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- Safety Engineering, Materials Procurement, Budgeting & Cost Engineering
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Embedment of Building Information Modelling for Automated Sustainable Building Design Evaluation

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A B S T R A C T

During the last decades, the Architecture, Engineering and Construction (AEC) industry have experienced intensive attention towards sustainable building technology because of the strong impact in decreasing Carbon Dioxide emissions and mitigating climate change risks. There are multiple sustainability standards, guidelines and rating systems for different building types to be followed locally and globally. Meanwhile, Building Information Modelling usage has been rapidly increased among different disciplines in the AEC sector due to its leading role in facilitating the design process and increasing interoperability among construction project team members. Moreover, it also enables the design team members to perform different environmental analyses and energy simulations. Several previous studies have introduced the integration of BIM technology and sustainable building evaluation systems. Most of these studies have focused of the LEED rating system as it is the most commonly used evaluation system for sustainable building design around the world. Nevertheless, very limited studies have given attention to nationally developed sustainable building evaluation systems. Egypt, as one of the most vulnerable countries towards climate change threats, taking serious actions to adapt on both governmental level and community level. Assuring sustainability and energy efficiency in buildings plays an important role in mitigating climate change effects. In this research, it is intended to integrate BIM technology with TARSHEED rating system, as a community developed evaluation system for existing and newly built residential buildings. This integration is supposed to facilitate the process of evaluating the building design in reference to TARSHEED standards and guidelines.

Keywords - TARSHEED Rating System, BIM, LEED Automation, Rule-based Compliance Checking, Sustainable Building Design.

I. INTRODUCTION

Despite the very low contribution of Egypt in the global GHG's emissions, Egypt is considered as one of five highly vulnerable countries to climate change impacts. Egyptian cities are facing dramatic impacts of climate change pushing public debates to consider responses[1]. As for the urban areas affected; Egypt is ranked the fifth in the world concerning the biggest impact of Sea Level Rise (SLR) on the total urban areas[2]. Adaptation is a risk-reduction strategy for ameliorating the adverse effects of Climate Change on human and ecological communities and for capitalizing upon potential opportunities. Adaptation specifically refers to actions, policies, and measures that increase the coping capacity and resilience of systems to climate variability and CC[3]. Also, adaptation can be generally divided into two types of measures: vulnerability reduction and resilienceenhancement[1]. The EU Climate Action highlighted six areas where adaptation measures should be applied and financed. The first three measures are highly needed for Africa and mainly Egypt since water and energy shortages are high on the government agenda as followed; a. using scarce water resources more efficiently; b. adapting building codes to future climate conditions; c. building flood defenses and raising the levels of ditches[4]. Accordingly, The Egyptian Cabinet for Information and Decision Support Center in collaboration with UNDP has developed Egypt's National Strategy for Adaptation to Climate Change and Disaster Risk Reduction. As for the Rural Areas, Housing and Roads Sector; there are three proposed Adaptation strategies in the field of buildings, roads and low flows of the river Nile[5].The adaptation in the fields of buildings includes numerous actions for instance:"Efficient energy utilization that will reduce GHG emissions, Rationalization of water use and reusing gray water, Environmental compatibility of buildings, and Adoption of an energy code pertaining to energy in residential and commercial buildings"[5]. Governmental measures that have been carried out to achieve the strategic objectives for energy pillar by 2030 and enhance energy efficiency in buildings. Therefore, Many campaigns have been published to increase awareness for importance of energy efficiency and how to be achieved in buildings, especially residential buildings[6][7] and also raising Energy efficiency internationally funded projectsuch as the UNDP-GEF Energy Efficiency Improvement Project implemented by Ministry of Electricity and Renewable Energy[8][9].In addition, regarding the sustainable building rating system, the Supreme Council of Green Buildings was founded in order to propose a New local Green Building Code for new Communities called Green Pyramid Rating System (GPRS)[10]. As residential building, according to a study about energy consumption according to building sector conducted by Central Agency for Public Mobilization and Statistics (CAPMS) in 2016,consume approximately 51 % of the total energy consumption[11],an incentive has also taken place by Egyptian professionals that work in the field of sustainability and environmental design, have collaborated and released TARSHEED rating system for residential buildings, new and existing communities[12].Accordingly, there was an utmost necessity to create a reliable platform that assist in facilitating the application of such sustainable building rating systems and standards.

II. TARSHEED RATING SYSTEM

Even though many international sustainable building rating systems can be easily implemented in the construction market in Egypt, none of them could lead the market transformation requirements. Hence came the need to develop a rating system that match the Egyptian market properties[13].TARSHEED is a simple, easy to understand andapply rating system created especially for Egypt and other developing countries. Unlike other rating systems that contains more than six categories, TARSHEED consists of three main categories: Energy, Water and Habitat[12].TARSHEED is point-based sustainable building rating system aiming at encouraging stakeholders to improve their achieved points for each credit that mainly focus on innovation and zero pollution. There are four different levels of certification for

TARSHEED rating system; Bronze, Silver, Gold and Platinum, based on the achieved points as indicated in Table 1[12].

Certification Level	Points Achieved
TARSHEED Bronze	40 – 49 points
TARSHEED Silver	50 – 59 points
TARSHEED Gold	60 – 69 points
TARSHEED Platinum	70 points and above

Table 1. Certification Levels of TARSHEED

III. BUILDING INFORMATION MODELLING

There are various definitions of Building Information Modelling, one of the most reasonable definitions was byMiettinen and Paavola 2014 as "a digital representation of a building, an object-oriented three-dimensional model, or a repository of project information to facilitate interoperability and exchange of information with related software applications"[14].

One of the most important advantages of BIM is that it works as a platform of collaboration and interoperability among all project phases from design, construction, facility management to post occupancy and maintenance. The interoperable usage of BIM decreases ambiguity, inconsistency and inaccuracy in design and increases efficiency and productivity in the AEC industry[14].

Moreover, it enables users to embed external applications by developing add ins or plugins that can automaterepetitive or complicated functions that cannot be performed manually. So that it enables applying external features to a BIM model [11][15].therefore,BIM introduces a new technological paradigm shift for Architecture, Engineering and Construction industry[16].

IV. BIM-EMBEDMENT MEASURES FOR SUSTAINABLE BUILDING EVALUATION

Multiple processes of integration, differentiation and solutions are taking place simultaneously as a major feature of BIM implementation and development[14]. For example, previous measures during the last decade studied the integration of BIM for automation of sustainable building rating system process of LEED rating system, as the most commonly used rating system worldwide[11]. Ohueri et al. 2019 have introduced the integration approach between BIM and the Malaysian Carbon Reduction and Environmental Sustainability Tool MyCREST in order to support making decisions related to sustainability in the early stage of green building design project, and also automates the process of Carbon Dioxide rate evaluation and calculate the potential achieved points for certification[17].

Seghier el al. 2019 have developed Auto-CUI which is a computational BIM-embedded system using Visual Programing Language for automating Concrete Usage Index (CUI) rating and evaluation [18]. Khan et al. 2018 have developed MyCrest-LCC, an automated system that applies sustainable building rating assessment, and life cycle cost analysis. It can assist in eliminating construction planning duration and expenses. It may also assist in supporting reliable decision making, strategic planning and calculate expected initial and future costs of a construction project in a systematic automation [19].Han et al. 2017 have also introduced a BIM based sustainable building design support system can evaluate the building design at an early stage, calculate the potential acquired points of LEED rating system and provide real time feedbacks and practical revision guidance [20].Nguyen et al. 2016 have proposed an automated add-in that asses the potentially achieved LEED score of a building in the design stage. In this case, LEED prerequisites and credits are translated into assigned parameters that can be extracted in order to calculate the maximum potential achieved points for LEED ratings by specific algorithms [15]. Zhang and Chen 2015 have developed a rule-based automation tool for lifecycle assessment of building sustainability.

It is supposed to provide various alternative scenarios to achieve more LEED points[21]. Zhao el al. 2015 have developed LEPOST, a web-based tool that can decrease the submission expenses of LEED application and facilitate sustainable building design process [22].Most of these previous measures have used BIM platform giving the reason that it provides the ability to embed external applications whether via hard- coded programming languages or via visual programming languages.

V. TARSHEED SUSTAINABLE BUILDING EVALUATION TOOL

To outline the required data for TARSHEED automated evaluation tool, the evaluation criteria need to be added into BIM project information using the option of adding project parameters from parameter properties as indicated infig.1.

