilateral triangle faces), octahedron (8 faces are equal equilateral triangles), cube or hexahedron (6 equal square faces), icosahedron (20 faces equal equilateral triangles), dodecahedron (12 faces equal pentagons).

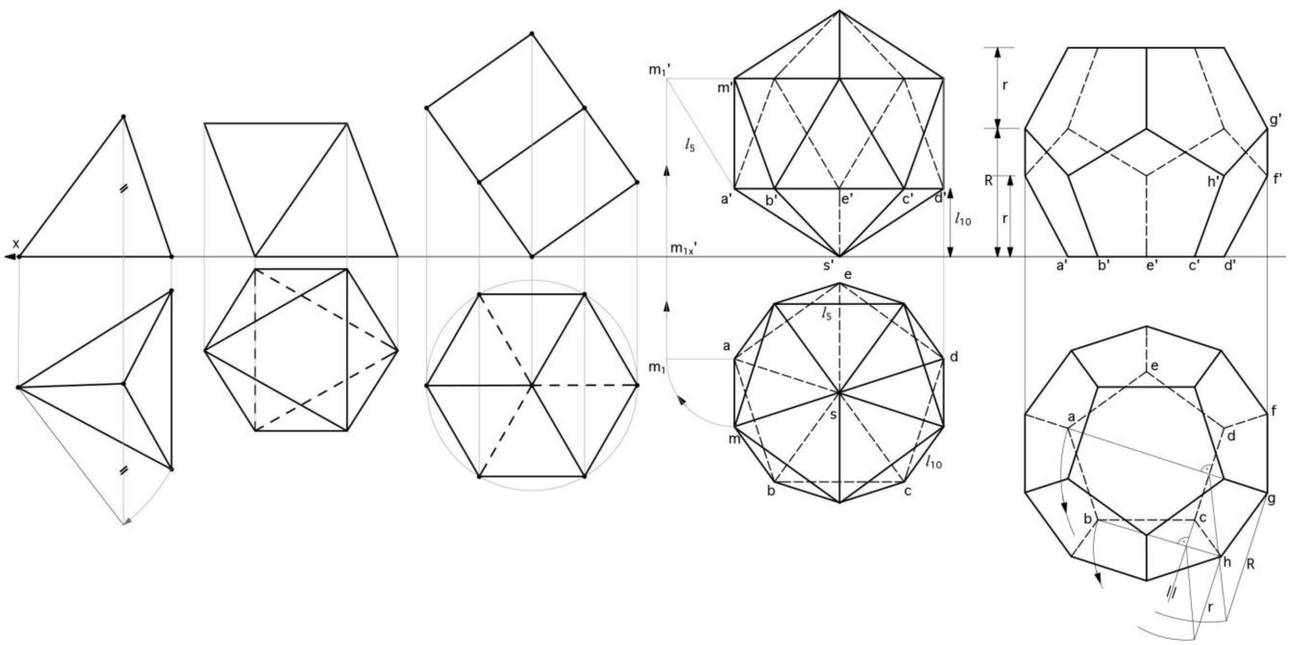

Fig. 4 Platon's polyhedra - tetrahedron, octahedron, hexahedron, icosahedron and dodecahedron.

This fact is a result of Euler's theorems as follows: if a convex polygon is divided into a certain number of polygons, then the sum between the faces of the polygons and the number of the vertices exceeds by one unit the number of the sides; in any convex polyhedron the sum between the number of faces and that of the vertices is equal to the number of edges increased by 2; there can be no more than five covex polyhedra having all faces having the same number of sides and all angles polyhedrons having the same number of edges [6]. Regular polyhedra are polyhedra that enjoy the following properties: all faces are equal regular polygons; the vertices are equal solid regular angles; they can be inscribed or circumscribed to spheres with the same center.

4.1 Achievements in the Field of Architecture

The architectural object is unique in relation to nature, more precisely to the site, and in relation to the city, socio-cultural, historical context. In this sense, the architecture uses the same interface language that also describes the physical reality, which it simulates and even more competes with through the organic architecture. But beyond the copying of nature, architecture aims, the other operating language of reality, geometry. When the geometry of regular polyhedra is used, harmony appears in the architecture, symmetry and regularity appear.

4.2.1 The Tetrahedron

Looking at The Great Pyramid of Giza we see a wonder of the ancient world that today still attracts people from all over the world. The pyramid managed to survive the present, defining our attractiveness to this simple and powerful form. Architects continue to design pyramids, in other forms, for example an identical repetitive linear sequence of a tetrahedron structure to generate a bridge. It is the case The Tetrahedron project by Christopher Charles Benninger Architects in 2011, Kolkata, West Bengal, India (Fig. 5a).

The architect invented a system of interconnected tetrahedrons along a line. He eventually called this unique structure The Tetrahedron. The result is a number of geometries within one another, at one level being composed of three parallel and horizontal pipes, forming in section a triangle, with two pipes below a carriageway hung between them for pedestrian movement. The users walk under the third pipe above their heads, and amongst the diagonal pipes forming the tetrahedrons [8].

Finally we see that the triangular polyhedrons are not deformable, and among them the tetrahedron is the only one which can constitute on it own a covering surface [9]. To generate a complex architecture we will use the tetrahedron in a chaotic assembly. In this way we can obtain spaces both inside the tetrahedra and outside them, by joining several tetrahedra (Fig. 5a). We can use this design on office or apartment buildings, which can be developed both horizontally and vertically, multi-storey buildings. Tetrahedron can be used to create a complex spatial surface or envelope resulting from joining according to the (Fig. 5b).

Fig. 5 (a) The tetrahedron, West Bengal, India [7], (b) Multiplication of the tetrahedron.

4.2.2 The Cube

The cube represents an important form in architecture because it is the basis of the geometric principle of forces in a building of most frame type structures. But we want to present a less obvious example of the use of the cube as a form of inspiration in architecture, the Kubuswoningen is located in the Oude Haven, the most historic section of Rotterdam's port, Netherland, architect Piet Blom, completed in 1984 (Fig. 6a).

Inside, the houses are divided into three levels accessed via a narrow staircase.The lower level is a triangular area used as the living room. The middle level houses the sleeping and bathing area, and the highest level is a spare area used either as a second bedroom or another living area [10].

Such an agglomeration of cubic spaces uses proximity to relate the spaces to each other. There are cellular spaces, repetitive with the same use. Using the cube as a closing surface, by a slight sliding or translating, you obtain tubes that vary in size, and the generated surface constantly surprises. This is also the case of the Serpentine Pavilion 2016 project (Fig. 6b). Bjarke Ingels declares: "we have attempted to design a structure that embodies multiple aspects that are often perceived as opposites: a structure that is free-form yet rigorous, modular yet sculptural, both transparent and opaque, both box and blob" [13]. In this example we are dealing with the principle of reverberation, like an increasing repetition, which has to do with elements similar in shape but different in size, hierarchically graded.