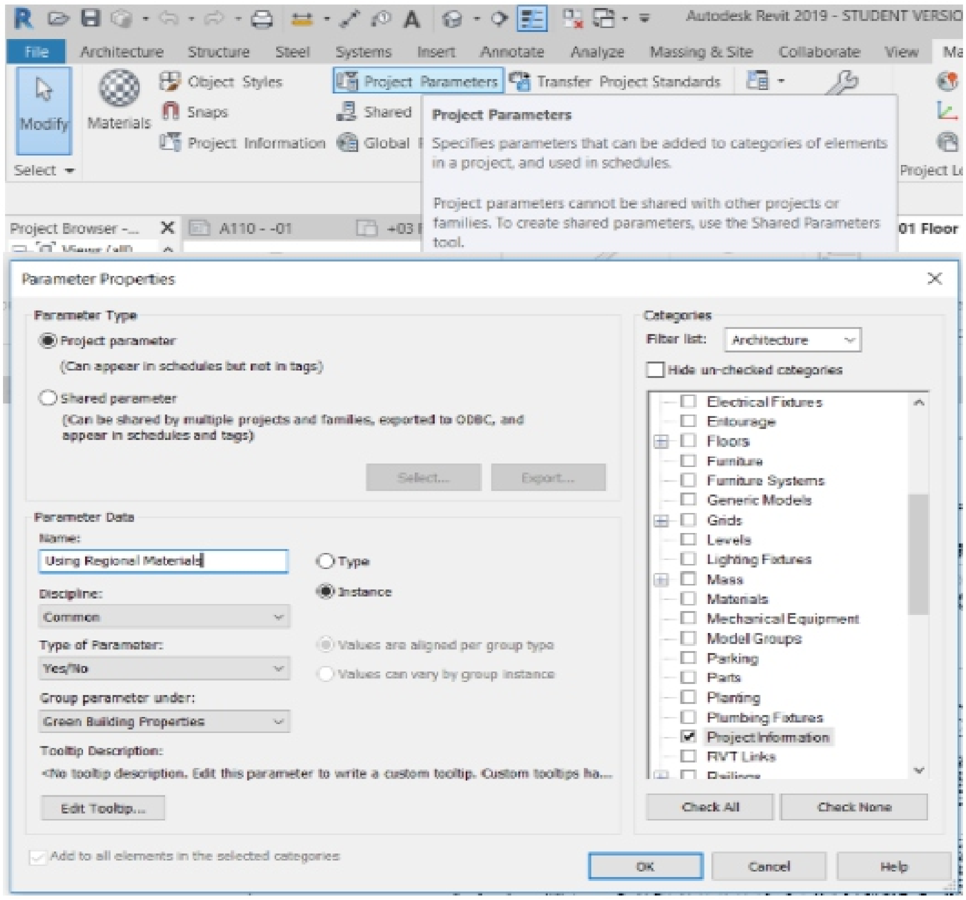

Fig.1: Adding project parameters

In order to check compliance with TARSHEED criteria and calculate points, required information need to be extracted from the BIM model. As for the numerical data, it can be easily extracted from the BIM model using specifically developed algorithm such as Window Wall Ratio WWR, Wall Resistance R-Value, Roof Reflectivity, Solar Heat Gain Coefficient SHGC, etc. This algorithm can be developed with the assistance of Revit API and C#.

For non-numerical data, that has been added into the BIM model as project parameters it is required to be completed by the working team during design process as indicated in fig.2. The most commonly used frame work for developing such algorithms depends on translating the evaluation criteria into logic sentences and then converting such sentences into actual programming codes[11].

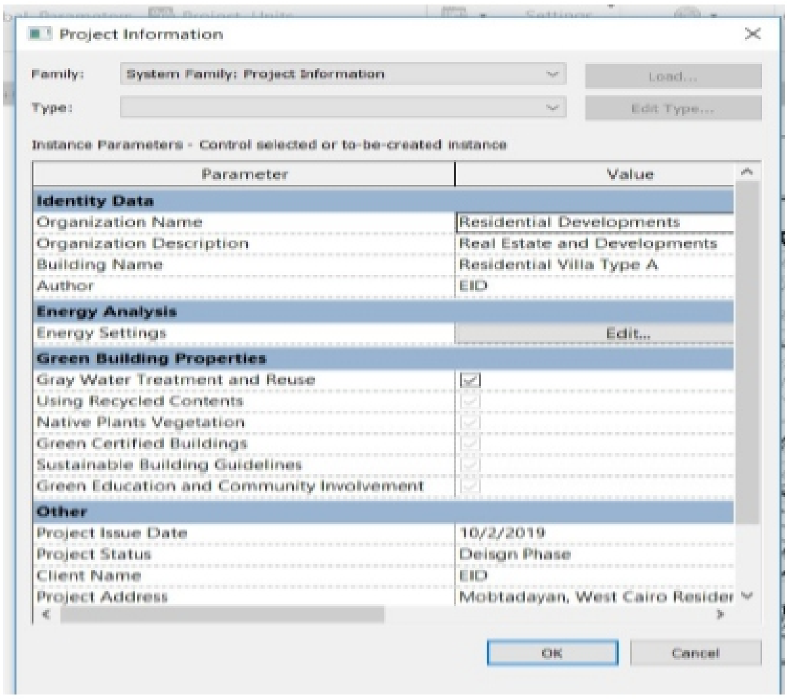

Fig.2: Project parameters created in the BIM model

VI. EVALUATION FUNCTIONS

As previously mentioned, the evaluation developed code extract the needed data whether from the BIM model itself or from the manually added information of the project parameters and test, for each evaluation category, whether this data is complied with TARSHEED prerequisites or not and then follow-up to check compliance with other credits in order to calculate the potential achieved points for each category. The sum of the total potential TARSHEED scored points is calculated as an output.

VII. IMPLEMENTATION

The proposed BIM embedded automation tool was developed and the used BIM model for verifying the automated tool was created in Autodesk Revit 2019 student version. All the needed information was fulfilled to enable the developed code to work properly. The developed code and user interface were created with the assistance of Microsoft. NET platform using C# programming language and can be implemented via Revit API. The embedded automation tool test whether extracted data with TARSHEE Devaluation criteria or not, in order to sum the potential achieved points and potential certification level.Moreover, TARSHEED score point report can be generated via exporting the calculated output to Microsoft Excel and complete TARSHEED score checklist. Fig. 3presents the user interface of the developed automation and the used BIM model for evaluation.

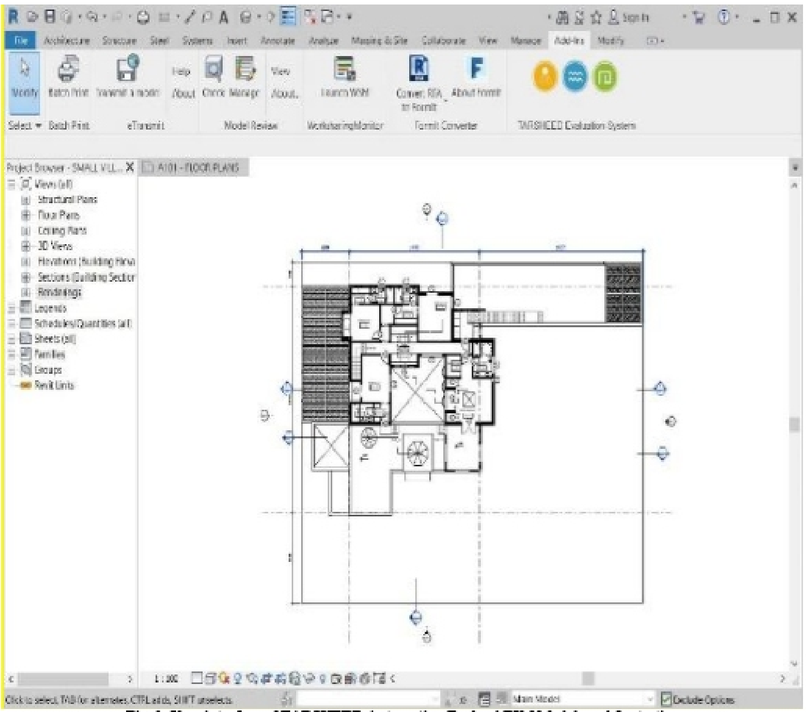

Fig. 3: User interface of TARSHEED Automation Tooland BIM Model used for testing

TARSHEED evaluation automated tool icon usually appears in the top-right at add-ins tab in Autodesk Revit. After pressing the icon, a window shows up as indicated in fig.4. The button of "Import extracted data from BIM model" is supposed to let the functional code to run in the background to extract the needed information for credit calculation depends on the selected evaluation category whether it is Energy, water or habitat. The user interface also enables the user to upload supporting required documents for each category credit. The button "Calculate TARSHEED Score" is responsible for provide the calculated potential score summary based on the achieved points of each credit of TARSHEED evaluation system.

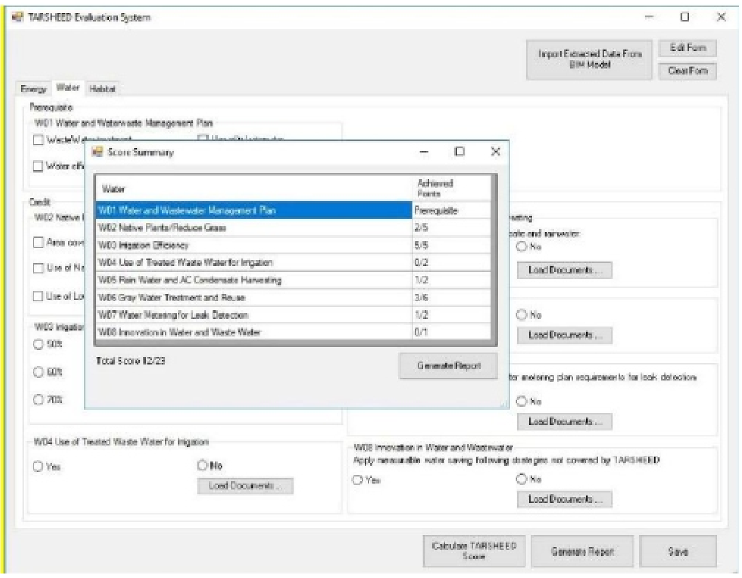

Fig. 4: User Interface of TARSHEED automation tool and evaluation summary

TARSHEED score point report is generated after exporting the calculated output to Microsoft Excel and complete TARSHEED score checklist by pressing the button of generate report. Fig. 5presentsthe generated TARSHEED evaluation checklist.