4.2.3 The Octahedron

The architect Christian Norberg-Schulz (1926-2000) said that the purpose of the architecture is to give meaning to a solid and implicit matter, obtaining an identity resulting by uniqueness and identification. One of the projects we will present is an interactive and experimental pavilion made in United States, in 2013 by LMNTechStudio (Fig. 7a). This architectural object attracts the passer-by and invites the Seattle community to interact. The pavilion is clad with over 400 triangular panels. The inner face was the canvas for 54 sets of CNC cut patterns generated as part of a technology training exercise. The outer face was a canvas that addressed the community, with the help of chalk, the passer-by completely transformed the outer surface of the Octahedron [14]. With the multiplication of the octahedron we can obtain a complex shape that incorporates in each octahedron an architectural space Joining the volumes is done either on one side or on one side of the octahedron. Another approach is to join in a flat spatial network, full or aerated by octahedra, (Fig. 7b). The design of roofs or facades is varied, and different sizes of geometric bodies can be combined.

Fig. 6 The Kubuswoningen, Rotterdam, Netherland [11], (b) Serpentine pavilion and summer houses 2016 [12].

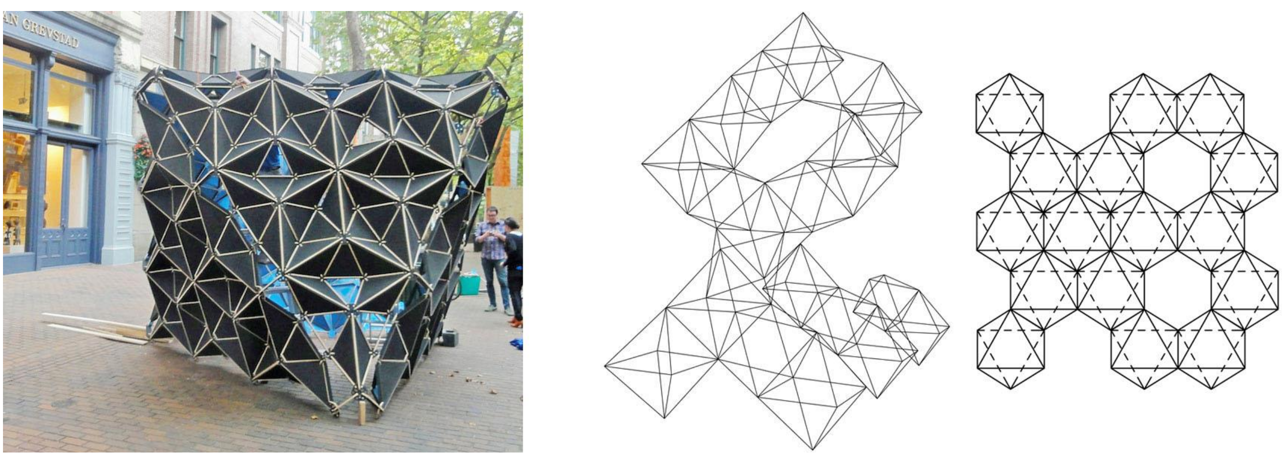

Fig. 7 (a) The Octahedron, Seattle, United States [15], (b) Multiplication of the Octahedron.

4.2.4 The Dodecahedron

Within this section, the dodecahedron, we will present a residential project presented at a competition by the Tammo Prinz architecture office in 2014, Platonian Tower in Lima, Peru. The concept was the introduction of a cube in a dodecahedron to create a unique living space, with the possibility of extension. Obtaining such a module attempts to join them, resulting in a modular tower. The matching flat surfaces fit together perfectly for stacking. The internal cube hosts the interior spaces, while the extruded spaces can be used as additions, exterior living or just open outdoor air. Flexibility in these external sections allows for residents to change or adapt spaces as needed [16]. This repeated and combined module in terms of architectural composition generates harmony, (Fig. 8a). This example deals with the singular geometric volume, but through a repetitiveness of the octahedron we can obtain an image of a complex architecture developed according to the architectural theme. A much more complex configuration can be obtained through a surface defined by the dodecahedron (Fig. 8b).

4.2.5 The Icosahedron

Joseph Mikrut, a graphic designer, lives in Costa Rica and initially thought of building this icosahedron structure on the ground (Fig. 9a)., but he noticed the trees that attracted his attention through the branches of the branches that could sustain through the five branches the vertices of the bottom pentagon, a perfect support point.

Another icosahedron structure is suspended by cables between five Melina trees [19]. These structures are grouped by proximity and have the common feature of the architectural form, the icosahedron. Here monumentality was obtained by capitalizing on only one geometric body, the icosaerd. The way to get an architecture with free forms is, as we noticed before, the repetitiveness. The geometric body has a modularity that allows the association of other icosahedrons and, thus, we extend the building in any direction we want. By using this multiplication of regular polyhedra we can also imagine envelopes that form spatial structures of simple (flat facades) or complex (volumes with a complex geometric design) architectural volumes. A surface that can become a facade can be obtained by joining icosahedrons placed on a face (Fig. 9b). Having no rigid plan, a crowded organization allows flexibility, accepting growth and change without changing its character.

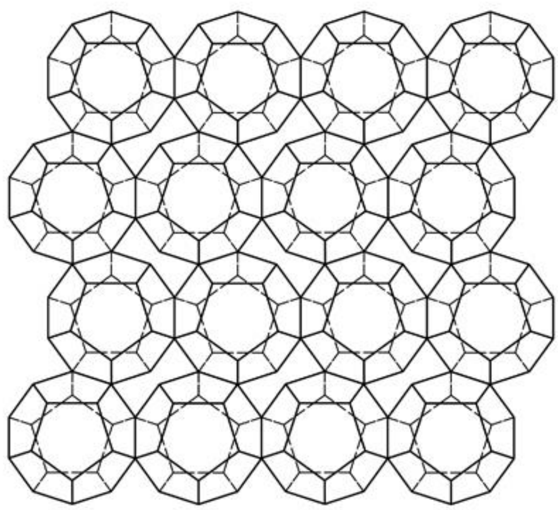

Fig. 8 (a) The Platonian Tower in Lima, Peru,[17] (b) Multiplication of the Dodecahedron.

Fig. 9 (a) The Icosahedron Structure, Costa Rica [18], (b) Multiplication of the Icosahedron.

5. Research Directions

Today, the great test of architecture is the implementation of non-standard, non-Euclidean geometries, and especially those of complex sciences (fractals, strange attractors, dissipative systems). The structural efficiency and the expression or form of the building become paramount criteria in the materialization of the architecture. These complex shapes can be materialized from a geometry based on that of polyhedra, in some situations the architecture can be designed in the form of geodesic domes or parts of them, combined with other portions of free surfaces. An important feature of free-form architecture is that it structures a type of fluid space, which simultaneously forms the form, structure and facade.