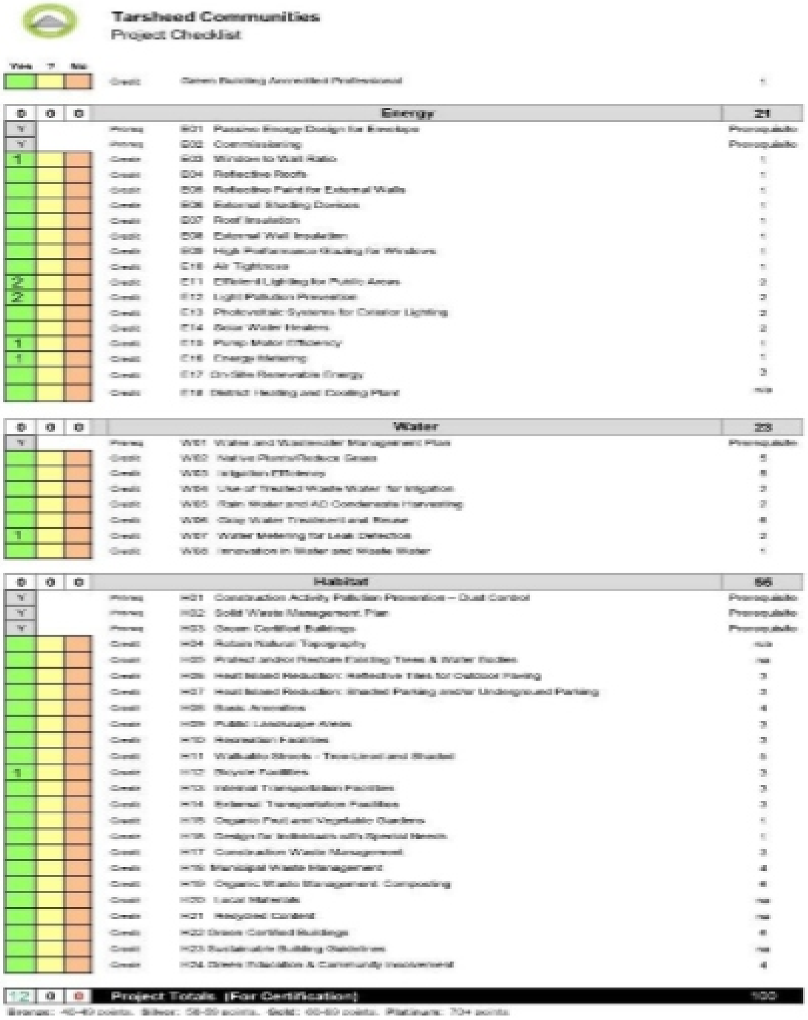

Fig. 5: Generated TARSHEED score checklist

VIII. CONCLUSIONS

The proposed BIM embedded tool for sustainable building design evaluation is meant to checking the applicability of TARSHEED criteria within the BIM model. Moreover, it can calculate the potential achieved score points of TARSHEED credits. The BIM embedded tool has shown high accuracy, increasing reliability in sustainable design evaluation and assuring quality of design rather than the conducting the checking process manually on 2D drawings. The developed tool can also assist in reducing evaluation ambiguity or inconsistency. However, further research can be performed to enable the automated tool to visualize and highlight the compliant and non-compliant elements of the model during the checking process. It can also suggest recommendation for possibility to increase the achieved points. Accordingly, BIM embedded tool for automated sustainable building design evaluation can facilitate the process of implementing sustainable building standards and guidelines that can assist it achieving energy efficiency in buildings and reducing green house gases emissions in order to achieve the Egypt's National Strategy for Adaptation to Climate Change and Disaster Risk Reduction.

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Development of NZEB and Greener Buildings in Bucharest – Solutions for Urban Problems

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A B S T R A C T

The purpose of this paper is to present an urban proposal for the current problems in Bucharest. The proposal promotes the development of a certain type of buildings that would improve the air quality in the European capital. This type of buildings combines the concept of NZEB (Net/Nearly Zero Energy Building) with the one of green buildings and therefore, implementing it would provide the advantages of both concepts. The proposal is based especially on the author's professional experience as a coordinator of major urban and architecture design projects. The article's originality is supported by the novelty of the urban concept proposed.

Keywords- Green Building, Nzeb, Solution, Urban Concept.

I. INTRODUCTION

The article presents an urban concept for solving the present problems related to air quality in Bucharest. The first chapter explores the literature review carried out regarding successful urban solutions implemented in other countries.

The second chapter describes the present situation in Bucharest referring to the air pollution and lack of green projects.

The next chapter suggests the new urban concept proposed by the author in order to improve the current situation in the European capital.

II. LITERATURE REVIEW – URBAN CONCEPTS

The literature review carried out was focused on the urban concepts of NZEB and green buildings.

According to [1],[2], urbanisation is one of the main health problems of the 21st century as cities are becoming the generators of chronic physical and mental diseases. [1], [3].

Buildings are responsible for aproximately 40% of the global energy use and 24% of greenhouse gas emissions. The need for new buildings' growth is proportional to the world population increase. Therefore, the energy efficiency and the use of renewable sources are essential to face the climate change [4].

Commercial building development support the economic development of a country [5], [6].

This development led these countries to become the highest emission generators as EU is producing 22,3%, USA 13,4% and China 9,3% of the world's total emissions [5], [7].

To face the urbanization problems, one of the urban solutions implemented worldwide is the concept of NZEB.

The concept of NZEB has flourished in developed countries, respectively EU countries, USA and Canada [8].

The European Union has started to impose the urban concept of NZEB through Directive 2010/31/EU on the energy performance of buildings states that Member States must have all new buildings nearly zero energy by 31 December 2020 and since 31 December 2018 all new public buildings have to be nearly zero-energy [9].

Consequently, France has set as a target for 2020 that all new buildings will be producing more energy than the energy they consume [10].

Brussels (Belgium) has proposed that since 2015 all new public and residential buildings will have an energy demand performance in accordance to the PassivHaus standard [10], [11].

On the other hand, in the Southern countries of Europe, the progress related to NZEB objectives is very slow. For example, Romania and Portugal encounter problems such as: lack of expertise about design and execution of NZEBs, lack of local high standard construction materials and lack of locally manufactured HVAC equipment to reach high energy performance [10], [12]-[14].

One purpose of zero energy buildings is to diminish the climate change [15].

Besides the global need to improve energy performance, by the end of the 21st century, the global temperature is gradually increasing and, therefore, the buildings have to be more energy efficient and sustainable.

A correct selection of the building concept should take into consideration the main heating source. In Nordic countries it is represented by ground source heat pumps. Therefore, in Norway and Finland the passive building design principles can lead to the nearly zero energy buildings. Moving to South, in Sweden and Estonia it is necessary to implement solar technology in order to reach the same requirements. However, in order to reach the Net Zero Energy target in the Northern countries, further research on the innovative solutions have to be carried on [16].

An example of such an innovative solution is presented in [17] which demonstrates the possibility to develop a net zero energy building in Bergen.

Analyzing the situation of NZEB development in other countries, the study of [18] revealed that China has a greater potential to reach the net-zero requirements and USA, whereas Germany surmounted the other two.

Despite the numerous benefits of NZEB, there are certain problems encountered in this building concept, such as overheating due to poor estimations of the cooling potential [19].

A complete building concept have to be based on social, economic and environmental aspects and also take into consideration the issues implied related to resource conservation, comfort, safety and health, also known as the green building concept [5], [20], [21].

One way to improve the concept of NZEB is to combine it with the green building concept.

In order to increase the green building implementation projects in Indonesia, Wimala et al. (2016) suggested that education programs should be organized, green building related practices should be included in the school curricula, grants, rewards, premium costs reduced and regulation detailing should be provided [5].

Another important discovery made on green building concept is represented by the green walls covered by vegetation which helps to increase the green areas, to limit the heat island effect, to limit loads for summer cooling and to ameliorate air quality [22].

The success of green buildings depends on various factors such as: cost economies, financial incentives and increased gains.

In the initial stage of developing a green building, the costs are higher than the ones implied by a non-green building [23],[24].

In conclusion, the urban concepts of NZEB and green building would certainly improve the present situation related to energy performance, environment and quality of life in cities worldwide.

III. NZEB GOAL IN ROMANIA

As a EU Member State Romania must accomplish the objectives imposed by the EU Directive 2010/31/EU on the energy performance of buildings and, as a result, the number of NZEB has to be increased.

Another commitment that Romania made is the reduction of toxic emissions through Directive 2016/2284.

The objectives Romania established are hard to reach as integrated urban strategies are missing. The analysis conducted by Buildings Performance Institute Europe (BPIE) entitled "The NZEB implementation in Romania" highlights the following estimated effects of NZEB implementation since 2020 to 2050 [26]:

Indicator	Reduction of CO2 emissions	Economy of energy	Annual additional investments	Number of new jobs
Effect	6,8 Mil. t	40 TWh	82-130 Mil €	1.390 - 2.203 fulltime jobs

Table 1 – Effects of NZEB implementation [26]

The expected effects of NZEB include the improvement of the economic, social and environmental situation in Romania.

Among the most significant advantages of implementing NZEB, the BPIE analysis suggests: the improvement of the quality of life due to the better thermal comfort, a superior air quality, protection against the outside noise. Another advantage would be the environmental benefits as the amount of energy demand would be reduced. Social benefits would be enabled through the lack of combustible dependence. The inhabitants would benefit from healthier conditions due to the air improvement and thermal comfort. In addition, the NZEB implementation would empower economic advantages such as: new jobs creation, efficient and innovative new technologies.

However, the benefits illustrated above can be achieved only if applicable integrated policies and strategies are implemented. The following chapter illustrates an example of practical urban concept to face the Romanian urban problems.

IV. URBAN CONCEPT PROPOSED

The new urban concept proposed represents a new stage in the NZEB standard implementation and it combines the NZEB standard with the green building concept.

A nearly zero energy building is a type of building that consumes the same amount of energy it produces. The proposed NZEB is an integrated part of the landscape. As it can be observed in the following figure 1, the new type of building cannot be seen from above, as it is partially below the ground level. It has from 1 to 3 facades opened to an underground courtyard that provides light and air ventilation of the building.

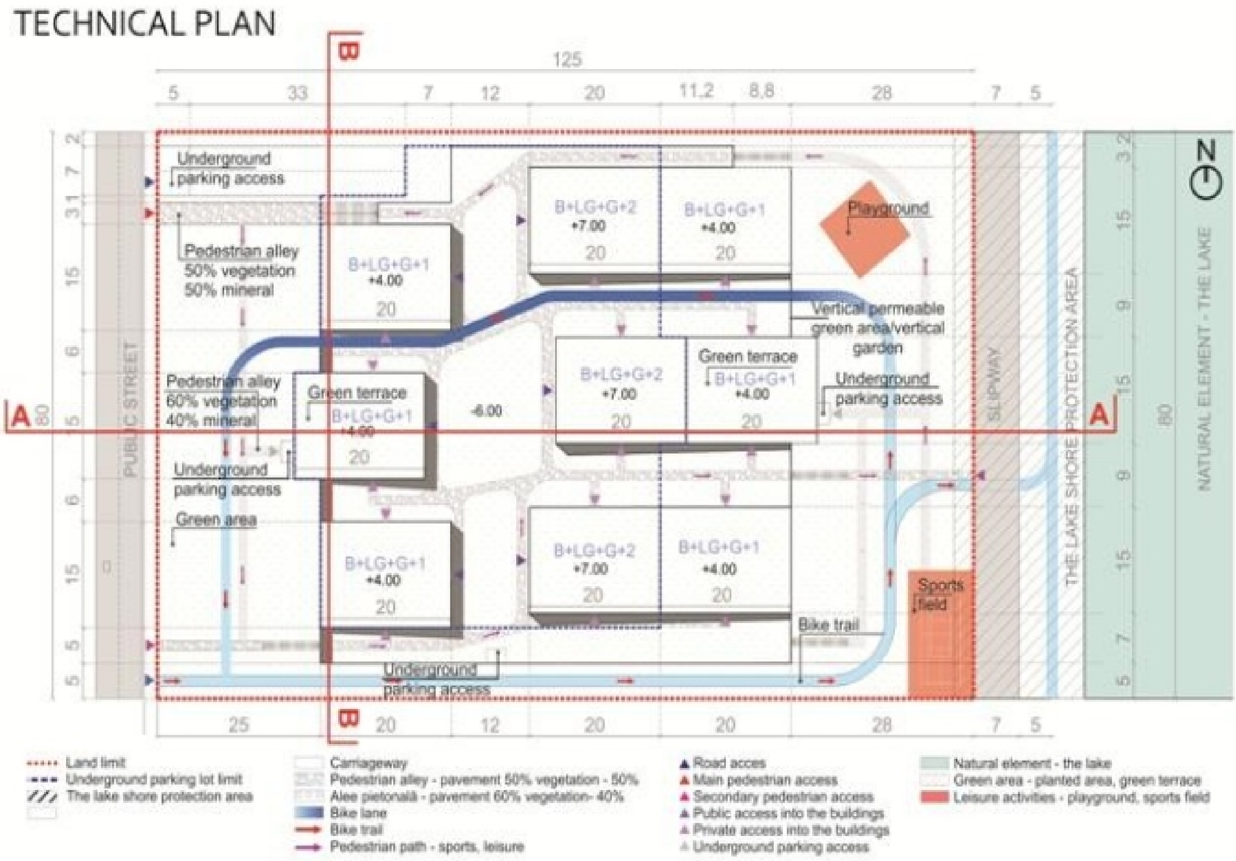

Figure 1 – Technical plan for the new type of building (own contribution)

The most important advantage of this type of building is that it does not reduce the surface of green space. In addition, the possibility of creating walls or facades covered with vegetation which would increase the green surface.

This concept can be implemented in a residential complex of 5.000 to 10.000 square meters having a height regime of Underground + Ground-floor+ 1 Floor/2 Floors, having one or more basements and a semi-basement depending on the unevenness of the ground the next figure 2 shows:

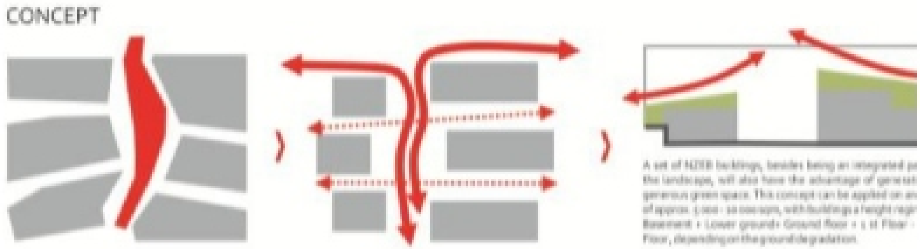

Figure 2 – The new type of building part of the landscape (own contribution)

Besides being an integrated part of the landscape, the new type of building would contribute to create a considerable green space as a private park providing numerous leisure facilities for the inhabitants.

An example of space planning for such a residential complex would include an entrance directly to the underground parking in order not avoid the car traffic inside the green space.

Among the numerous advantages of choosing to build this type of building it can be mentioned: the large green space next to the inhabitants' houses which provide leisure and sport facilities; organization of outdoor pedestrian traffic through slopes and / or stairs, thus enabling you to make physical exercise even in the park. These would ensure the inhabitants a healthy lifestyle.

The playgrounds would be safe and would offer the possibility for children to grow and develop in a community. The complementary functions as educational units, fitness center, spa, dance, dance room, beauty salons, car wash would be situated in the buildings' underground, not consuming the urbanistic indicators, as illustrated in the next figure 3:

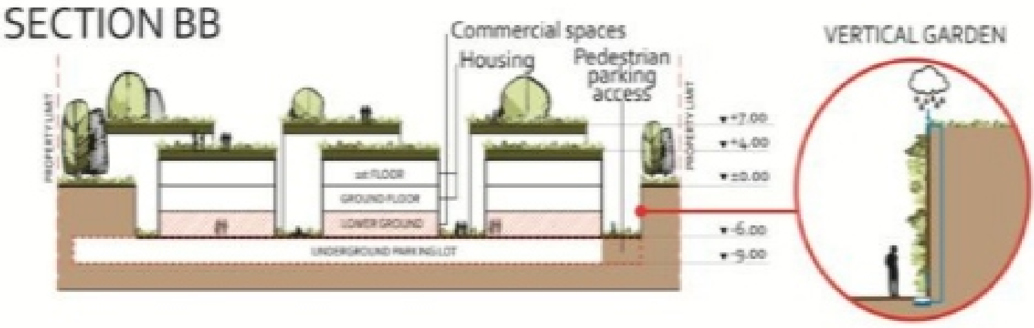

Figure 3 – Complementary functions underground (own contribution)

The water accumulated on the buildings can circulate and remain at the ground level whilst the water accumulated in the underground courtyards would be stored in water tanks and subsequently used to irrigate the green space of the complex. The following figure 4 presents the rainwater circuit in the complex:

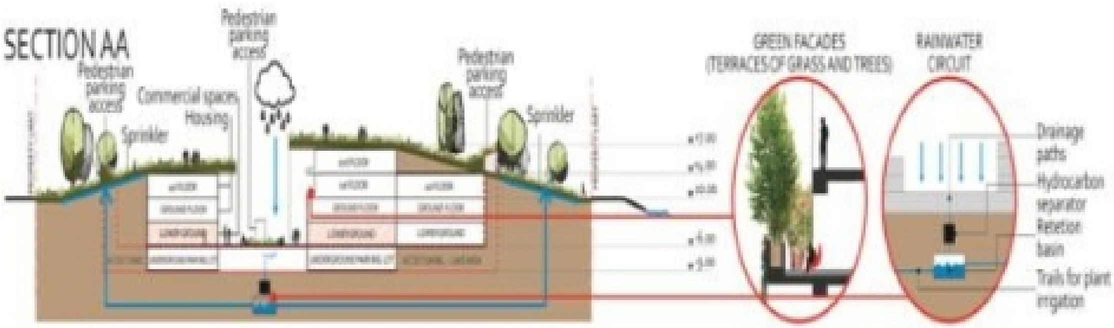

Figure 4 – Rainwater circuit in the complex (own contribution)

The concept of green building is applied through the green space provided by this type of residential complex and also through planting trees which offer a wide range of benefits being more effective than green spaces. The trees occupy small land surfaces, approximately 1 square meter per tree. However, their crowns cover large diameters; for example the linden's crown diameter reaches 25 meters and the crown's sphere volume reaches approximately 8177.083 m3.

In the following table, there is illustrated the calculation of the volume of the crown's sphere, observed from above:

	Formula		*Value*	*Unit*
Diameter	2 r		25	m
Radius	r		12.5	m
Circle Area	πr^2	≈	490.625	mp
Sphere Area (A)	$4\pi r^2$	≈	1962.5	mp
Sphere volume (V)	$4\pi r^3/3$	≈	*8177.083*	m^3

Table 2 – Calculation of the crown's sphere volume (Source for the applied formulas: https://www.math.hmc.edu/funfacts/ffiles/20004.2-3.shtml)

In order to propose certain species of trees to be planted inside the residential complex, the author analyzed the specialty literature. One of the most important references was the Salisbury and Ross Plant Physiology. [27]

The selection of trees species took into consideration the capacity of absorbing toxic emissions, the level of allergenic risk for sensitive inhabitants and the climate conditions in Romania.