The approximation of a surface with a polyhedron is more accurate as the polyhedron has smaller edges. Otherwise the two-dimensional equipartition in space lead, as particular cases, to the five regular or Platon's polyhedra.

To achieve large opening reticular domes, it is necessary to multiply the faces and vertices of these polyhedra, such as to result as many equal edges (struts) and identical solid angles (knodes). This multiplication, which is performed according to certain laws, involve that the polyhedron to follow a sphere through a series of quasi-regular polyhedra having increasingly smaller edges and faces, closer in size to the surface of the sphere or, in generally to the curved surface which supports. The reticular surfaces can be treated as a succession of joined polygons, lying on a surface [20]. We can make an infinite number of polygons that are regular, so that their peaks are located on the circumscribed circle and all their faces reach the inscribed circle.

6. Conclusion

People have always studied nature and found inspiration in everything around them. This imitation finds its answer in the geometry of the construction and in the optimization of the design solution in terms of structural and functional efficiency. Fernand Léger (1881-1955) said "Architecture is not an art, but an organic function. It grows on the ground like animals and plants, it is a function of social order. " This organic function denotes an increase and development of the architectural form, from simple to complex derived from simple geometric solids, polyhedra. In this paper we analyzed several architectural volums and how complex surfaces in descriptive geometry are easy to materialize if they are known under the analytical aspect. Thus, we can extract some features from this analysis: first of all the call in architecture to simple, primary geometries, polyhedra of all types, capable of symbolizing by themselves the monumentality and symmetry in architecture. But in the complex architectural programs that lead to compositions with large proportions, to follow the geometric symmetry becomes a nonsense, due to the proportions it would be difficult to observe the symmetry visually. Thus, in the second variant one resorted to complex geometries using the multiplication of the same geometric volume or combined with other geometric volumes resulting in complexity, dynamism, growth, asymmetry. The possibility to multiply polyhedra in order to obtain free forms in architecture offers flexibility and can directly meet the requirements of the place, the site, becomes a spontaneous, more interesting, more natural architecture and allows in the future a possible expansion/extension of space, but without changing the original character of the architecture.

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The Role of Organizing Routine Maintenance of Central Java Provincial Roads in Reducing Poverty and the Utilization of Android Device Technology

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Abstract: Road operators prioritize regular road maintenance and inspection to maintain road service levels and improve road performance. In its implementation, The Department of Public Works of Highways and Human Settlements of Central Java Province organizes the Bina Marga Community Group (Mas Bima) which is consisted of poor and healthy people around the provincial road. The high public expectations of the demands for fulfilling road infrastructure are conveyed through social media and mass media. The resolution is then accommodated through the use of technology that is easy to apply, namely the Jalan Cantik application that can be operated with an Android device. This study uses a descriptive method that is to describe the object under study through the data and samples that have been collected by conducting a simple analysis and making conclusions that are applicable to the public. The analysis showed that there were 577 complaints from the public that enter the Jalan Cantik Application (as of August 2019) that were responded quickly within 1 × 24 hours. The condition of Provincial Roads in Central Java is maintained well, it gradually exceeds the 2019 RKPD performance target of 90.20%. Recorded 1,018 people of Bina Marga Community Group spread all over 9 Road Management Centers, this means that The Department of Public Works of Highways and Human Settlements of Central Java Province participated in reducing poverty by 0.109% of the poverty rate in Central Java.

Key words: road routine maintenance, Jalan Cantik application, poverty rate

1. Introduction

Road operators prioritize regular road maintenance, handling and inspections to sustain road service levels and improve road performance. Road maintenance is a road handling activity, in the form of prevention, maintenance and repairs needed to maintain road conditions so that they continue to function optimally to serve traffic so that the determined design life-can be achieved. Road maintenance consists of routine maintenance, rehabilitation programs and road improvement programs. Routine road maintenance is an activity to maintain and repair the damage occurring on road sections with steady service conditions. Roads with steady service conditions are road sections with a design life that can be calculated and qualify a certain standard. The rehabilitation program is an activity to prevent extensive damage and any damage that that does not count in the design, which results in a decrease in the stability condition in certain parts/places of a road segment with mild damage, so that the decrease in the stability condition can be returned to a stable condition in accordance with plan. Improvement program is a handling activity to be able to increase the ability of sections of roads that are in a heavily damaged condition so that the road sections have a steady condition again in accordance with the specified design age or activities to improve road structures including complementary buildings and road equipment, with capacity building.

The Department of Public Works of Highways and Human Settlements of Central Java Province as a

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government agency that has the main duty and function in carrying out road handling in the program of routine maintenance, rehabilitation and improvement activities. As an illustration, in 2019, the length of the provincial road handled by The Department of Public Works of Highways and Human Settlements of Central Java Province was 2,404.741 Km, which is 95.77% (2,302,961 Km) with routine maintenance programs and 2.07% (49. 89 km) with a rehabilitation program, and 2.16% (51.89 km) with an improvement program as shown in Fig. 1. Bridge handling 23,955.8 M', that is 96.16% (23,014.8 M') with a maintenance program routinely, 2.17% (519 M') with a rehabilitation program, and 1.67% (400 M') bridge replacement, can be seen in Fig. 2.

The expectations of the people of Central Java are very high for the demands of fulfillment of needs, especially road infrastructure, which is expressed in many complaints and expectations on Twitter, Short Message Service (SMS), e-mails, Lapor Gub and community reports from various mass media. The

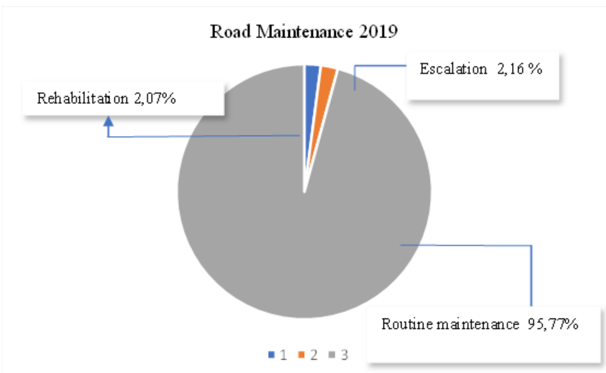

Fig. 1 Road Maintenance Diagram in 2019.