Therefore, in the following figure 5 presents an illustration of trees species planted through the residential complex in order to improve the air quality:

Figure 5 – illustration of trees species (own contribution)

The author recommends the harmonization of the specific urban legislation in order to introduce new modern urban concepts, similar to the one proposed in the present paper. In this way, green projects could be implemented also on the plots regulated as green spaces. Due to the fact that some plots are regulated as green spaces, the present regulation does not permit the construction of buildings on them. However, the urban concept proposed would increase the green space and the tree planting. Therefore, the new urban concept would contribute to the creation and enlargement of green spaces instead of jeopardizing them, as it happens in the present with the classic residential complexes. Consequently a legislative update would be necessary to clarify the situation of new urban green concept and the possibility of implementing them on green spaces.

Due to the fact that NZEB and green buildings tend to be more expensive in the initial stage but also in the operation and maintenance stage, convenient legislative mechanisms are necessary in order to increase their attractiveness for private investors. These legislative initiatives would promote energy efficiency and economic incentives such as: reduced taxes, exemption from notarial taxes, access to funds dedicated to individual and also to the legal entities.

V. METHODS AND PRINCIPLES

The first method the author used was the literature review of over 100 scientific publications available on the Web of Science database related to NZEB implementation worldwide and green buildings concept.

The second important method applied was the observation from a scientific point of view. As a coordinator of major urban design projects, the author could understand the current urban problems in Romania and could offer the appropriate solutions.

In addition, the author extrapolated benchmarking, usually applied in business related activities to scientific research. Therefore, through benchmarking the existing national policies and strategies connected with the urban design planning were evaluated in comparison with the ones applied in developed countries, in order to propose an appropriate solution to improve the current situation in Romania.

The principle of sustainable development was taken into consideration when proposing the new concept for urban buildings, as it promotes "a better quality of life, now and for generations to come" [28]. It brings in an image of "progress that integrates immediate and longer-term objectives" [28].

VI. CONCLUSION

The new urban concept was developed taking into consideration NZEB standard and green building concept.

The innovative solution can be implemented in any European country in order to achieve the NZEB requirements. In addition, the implementation of the concept would contribute to the improvement of air quality, toxic emissions reduction and inhabitants' lifestyle.

The green space created through the residential complex proposed would provide the perfect place for communities to develop. These communities would be similar to the ones found in the traditional ancestral Romanian village in which collectivism and the care for the public goods were cultivated.

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Building Energy Modeling using Non-Linear Auto Regression Neural Networks

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ABSTRACT

The paper discusses the modeling methodologies for building energy system using non-linear auto regression artificial neural networks. The model predicts whole building energy consumptions as a function of four input variables, dry bulb and wet bulb outdoor air temperatures, hour of day and type of day. To train and test the models, data from two existing buildings and from simulations are collected and used. The data are pre-processing using wavelet basis to remove the noise and anomalies. Different neural network structures are then tested along with various input delays to determine the one yielding the best results. The results show that the model can predict the energy consumptions accurately and it can be then used for various energy efficiency and saving estimation applications.

Keywords - Building Energy Model, Neural Network, Wavelet Transfer, HVAC System, Regression Model.

I. INTRODUCTION

According to U.S. Energy Information Administration EIA [1], today buildings in the U.S. consume 72 percent of electricity produced, and use 55 percent of U.S. natural gas. Buildings account for about 40 percent of the energy consumed in the United States, more than industry and transportation. Of this energy, heating and cooling systems use about 55 percent. If energy-use trends continue, buildings will become the largest consumer of global energy by 2025. The development of building energy savings methods and models becomes apparently more necessary for a sustainable future. Although today modern buildings are mostly equipped with advanced building automation system (BAS) with the ability of collecting a large amount of data, those buildings still do not operate optimally due to the lack of embedded computational means and centralized solutions. Therefore, there is a significant need to investigate how modern computational techniques can help generate the analysis needed to gain full benefit from the available online data and at the same time perform many potential intelligent applications such as modeling, optimization, energy efficiency and energy assessment, and fault detection and diagnosis [2-5]. The author's overall objective is to develop energy efficiency solution tools for building energy systems through computational intelligence approaches and computational methods for data analysis. In the process of developing those tools, data-based models are developed. This paper presents the model using time series data available from building-level power meters. Although the aim of the model is to be integrated into the energy solution tools for building energy assessment and fault detection and diagnosis, the model can be also used for many other applications such as for establishing baselines and calculating retrofit savings. Many researchers have investigated data-based models for building energy systems such as single variate and multivariate change point [6-7], and Fouries series [8]. A single or multivariate regression model is widely used as a means of monitoring building energy consumptions, identifying energy efficiency measures and O&M problems, and development of baseline model in energy conservation measurement and verification projects [9].

The steady state model based on artificial neural network are also used for modeling heating, ventilation, and air conditioning HVAC components [10] and estimation of energy savings for building retrofits [11]. However, in this paper, a dynamic non- linear model based on auto regression neural network is proposed. Various structures of ANN are investigated to determine the best one that could produce best accurate results. The paper also introduces data analysis methods using wavelet analysis for pre-processing, de-noising, and potential compressing the training data.

II. METHODOLOGY

To achieve our objectives, the following methodology is used: (1) data collecting and preprocessing, (2) developing, training, testing, and refining the models using artificial neural network ANN methods, and (3) integrating the developed model into the tools for building energy assessments and other intelligent functions. The whole building level modeling and data analysis are the main focus in this paper. The data are collected from two real buildings selected from a university campus, covering eight months. In addition, an existing building is also modeled using well-known energy simulation software eQuest [12] to generate hourly energy consumptions “simulated or synthetic data” for further analysis. The actual data and simulated data are used for model training and testing.

III. DATA COLLECION AND PREPROCESSING

The 25,000 ft2 three-floor office and class room building is modeled by the energy simulation software eQuest. The hourly total energy consumptions are collected along with weather conditions for Greensboro, NC. The simulated data are divided into two sets for model training and testing. Other data collected are outdoor air dry bulb and web bulb temperatures, type of day (weekend/weekday/holidays), and the hour of day. Those data are the model inputs as discussed in model section below. Fig. 1 shows the hourly energy consumptions as a function of outdoor air temperatures. Three different trends are noted, occupied period which is between 8 am and 5pm, unoccupied period (between 5 pm and 7 am) and holidays, and HVAC system start and stop period. HVAC system turns on at 7am, one hour before occupied period, and it turns off at 4pm, one hour before the end of occupied period, but the ventilation system stays on between 4pm to 5pm.

For further analysis, two buildings from a university campus are selected. The data are collected on a five- minute interval for eight months. To exclude the noise and anomalies, the data is de-noised using wavelet transfer. Comparing Fourier transfer, the wavelet is simply another expansion basis for representing a given signal or function. The power of the wavelet basis is its ability to take a function or signal and express it as a limit of successive approximations, each of which is a finer and finer version of the function in time. These successive levels. Fig. 2 shows the energy consumption data for one building and for 30 days using 'HAAR' transfer function and with five levels of resolution. The data are smoothed by removing high frequency signals (using threshold settings of 2.4 for high frequency signals d1 and d2 in Fig. 2). Fig. 3 shows the de- noised and actual energy data for two buildings, called building#1 (Blg#1) and building #2 (Blg#2).

The smoothed signals are used for the model training. Other advantage of wavelet analysis is that the data can be compressed by retaining high percentage of energy (e.g. 99% of energy).

IV. MODELING USING ANN PREPROCESSING

Themost important factor in developing the energy solution tools is the need for accurate dynamic models. Depending on the type of functions and the accuracy required, the models can vary from simple to more detailed and sophisticated calculations [13]. However, it is of practical importance to develop simple, yet accurate and reliable models to better capture the real dynamic behavior of the subsystems and overall system over the entire operating range. In this paper, non-linear time series auto regression artificial neural networks are used. A large set of various neuron networks structures with different time delays are tested in order to determine the best and simple structures yielding adequate accuracy in term of mean square errors or coefficient of variances COV.

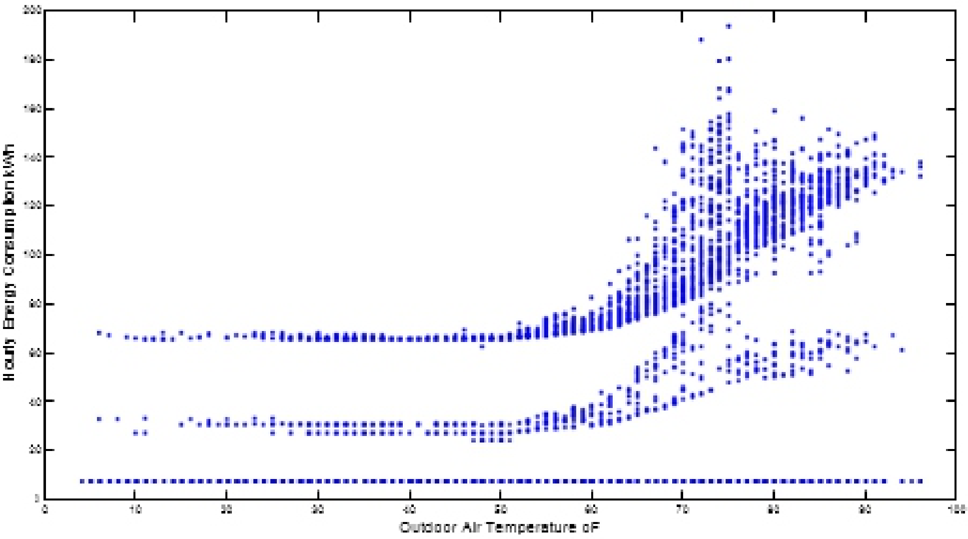

Fig.1Hourly energy consumptions as a function of outdoor air temperatures for the simulated building.