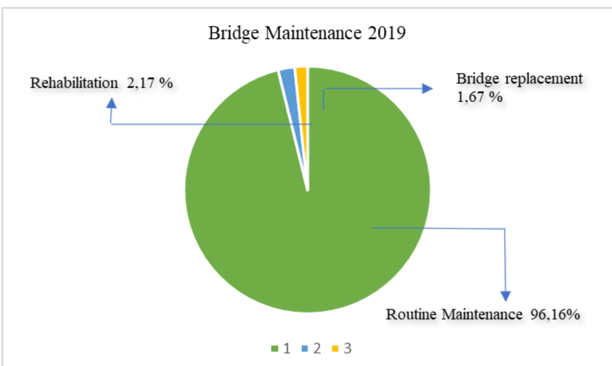

Fig. 2 Bridge handling diagram in 2019.

handling of complaints and public expectations is also accommodated through the easy-to-use technology, namely the Jalan Cantik application that can be operated using an Android device. With the easiness of reporting system that contained in Jalan Cantik application, it is expected to be able to improve the quality and speed of handling any road damage that has been recorded in the application system. To support the acceleration of handling in line with the target of the Public Works Department of Highways and Human Settlements of Central Java Province, which handling in 1×24 hours, a Bina Marga Community Group (Mas Bima) was formed consisting of poor and healthy communities around the provincial road. By looking at this fact, the Department of Public Works, Highways and Human Settlements of Central Java Province participates in providing job opportunities for the people of Central Java.

2. Material and Methods

The research method is a way of working to collect data and then process the data to produce data that can solve research problems. The type of research method chosen is analytical descriptive, while the notion of analytical descriptive method according to Sugiono (2009) [1] is a method that serves to describe or provide an overview of the object under study through data or samples that have been collected as they are without analyzing and making general conclusions. In other words, analytical descriptive research takes problems or focuses on problems as they are when the research is carried out, the results of the research are then processed and analyzed to be concluded.

This research uses descriptive analytical method with a quantitative approach. As stated by Nana Sudjana (1997) [2] that descriptive research method with a quantitative approach is used to describe or explain an event or an event that is happening at the present time in the form of meaningful figures. So that the research results obtained from the calculation of the indicators of the research variables are then presented in writing.

The location of the research took place along the provincial road and the area of the Public Works Department of Highways and Human Settlements of Central Java Province along with 9 Road Management Centers and focused on the Bina Marga Community Group (Mas Bima). The steps taken in this study are presented in a flow chart as shown in Fig. 3.

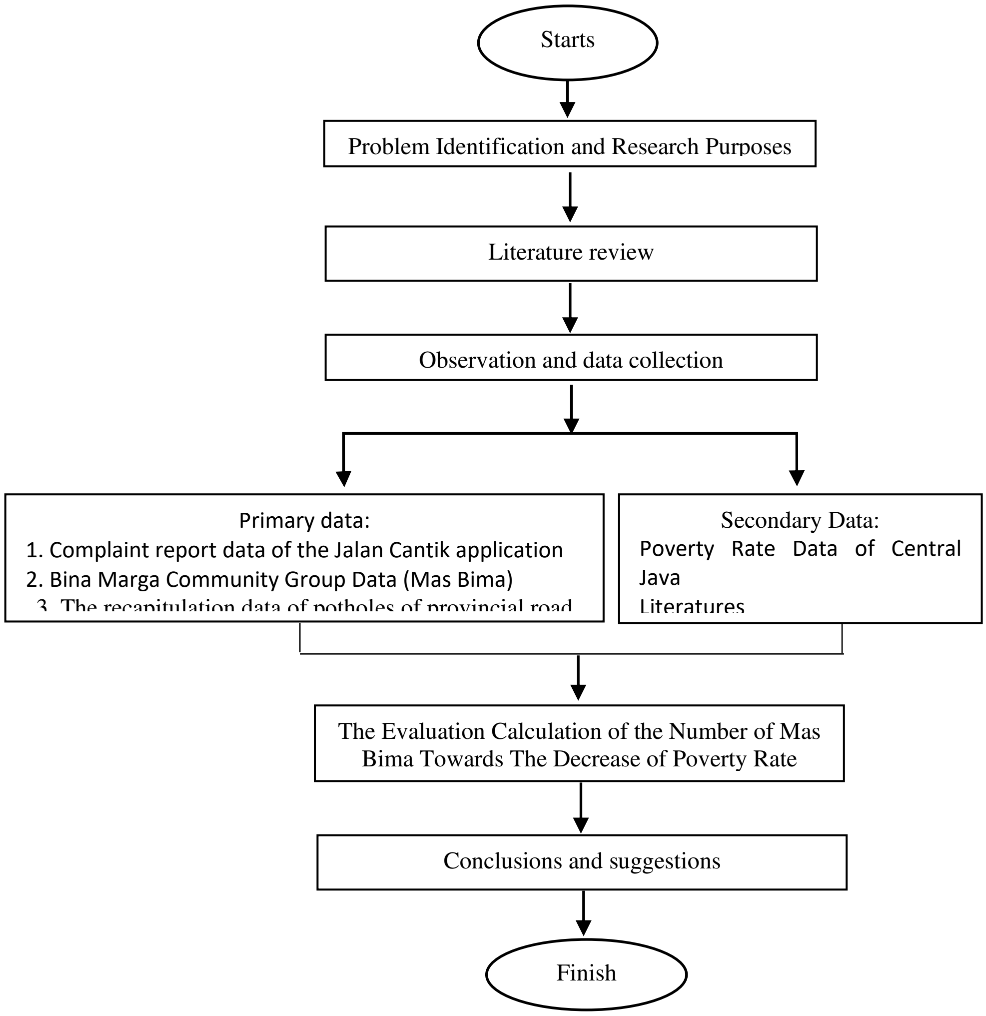

Fig. 3 The flow diagram of research.

3. Results and Discussion

3.1 Report From the Jalan Cantik Application

The *Jalan Cantik* application is an application provided on smartphones based on the Android System which is designed as a means or media for reporting damage to provincial roads (can also be applied to national roads, district or city roads and village roads). It is hoped that with this application, incoming reports can support better roads and bridges. *Jalan Cantik* is defined as a road with good or moderate pavement conditions, free of potholes or things that endanger users and the fulfillment of shoulders, complementary buildings, and road equipment according to technical standards, with the condition of the Road Owned Space (*RUMIJA*) being regularly and neatly maintained.

The Jalan Cantik application is very easy to use by the people of Central Java. The Jalan Cantik application can be downloaded via the play store using an android-based device. The steps for using the Jalan Cantik application are as follows:

1) Download the "*Jalan Cantik*" application on the Play Store, click install and wait until the application installation process is complete;
2) Login using the registered e-mail;
3) Enable location and select allow app access to detect device location;
4) To start reporting, select the "Report Damage" menu;
5) Enter at least 3 (three) photos of the reported location conditions;
6) Set the map of the location of the road to be reported by typing the location of the road or marking the point of the road location on the available map, then selecting the Regency/City according to the location of the road reporting;
7) Select the road complaint according to the available options, then provide information about the reported road to facilitate the road checking process;
8) Click "Report" when the data has been entered;
9) To see the progress of the report, return to the main menu and click "Progress Report";
10) Click "more" to view the detailed progress of the report. Or it can be seen in Fig. 4.