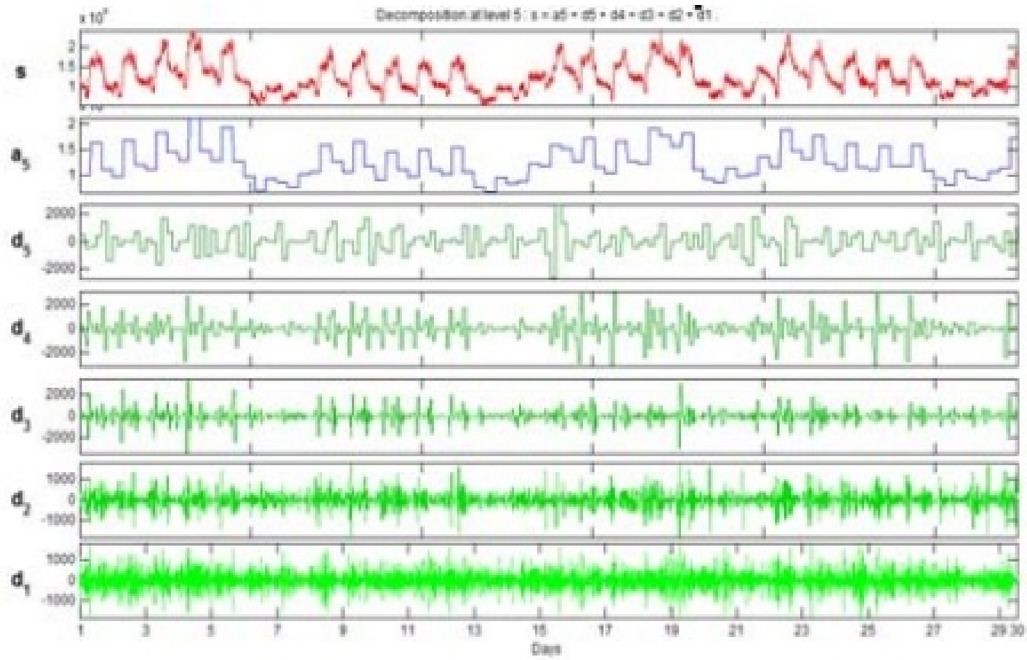

Fig.2. Data analysis for one building and 30 days (five min intervals) using 'HAAR' transfer function and with five levels of resolution.

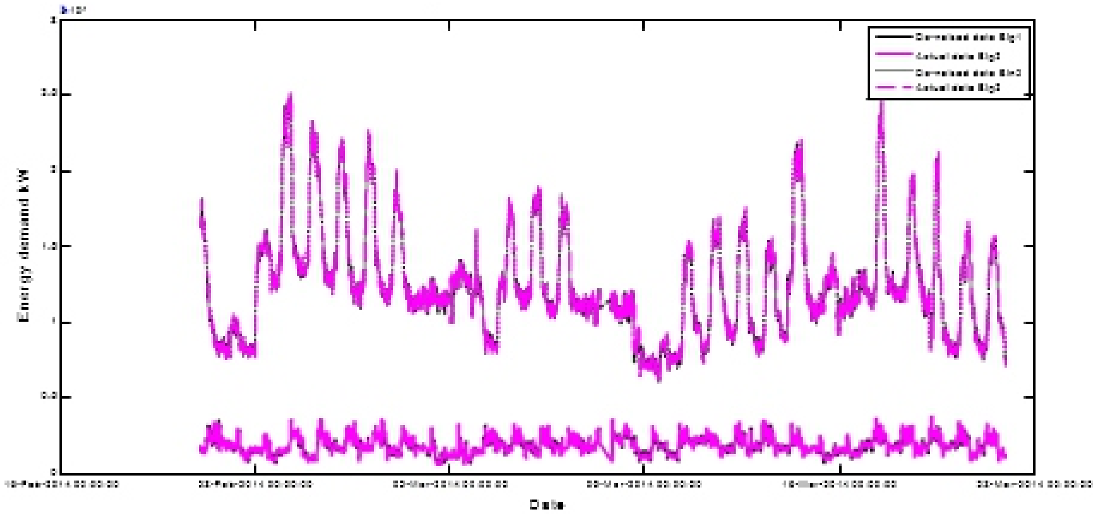

Fig.3. Actual and smoothed energy consumptions for two buildings.

Artificial neural networks are computational models that are inspired by the natural neurons of the brain. As showing in Fig. 4, natural neurons receive signals through synapses located on the membrane of a neuron. When the signals that are received are strong enough, the neuron is activated and emits a signal through to the axon. That signal may be sent to another synapse, and also might trigger other neurons for activation. The strength of the neurons' interconnections is called the adaptive weights. These are numerical parameters that are tuned by a learning algorithm. The higher a weight of an artificial neuron, the stronger the input which multiplied by it will be.

Weights can also be a negative value, so signals may inhibited by a negative weight. Depending on the weights, the computation of the neuron in a network will be different. Adjusting the weights can produce the outputs needed for specific inputs.

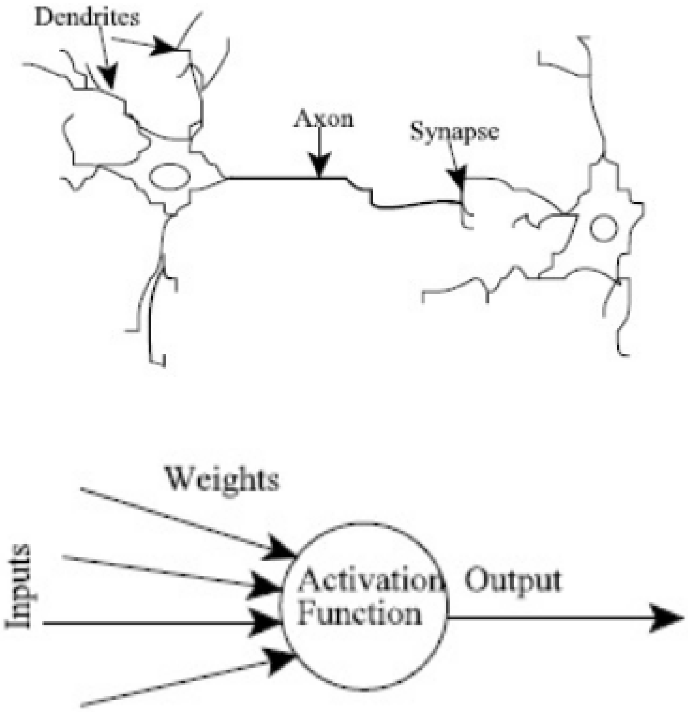

Fig.4. An artist conception of a natural neuron (top) and an artificial neuron (bottom).

Neural networks require appropriate learning algorithms to be trained. When a neural network is trained with a given set of data, it builds a predictive model based on the data. This model reflects a minimization in error when the network's out prediction is compared with the known outcome. Each learning algorithm has its own set of error- correction rules for reducing this error.

Fig. 5 shows the schematic of non-linear time series Mean Square Errorauto regression artificial neural netwrok used in this paper. The model inputs are outdoor air dry bulb temperature, web bulb temperature, type of day 2010(weekend/weekday), and the hour of day. The model output is building level energy consumption. The type of day variable is either “zero” or “one” corresponding to weekdays or weekend and holidays. The hour of day varies from 1 to 24 hrs. The best input delays n will be determined in this study based on the minimum mean square error during the testing period.

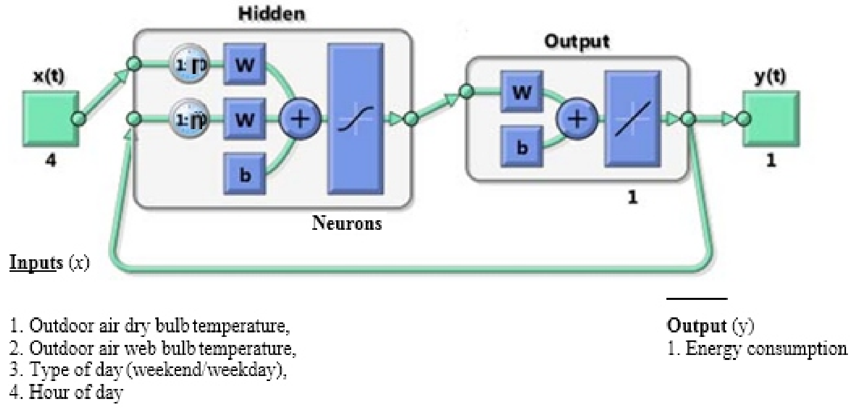

Fig.5. A schematic of non-linear time series auto regression artificial neural networks.

V. RESULTS AND DISCUSSION

The synthetic data are divided into two sets (1) training set, from Jan 1st to August 31st and (2) testing set from September 1st to December 31st. Various ANN structures are tested with various input delays in order to find the best structure. Figure 6 shows the resulted mean square errors for different number of neurons and input delays for testing and training period.

The test has been done for input time delays varying from 1 to 6 and number of neurons varying from 5 to 120 with an increment of five. Only some of those results (best results) are depicted in Figure 6.