Based on the recapitulation of data obtained from the "*Jalan Cantik*" application (Table 1) as of September 30, 2019, data on complaints received were 604 complaints which were divided into 6 complaints (0.99%) on national roads, 14 complaints (2.32%) provincial roads, 310 complaints (51.32%) district/city roads, 51 complaints (8.44%) village roads and others, namely the trial process during the launch of the *Jalan Cantik* application as many as 205 complaints (36.92%).

Fig. 4 Steps for using the Jalan Cantik application.

Source: IT Team of the Department of Public Works, Highways and Human Settlements, Central Java Province.

Table 1 Recapitulation of crash reports from applications Jalan Cantik.

NO	MONTH	NATIONAL ROADS	PROVINCIAL ROADS	DISTRICT/ CITY ROADS	VILLAGE ROADS	OTHERS	INCOMING REPORTS
1	June	0	2	42	27	186	257
2	July	1	7	212	13	0	233
3	August	4	3	45	7	28	87
4	September	1	2	11	4	7	29
	Total	**6**	**14**	**310**	**51**	**221**	**604**
	Percentage (%)	0,99	2,32	51,32	8,44	36,92	100,00

Source: IT Team of Department of Public Works, Highways and Human Settlements of Central Java Province.

The benefits of *Jalan Cantik* applications on road conditions include:

1) Drastically reduce potholes so that it becomes a pothole-free road
2) Road damage can be handled within 1×24 hours.

Based on Fig. 5, the highest number of holes was in March, which was 5,100 holes. With 1×24 hour handling, the number potholes significantly decreased to 211 in September 2019.

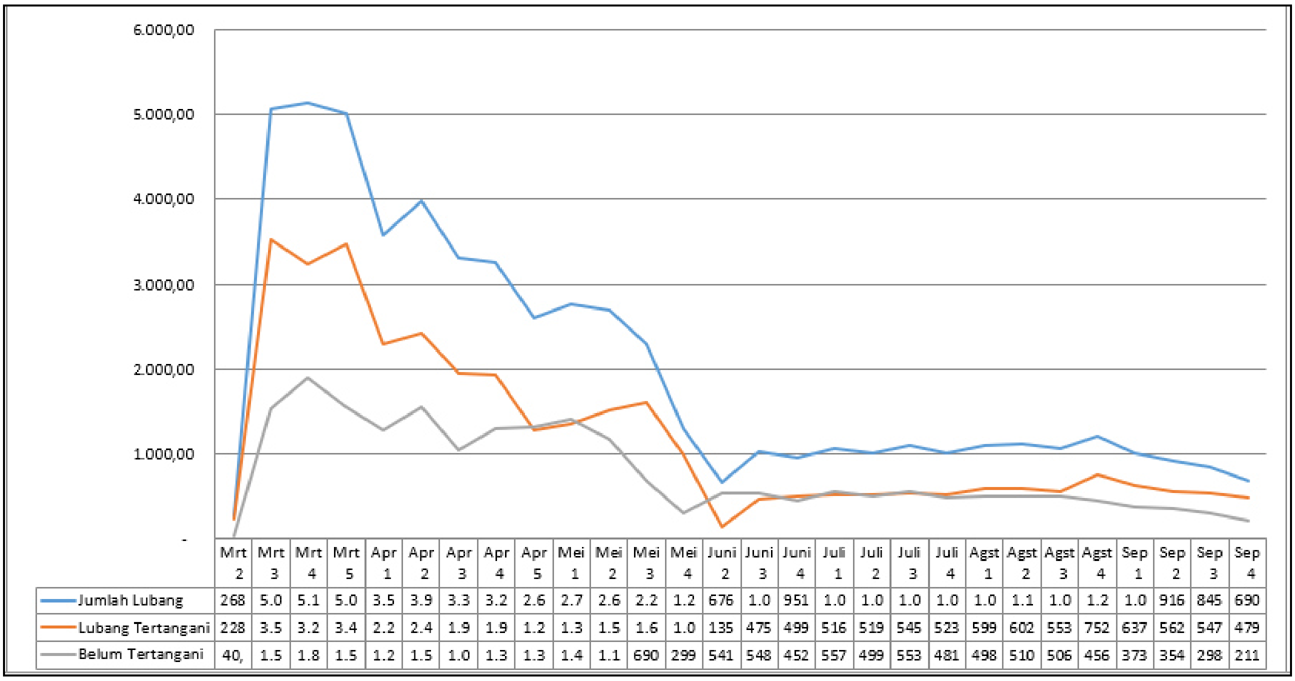

Fig. 5 Graph of hole handling for March – September 2019.

Source: Department of Public Works, Highways and Human Settlements of Central Java Province.

3.2 Bina Marga Community Group (Mas Bima)

The Bina Marga Community Group (Mas Bima) is a poor and healthy community around provincial roads, both skilled and unskilled workers formed by the Public Works Department of Highways and Human Settlements of Central Java Province to support the third mission of the Central Java Provincial Government, namely strengthening economic capacity. people and expand employment opportunities to reduce poverty and unemployment. The Bina Marga Community Group (Mas Bima) joined 9 (nine) Road Management Centers to support routine maintenance on provincial roads. Skilled workers are workers who do technical work such as patching holes, while unskilled workers are workers who do light work such as cleaning rumija and drainage. The inability to meet the minimum standard of living in accordance with the level of living is considered poverty [3], so that the existence of this group can increase the income per capita of the family. The number of Bina Marga Community Groups (Mas Bima) until 2019 there were 1018 workers with details as shown in Table 2.

3.3 Poverty Rate in Central Java

Based on the Official News of Poverty Statistics of Central Java Province No. 47/07/33/Th. XIII On 15 July 2019 [4], in March 2019, the number of poor people (people with monthly per capita expenditure below the Poverty Line) in Central Java reached 3.74 million people (10.80 percent), a decrease of 124.2 thousand people compared to the conditions in September 2018 which amounted to 3.87 million people (11.19 percent), it can be seen in Fig. 6.

As shown in Fig. 6, Central Java Province experienced a decline in the percentage of the poor from March 2011 to March 2019.

3.4 Evaluation of the Number of Mas Bima on Poverty Reduction

From the observations and data collection that has been done, it can be analyzed toward poverty rate reduction as follows:

Number of Poor Central Java: 3,740,000 people

Number of Mas Bima: 1,018 people

Assume that in a family there are four members consisting of father, mother and two children.

Table 2 Recapitulation of routine workers at Balai (Bina Marga Community Group (Mas Bima).

NO	Road Management Center	Number of Workers	Workers	
			Skill	Unskill
1	Wonosobo Area 1	90	20	70
	Wonosobo Area 2	58	18	40
2	Pekalongan Area 1	65	15	50
	Pekalongan Area 2	39	9	30
3	Tegal Area 1	18	7	11
	Tegal Area 2	32	12	20
4	Magelang Area 1	58	15	43
	Magelang Area 2	103	29	74
5	Cilacap Area 1	37	12	25
	Cilacap Area 2	38	16	22
6	Purwodadi Area 1	77	34	43
	Purwodadi Area 2	85	35	50
7	Pati Area 1	42	12	30
	Pati Area 2	41	12	29
8	Surakarta Area 1	67	15	52
	Surakarta Area 2	100	25	75
9	Semarang Area 1	40	12	28
	Semarang Area 2	28	8	20
	Total Workers	**1018**	306	712

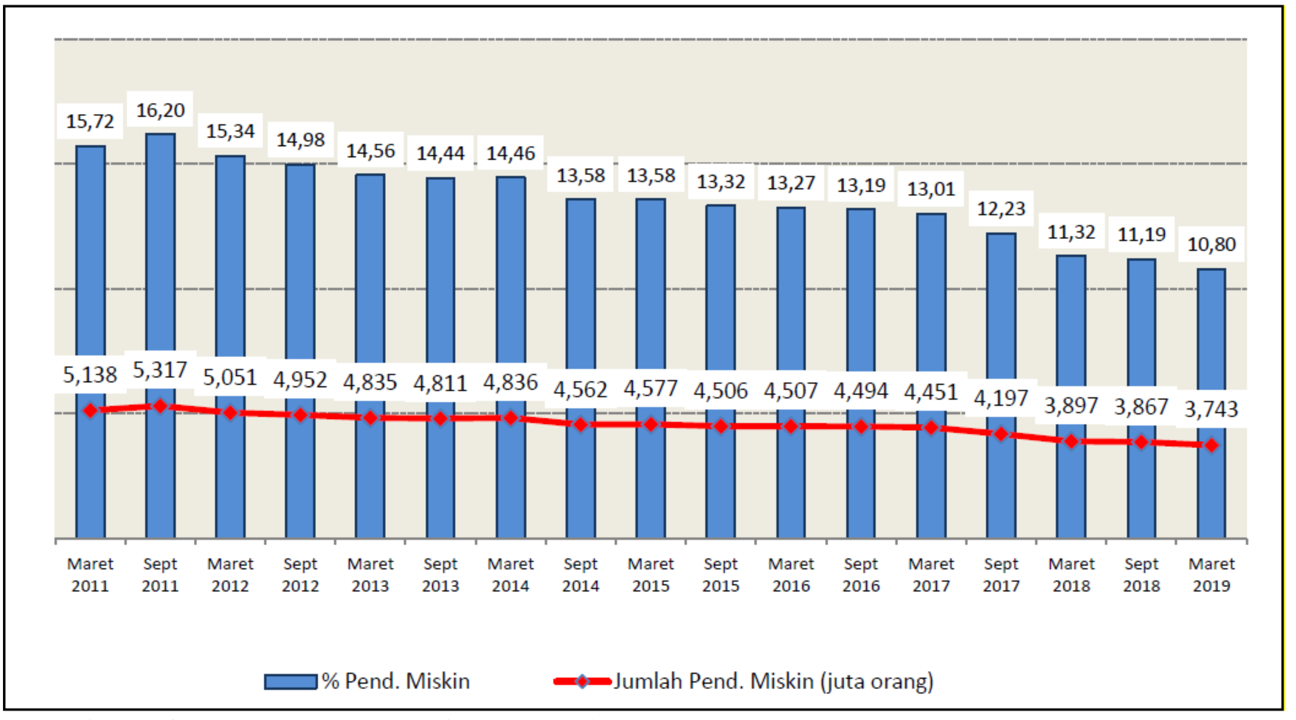

Fig. 6 Graph of number and percentage of poor population [4].

So we get the following formula:

Poverty Reduction:

$$\frac{Number\ of\ Mas\ Bima\ \ x\ 4}{Number\ of\ Poor\ in\ Central\ Java}\ x\ 100\%$$

$$\frac{1.018\ \ x\ 4}{3.740.000}\ x\ 100\%$$

: 0.109%

So, the poverty reduction rate is 0.109%

The Poverty Threshold is used as a boundary to classify the population as poor or non-poor. The poor are people who have an average monthly per capita expenditure below the Poverty Threshold. The poverty Threshold for the population of Central Java is Rp. 369,385.00 per capita per month in March 2019. Assuming that in 1 family there are 4 family members, then the poverty line limit per month in 1 family is Rp. 1,477.000,00.

In accordance with the 2019 budget of the Public Works Department of Highways and Human Settlements of Central Java Province, Mas Bima is given wages throughout the year every month based on the district/city minimum wage of Central Java Province. Based on the Decree of the Governor of Central Java Number 560/68 of 2018 concerning Minimum Wages in 35 (thirty five) Regencies/Cities in Central Java Province in 2019, the highest minimum wage is in Semarang City of Rp. 2,498,587.53 while the lowest minimum wage is in Banjarnegara Regency, which is Rp. 1,610,000.00. With the monthly wage received by Mas Bima, this means that the Public Works Department of Highways and Human Settlements of Central Java Province participates in alleviating poverty in Central Java.

4. Conclusion

Based on the research that has been done, it can be concluded as follows:

1) There were 604 complaints submitted to the *Jalan Cantik* application (up to September 2019) and were responded to quickly within 1×24 hours.
2) The condition of Provincial Roads in Central Java is maintained well, namely gradually exceeding the 2019 Regional Work Plan (RKPD) performance target of 90.20%.
3) There are 1,018 Bina Marga people spread over 9 Road Management Centers, this means that the

Public Works Department of Highways and Human Settlements of Central Java Province participates in reducing the poverty rate by 0.109% of the poverty rate of the population of Central Java.

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Possibilities of Use of Glass Recyclate From Photovoltaic Panels for Concrete Masonry Units

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Abstract: The paper deals with the possibilities of use of glass recyclate from photovoltaic panels for concrete masonry units. It compares different recipes and its physical and mechanical properties with the focus on the compressive strength, density. It then compares the values of these recipes with the values of commonly used composite materials for masonry units without recyclates. Recycling of materials from photovoltaic panels is a highly discussed topic nowadays. The paper presents possibility for secondary use of glass from these panels in building industry, namely the substitution of aggregate in concrete with glass recyclate.