It is generally noted that the performance in term of mean square error of each network improves with an increased number of hidden neurons in the training data set but this does not necessary produce better results in the testing data set. Indeed, the performance increase will be diminished sometime after 65 neurons. For instance, for the time input delay of one, the MSE for the training data drops from 29.93 to 10.16 when the number of neurons increases from 5 to 115. However, the MSE for testing data drops to minimum (i.e. 13.5) at 65 and then starts to increase with higher number of neuron. In addition, increasing the input delay leads to improve the results on the training data but not on testing data. As a result, for this investigated building, the delay input of one (one hour time step) holds best results on the testing data.

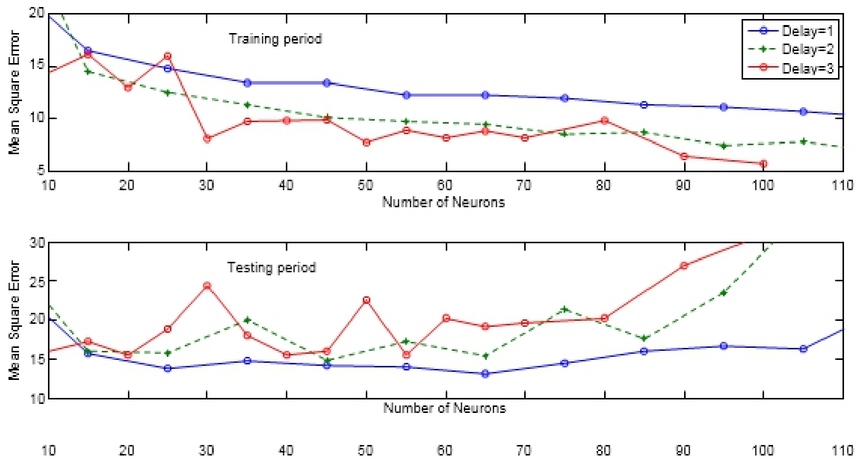

Fig.6.Mean square errors for different number of neurons and input delays for testing and training data.

Fig. 7 shows actual and predicted energy consumptions for training and testing sets. Two weeks for training and two weeks for testing data are shown in Fig.7. The results shown in this figure are corresponding to best neural network structure and input delay which are 65 neurons and the input delay of one. The days are counted from Jan 1st (day =1) to December 31st(day=365). For instance, the number of 236 in figure 8 represents Monday, September 25th, 2014. The model produces accurate results. The coefficient of variance (CV) is used as a statistical index for the model accuracy. The CV is 0.22% for training data and 0.24% for testing data.

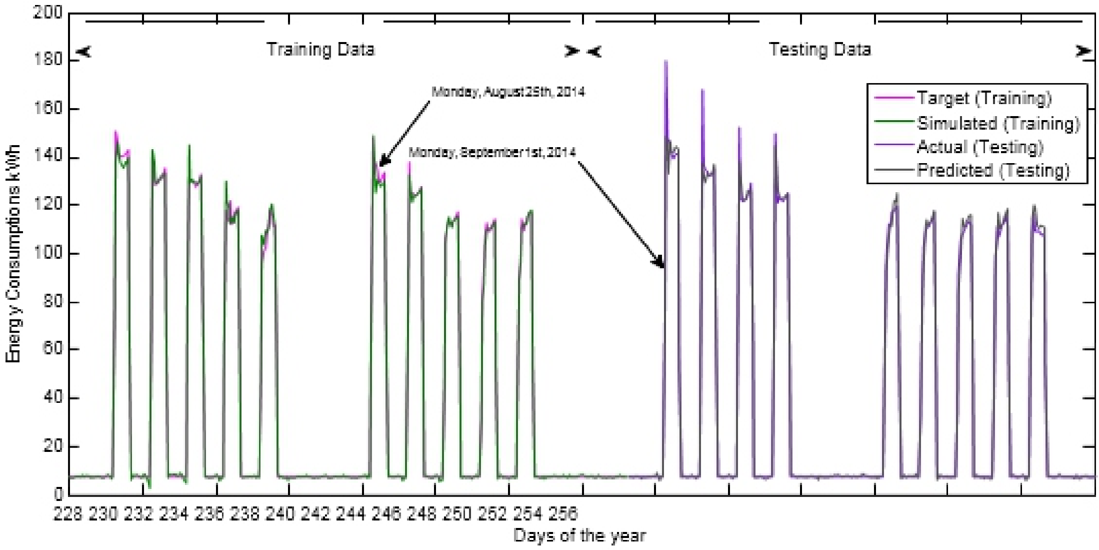

Fig.7.Actual and predicted energy consumptions for testing and training sets.

Figure 7 shows actual and predicted energy consumptions for training and testing sets. Two weeks for training and two weeks for testing data are shown in Figure 7. The results shown in this figure are corresponding to best neural network structure and input delay which are 65 neurons and the input delay of one. The days are counted from Jan 1st (day =1) to December 31st (day=365). For instance, the number of 236 in figure 8 represents Monday, September 25th, 2014. The model produces accurate results. The coefficient of variance (CV) is used as a statistical index for the model accuracy. The CV is 0.22% for training data and 0.24% for testing data.

The works are repeated, covering the two existing buildings (Blg#1 and Blg#2 as shown in Figure 3). The actual data are divided into training set of five months (from Feb to June 2014) and testing set of three months (July, August, and September 2014). The coefficient of variance for the training and testing data are calculated. The COV for Building 1 is 0.24% for training and 0.34% for testing data. The COV for Building 2 is 0.23% for training and 0.29% for testing data. These results are for the best ANN structures, which are 55 neurons for building#1 and 60 neurons for building#2. Time delay of one hold best results for both buildings. The results, from simulations and actual data on two buildings, show that the best ANN structures are within 50-65 neurons and time delay of one hour. The model can predict energy consumptions quite accurate with COV of less than 0.34% and it can be used for many energy efficiency and saving estimation applications.

VI. CONCLUSIONS

This paper presents modeling methodologies for building energy systems using non-linear auto regression artificial neural networks. The model predicts whole building energy consumptions as a function of four input variables, dry bulb and wet bulb outdoor air temperatures, hour of day and type of day. Data from simulations and actual buildings are used for model training and testing. To exclude the noise and anomalies, the data are de-noised using wavelet transfer. Different neural network structures are tested along with various input delays to determine the one yielding the best results in term of mean square errors. The model with neurons of between 50 and 65 and with a time delay of one hour holds the best results. The testing results show that the coefficient of variance is 0.24% for the simulated building, 0.34% for Building #1, 0.29% for Building#2. The model can provide accurate prediction of building energy consumptions and that can be used for many applications such as energy building assessment, fault detection and diagnosis, energy saving estimation, and saving measurement and verifications.

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Review on the Practicing of Prefabricated Building Construction Technology in Ethiopia VS World Experiences

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ABSTRACT

Prefabricated Method of Construction (PMC) is a prior method of construction in the world. Especially after WW II many European countries use PMC to solve their housing demand. This technology was also introduced in Ethiopia before thirty years ago. Nevertheless, the development and expansion is limited and it could not be saturated the sector. The purpose of this article is to review the implementation and expansion of PMC in Ethiopia versus the World experience. The study identified greater than 40 prefabricated buildings constructed for the last 30 years since the factory established and its distribution. The study showed that, the development of concrete prefab in the country were dramatically declining and its expansion was limited in the capital city Addis Abeba. Whereas, the agro-stone and steel prefab is in contrary.

KEYWORDS: Building, Expansion, Method of Construction, Prefabrication.

INTRODUCTION

Prefabrication is defined as a continuity of production implying a steady flow of demands, standardization and integration of the different stages of the whole production process, a high degree of organization of work, mechanization to replace manual labor wherever possible, and search and experimentation integrated with production process [1]. The government of Ethiopia operates a housing building program to address the high demand for affordable housing brought about by the fast growing rate of urban expansion [2]. However, this plan cannot be easily achived by means of conventional method of construction (CMC). Incontrary, the prefab factory in Ethiopia becomes to terminating. PMC is more adopted method of construction in the world. It was also introduced in Ethiopia before thirty years ago. Nevertheless, the development and expansion is limited and it could not be lead the sector. Now in Ethiopia, different types of buildings are under construction for different purposes especially apartment buildings. However, the constructions are carried out by using CMC. This can shows that, the dependency of the construction sector on CMC. This dependency on CMC leads the sector to different problems. CMC focuses on on-site operations and results in long cycle time and high cost. Due to that, project delay becomes a commomn problem in Ethiopia [19].

REVIEW ON WORLD PRACTICES

The Britain experience

The first example of prefabrication by Europeans can be seen in the 1850's. In 1851 the Crystal Palace was constructed for Britain's great exhibition. The building was made up entirely of prefabricated glass panels, wood, and cast-iron components. Once the Great Exhibition was over, the building was then deconstructed and moved [3]. This implies that, the flexibility and effectiveness of prefab in both erection and dismantling process. And the steel structure prefab building technology was begins in 1851. Most industrialized countries had begun industrialization of housing construction during WWII. The 1950s saw wide ranging attempts at mass housing using PMC and it became a mainstream construction technique, whose attractiveness has risen [4].The Former Yugoslavian Experience Demand for housing in the former Yugoslavia, like the other European countries, was very high after the end of the WW II. This helped them to develop a pre-casting system, IMS system, which was meant to fulfill: structural safety, fast rate of building, and rational use of building material and labor. Since then, the system has proven its flexibility and adaptability to newly arisen situations and has found acceptance in many countries, such as in Cuba, Hungary, Egypt, Angola, China, Italy, Austria and Ethiopia. The IMS is formed from precast concrete elements assembled in structures of different spans by pre-stressing cables to form monolithic entity. The first IMS buildings were erected in 1957 and 1982 over 60,000 housing units mainly schools, health institutions, office buildings, hotels, had been erected [1].