Key words: concrete, glass recyclate, photovoltaic panels, recycled building materials, recycling

1. Introduction

The Czech Republic is one of the best in Europe to sort waste and recycle. And it is great that this trend does not tend to cease [1]. However, regarding the recycling of industrial waste and its possible subsequent use, here we do have considerable space for improvement. This paper deals with the recycling of glass from photovoltaic panels and studies the possibilities of use of this glass for concrete masonry units.

Photovoltaic panels installed in Europe, including the Czech Republic, will begin to reach the limits of their lifetime in few years. Therefore, the topic of recycling of photovoltaic panels is more than actual and the possibilities as well as the limits of recycling are increasingly being discussed. Waste material from photovoltaic panels consists mostly of glass, for which we can find a wide range of secondary use. Here we focus of the usage in the building industry, specifically as a substitute for aggregates in concrete. The paper examines the mechanical properties of concrete samples made from glass recyclate, that has supplemented or completely replaced the aggregate in the concrete recipe.

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2. Material and Methods

2.1 Recycling of Photovoltaic Panels

Recently, the recycling of solar panels has been a major topic and it brings several serious questions and unsolved issues.

EU Directive on waste electrical and electronic equipment aims to contribute to sustainable production and consumption by the prevention of electrical waste and by the re-use, recycling, and other forms of recovery of such wastes to reduce the disposal of waste and to contribute to the efficient use of resources. Since 2018, this EU Directive dealing with the disposal of solar panels requires recycling of at least 80% of the panel and minimum of 85% of waste recovery. Recycling means secondary material use; the waste recovery (use of waste) means both material and energy use. Table 1 shows the evolution of the quota over the time.

There are many types of photovoltaic panels — Monocrystalline (Mono-SI), Polycrystalline (Poly SI), Thin-film (TFSC, CdTe, CIS, CIGS, a-Si), or Concentrated (CVP, HCVP). Various types from different manufacturers are installed in the Czech Republic. Classic solar panels of first and second generation are largely made up of glass (typically 70%, up to 95% in Thin-film PV panels) [3]. In order to meet the quotas, it is therefore necessary to ensure primarily the recycling of glass.

For the presented research, crushed glass from photovoltaic panels was used for production of glass recycled concrete samples. The glass we get from the PV panels is not a 100% SiO_2. Table 2 shows the chemical composition of glass from the two types of panels commonly used in the Czech Republic.

Table 1 EU quota for recycling of photovoltaic panels

	2012-2015	2015-2018	Since 2018
Waste recovery of PV panels	75%	80%	85%
Recycling of PV panels	65%	70%	80%

Table 2 Chemical composition of PV panels glass.

	Loss on drying (105°C)	Loss by ignition 1100°C	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	CaO
LDK SOLAR	0.23	1.08	69.5	1.230	0.172	0.023	0.005	10.20
QS SOLAR	0.22	0.50	71.0	0.499	0.110	0.023	0.006	8.45
	MgO	K_2O	Na_2O	Li_2O	Cr_2O_3	BaO	ZrO_2	SrO
LDK SOLAR	1.44	0.032	12.9	<0.002	0.005	0.005	0.008	0.008
QS SOLAR	4.04	0.171	12.4	<0.002	0.005	0.009	0.009	0.005

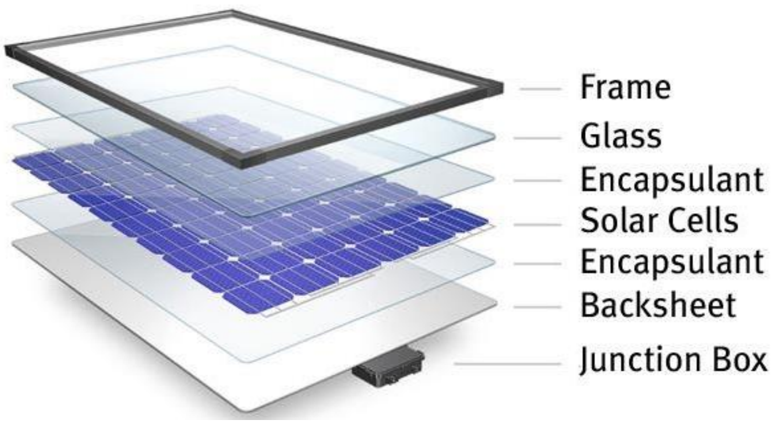

Fig. 1 Variance and percentage distribution of the electric power demand in the piglet's production.

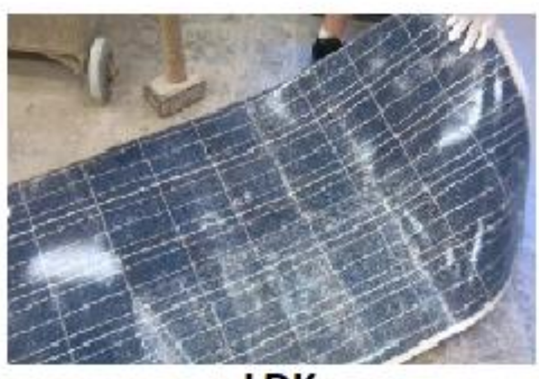

Fig. 2 PV panels – producer QS Solar and LDK Solar Co.

2.2 Concrete Recipes

The Glass recyclate from photovoltaic panels was obtained from BAMBAS Elektroodpady s.r.o., in two fractions, 1-2 mm and 4-8 mm.

By the sieving method (ČSN EN 933-1) we confirmed that in the case of fraction 1-2 mm 86% of the recyclate falls into the indicated fraction, in the case of 4-8 mm 84% falls into the indicated fraction [4].

Table 3 Results of sieving method for glass recyclate of fraction 1-2 mm.

Sieve Designation [mm]	Weight of the Partial Residue R_i [g]	Partial Residue on the Sieve [%]	Total Residue on the Sieve [%]	Total Sieve Drop [%]
16	0.00	0.00	0.00	100.00
8	0.00	0.00	0.00	100.00
4	0.00	0.00	0.00	100.00
2	1.09	0.05	0.05	99.95
1	1717.43	85.90	85.95	14.05
0.5	281.14	14.10	100.05	0.00
0.25	0.97	0.05	100.10	0.00
0.125	0.17	0.00	100.10	0.00
0.063	0.02	0.00	100.10	0.00
0	0.17	0.00	100.10	0.00

Table 4 Results of sieving method for glass recyclate of fraction 4-8 mm.

Sieve Designation [mm]	Weight of the Partial Residue R_i [g]	Partial Residue on the Sieve [%]	Total Residue on the Sieve [%]	Total Sieve Drop [%]
16	0.00	0.00	0.00	100.00
8	9.59	0.50	0.50	99.50
4	1685.24	84.30	84.80	15.20
2	269.32	13.50	98.30	1.70
1	31.26	1.60	99.90	0.10
0.5	3.83	0.20	100.10	0.00
0.25	0.23	0.00	100.10	0.00
0.125	0.38	0.00	100.10	0.00
0.063	0.00	0.00	100.10	0.00
0	0.57	0.00	100.10	0.00

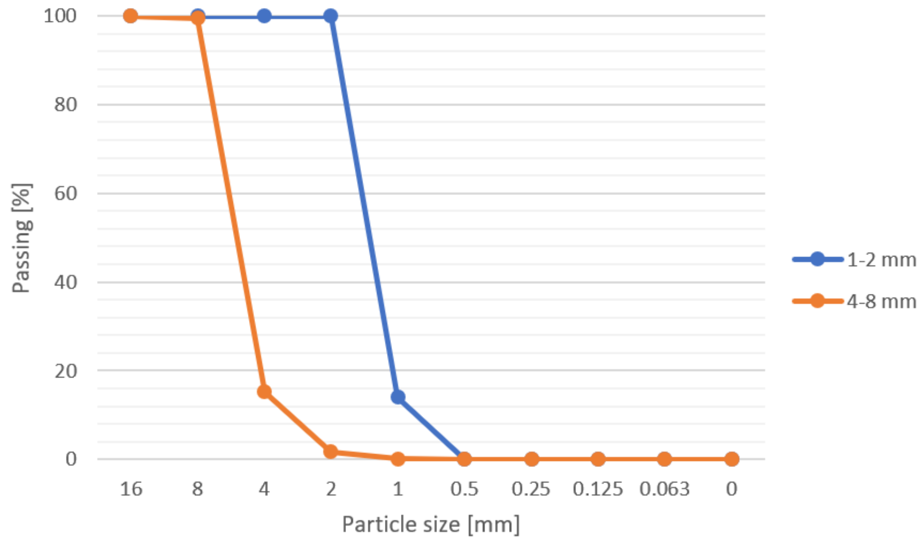

Fig. 3 Grain size distribution curves of the glass recyclate fractions.

Two recipes were used to produce concrete samples with glass recyclate, that we used for further research. The first recipe (A) contained glass recyclate of both of mentioned fractions and the aggregate of fraction of 4-8 mm. The second one (B) contained only the glass recyclate of both fractions, without the addition of aggregate. A detailed description of both recipes is given in the Table 5.

2.3 Performed Tests

Specimens made from concrete with glass recyclate (both recipes A and B) and the recyclate itself were subjected to the following test:

- Tests for mechanical and physical properties of aggregates — Determination of loose bulk density and voids (ČSN EN 1097) [5].
- Determination of bulk density of fresh concrete — 48 hours old (ČSN EN 206+A1, ČSN EN 12350) [6, 7].
- Determination of bulk density of concrete — after 28 days (ČSN EN 206+A1, ČSN EN 12390) [6, 8].
- Determination of compressive strength of concrete (ČSN EN 206+A1, ČSN EN 12390-3) [6, 9].

3. Results and Discussion

According to the standard ČSN EN 1097, we determined the loose bulk density and voids of glass recyclate from PV panels [5]. Where the void content indicates the ration of grain gap volume to total volume of mass. The measured results of bulk density and void content is shown in the Table 6.

Table 5 Recipes of concrete specimens with glass recyclate

Recipe designation	Cement CEM II 32.5 R [kg.m^{-3}]	Glass		Aggregate	Water [kg.m^{-3}]
		1-2 mm [kg.m^{-3}]	4-8 mm [kg.m^{-3}]	4-8 mm [kg.m^{-3}]	
A	350	700	300	1000	150
B	350	950	1150	-	150

Table 6 Measured results of loose bulk density and voids of glass recyclate.

Bulk density	fraction 1-2 mm [kg.m^{-3}]	fraction 4-8 mm [kg.m^{-3}]

Loose recyclate	1086	1265
Compacted recyclate	1261	1413
Void content	fraction 1-2 mm [%]	fraction 4-8 mm [%]
Loose recyclate	60	53
Compacted recyclate	53	48

Fig. 4 Determination of bulk density of glass recyclate of fractions of 4-8 mm and 1-2 mm.

The values of *fresh concrete density*, i.e., samples at the age of 48 hours, reached an average of 2160 kg.m^{-3} for the recipe A. For the recipe B, that contained only the glass recyclate, the average value was 1880 kg.m^{-3}.

Further test results are presented in the following Table 7. There are presented values for each specimen, as well as average values for *recipe A* and *B*. The compressive strength was determined after 28 days.

Table 7 Tests results and measured values.

Specimen	Weight [g]	Density [kg.m^{-3}]	Specimen Dimensions [mm]	Compressive Strength [MPa]
A1	7213.2	2137.2	150×150×150	20.9
A2	7227.0	-	150×150×150	22.6
A3	7243.6	-	150×150×150	22.0
A – average	7227.9	**2140**	150×150×150	**21.8**
B1	6220.4	1843.1	150×150×150	11.5
B2	6286.4	1862.6	150×150×150	11.9
B3	6198.6	1836.6	150×150×150	11.9
B4	6229.8	1845.9	150×150×150	11.3
B – average	6233.8	**1850**	150×150×150	**11.7**

The results of compressive strength, that we obtained from the measurements, show satisfactory values. For recipe A, with both glass recyclate and one fraction of aggregate, the average measured strength is 21.8 MPa. This value corresponds to the mean values of ordinary normal weight concrete. Recipe B, where all the aggregate is replaced by the recyclate from PV panels, reached the average value of 11.7 MPa. However, it also has a lower density and is therefore lighter. Both recipes, even the mix B with lower value of compressive strength, are suitable for load-bearing masonry units.

For illustrative comparison, we can take a short look at compressive strength and density of the widely used lightweight aerated concrete YTONG. See the data in the Table 8. We can see that the compressive strengths of different types of YTONG reach just half (or in some types quarter) of the value measured for the concrete with glass recyclate from PV panels. (This comparison only aims to illustrate differences in compressive strength and density, it does not seek to compare mentioned materials overall. More properties such as thermal conductivity and frost resistance need to be studied and compared.)

Table 8 Data and values for lightweight aerated concrete YTONG for peripheral and load bearing walls.

Type	Density [kg.m^{-3}]	Compressive strength [MPa]
Standard P2-400	400	2.7
Univerzal P3-450	450	3.5
Statik P4-550	550	5.0
Statik Plus P6-650	650	6.5

4. Conclusion

The results obtained from measurement proved that strengths of concrete units with glass recyclate from photovoltaic panels are satisfactory for use in building foundations as well as for load-bearing structures of low-rise buildings.

The admixture of polymer fibres could bring further improvements in mechanical properties of the material. Combination of coarse concrete recyclate with fine glass recyclate comes into consideration when preparing new possible recipe.

One limitation will always be the smoothness of glass surface in connection with cement and possible reaction glass — calcium hydroxide. Several scientific studies have already addressed this issue [10-13].

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