The American Experience

In US, manufactured housing was originated in 1950s. It starts with the mobile house. It is the rudiment stage in the development of manufactured housing. In 1976, Congress passed the national manufactured housing construction and safety act. At the same year, HUD (Department of Housing and Urban Development) started to establish the industrial standard for manufactured housing. This implies how much the government gives emphasis to implement PMC [5]. PMC in the US can be said to have started over 100years ago. The post-WWI years brought a strong stimulus to prefabrication. The U.S. continued to experiment with prefabrication, while Europe built with it [3].

The Indian Experience

In India, prefab came into effect with the foundation of Hindustan housing factory in 1950 as a solution to the housing crisis. This factory, mainly prefabricates precast concrete for various civil and architectural projects throughout India. Prefabricated materials are well-known for their durability and quality in India. Protection from climatic damages, precision work in factories and environmental

-friendly techniques have attributed to the good quality standards of prefab. These building systems are gaining popularity in India due to the need to use very scarce resources optimally. They also have the potential to address the problem of mass housing crisis in India that they face today. India started a fully precast residential G+23 building project in Parel, Mumbai in 2011. Speedy construction and design conforming to all IS design codes with less cost operations were the major objectives achieved by this project. A numerous of prefab companies are emerging within India in order to serve the housing demand of one of the most dense, heavily populated, and fastest growing economy in the world. Therefore, prefabricated residential projects can significantly reduce the cost of housing and could be effective solution to the massive shortage of housing. [17]

The Japanese Experience

The manufactured housing in Japan starts around 1960s. Due to WWII, lots of houses were destroyed. After the baby boom, the demand for residential houses was urgent. In order to construct more houses without sacrificing quality, Japanese companies used the prefabricated housing approach. Japan has its own industrial standard for PMC and construction process is finished in factory such as walls and floors, are pre- made following certain industry standards [6]. Around 1966 the ministry of construction of Japan announced "fundamental idea on industrialization of housing building" and promoted the construction of 4 to 5 story apartment houses with the aim of popularizing industrialization of housing, stabilizing building costs and improving the quality of houses. Building codes and standards were introduced to regulate structures, capacity and application for building permits and to improve quality and reduce cost and specifications of parts and accessories for public housing were standardized. In this sense 800, 5000 and 12,000 houses were built in 1962, 1963 and 1964 respectively. Prefabrication of building elements has brought great advantages in the development of industrialization and mechanization of the building industry in Japan [1].

The Chinese Experience

In China, the housing industrialization began in 1953 in Hong Kong, and in 1998 in Mainland China. In this year, the Chinese government implemented the commercial residential building reform. In about 10 years (from1998-2008), there was a significant growth in demand in the housing market and prefab materials increased from 17% (in 2002) to 65% (in 2007) since Chinese people usually live in apartment buildingswith many floors due to the huge population and limited land. Therefore, problem for Chinese real state companies was how to build more houses faster and with higher quality [6].

The Korean Experience

In Korea, the leading prefab company is Daewoo Corp, which developed a multi-room modular construction system used for multi-story buildings. The company typically has a prefabricating facility set up on the project site. Because the preassembly is completed onsite, the construction company does not have to deal with the transportation issues. All of the precast concrete modules are manufactured onsite and then lifted into position by a crane at the rate of one floor per day. Daewoo states that, their system was three times faster than conventional methods because all the factory-built panelized walls incorporated all of the mechanical and electrical systems. Like most other Asian countries, Korea's large population provides a great opportunity for using offsite construction techniques which have been widely adopted in constructing high-rise buildings that exceeded fifteen floors. [18]

The Swedish Experience

Due to the scarcity of houses, the Swedish government resolved a housing shortage into a highly professional construction industry that produced high-quality affordable homes. Today 90% of Sweden's housing is prefabricated, and most Swedes associate energy-efficiency and durability as a must with prefabricated construction. Because, PMC is a high-quality and "green" commodity [7].

The Russian Experience

Precast concrete technology was introduced in the former Soviet Union in the late 1920's, but found wide application between 1930-1936, mainly for industrial construction and for the erection of single story buildings. In 1950 and 1955 the volume of precast concrete reached 1.3 million m3 and 5.3 million m3 of concrete, respectively. The major prefabricated structural elements include: rectangular beams with length reaching up to 15m, roof beams (rectangular, T, I, and box section up to 1m length, crane runways, roof trusses, small span slabs (solid and ribbed) stairways and landing [1]. Lift-slab system with walls and pre- stressed slab-column systems were introduced in Soviet Union (period 1980-1989) in some of the Soviet Republics, including Kyrgyzstan, Tajikistan, and the Caucasian region of Russia [8].

The Singapore experience

Singapore has developed effective methods for offsite construction, especially in using precast reinforced concrete technology to construct multi-story buildings. At the same time, the Housing Development Board (HDB) has developed two systems to solve the shortage of houses. (1) fully prefabricated precast reinforced concrete systems: in this system, pre-cast column-beam-slab are connected together using bolts and anchors and post-tensioned flat plate floor system and (2) semi-precast reinforced concrete building system: in this system, the main building elements are made cast

-in-place and other elements are pre-cast in factories [9]. Since its inception the HDB is credited with constructing more than 750,000 apartments for housing, which is about 86 % of Singapore population. According to Singapore's experience, the standardization of building components is the key to successful utilization of offsite construction technologies. This standardization greatly reduces the number of modules needed to precast the concrete components and thus speed up the erection work [1].

The Egyptian Experience

In Africa, before 5000 years ago (around 2700 B.C), the Egyptian pyramid was constructed (fig.1b). It is composed of 2.3 million limestone blocks, some weighing 15 tons. The blocks were manufactured off-site and transported (pushed and pulled) in to place (on-site) by human muscles. This implies that there was the application of prefabricated construction process and the idea started thousands of years ago in Africa [10].

The Ethiopian Experience

A modern prefabricated building industry was introduced in Ethiopia in 1985 by the former Yugoslavian technical assistance under the former Ethiopian Building Construction Authority (EBCA) by the name ofPrefabricated Building Parts Production Enterprise (PBPPE). The establishment of prefab housing factory in Addis Ababa has brought new techniques for the construction industry and it was supposed to provide solution for the vast building needs. On top of this, it was aimed to accommodate the ever-increasing demand of housing within the shortest possible time and to minimize the pressing need of timber for formwork.

The factory has been producing structural elements for the construction of office, apartments, hotels, schools etc. (from G+0-G+9) by using IMS precast concrete system. At a time the IMS system has found acceptance in many countries, such as in Cuba, Hungary, Egypt, Angola, China, Italy, Austria and Ethiopia as well. However, now a day in Ethiopia, precast concrete is widely used for non-structural elements such as pipes, lintels, cladding, poles and for institutions fence work.

The other prefab factory, Ybel industrial plc was established in 2009 in Addis Abeba to construct buildings by applying prefab technology. It is the first and pioneer private prefab factory and in adoption of mechanized agro-stone panels and magnesium board technology in Ethiopia in the prefab building industry. The factory produces steel building structure, magnesium board (4.5-10 mm), agro-stone panel, light gauge steel frame (LGS), and PVC doors and windows. The factory has been constructed residence houses, project camp houses, guest houses, etc. by using steel frame, agrostone panel, magnesium board and PVC opening and ceiling in different places of Ethiopia.

The obelisks of Axum

The Axum obelisk is one of the prefabricated obelisks found in Ethiopia. The tallest of all was 33m and the second is 24.6m in height (fig, 1a). The Aksum obelisks were erected before thousands of years, during the Axum civilization, long before Christianity was permanently established as the state religion. They detached these huge blocks of granite from the adjacent mountain and transported them to the site where they were to stand and to raise them in to position. This implies that, there was a concept of prefabrication process because they prepare at the mountain (off-site) and transport to the site (on-site) [11].

During that time people prepared very big size obelisks off-site several kilometers away at the quarries of "Wuchale Golo" to the west of Aksum, and dragged from there into the city. They transport the monuments to another place by using perhaps wooden roller and whether the rather African elephant could have been utilized in helping to maneuver these giant stones is not known, but makes an interesting speculation. They also erect the obelisks with the aid of earthen ramps and tremendous human effort [12].

The figure (fig 1a.) shows that, the idea of multi-story building construction concepts by putting a grooved windows and door shapes in serious of distances in a multi-story floor styles. It also elaborates that the relation of prefab and architecture at the time. But at the time there was no school of engineering in the world, no technology, no university, no school of architecture, no standard, no codes and rules to manufacture and no cranes, trucks, heavy equipment's to transport. However, the country could introduce amazing prefab obelisks.

The stele of Tiya

Tiya is one of Ethiopia's UNESCO registered sites in home to Gurage tribes (fig.1c). It is found 80km south of Addis Ababa in Soddo Gurage zone. Most of the statues measure up to 3 m and the longest is about 5 m. Tiya is famously singled out from over 160 archeological discoveries at the site. The site contains 36 monuments, including 32 carved stele [13]. The tradition of erecting megalithic monuments is very ancient in Ethiopia. The largest and most representative collections of stele are to be found near the village of Tiya. Originally 46 steals were erected in between the 14th and 15th centuries [14]. This shows that, prefabrication concept was introduced in Ethiopia thousands of years ago.

(a) (b) (c)

Figure 1: the obelisks of Axum, Ethiopia (a), Egyptian pyramid, Egypt (b) and stele of Tiya, Ethiopia (c)

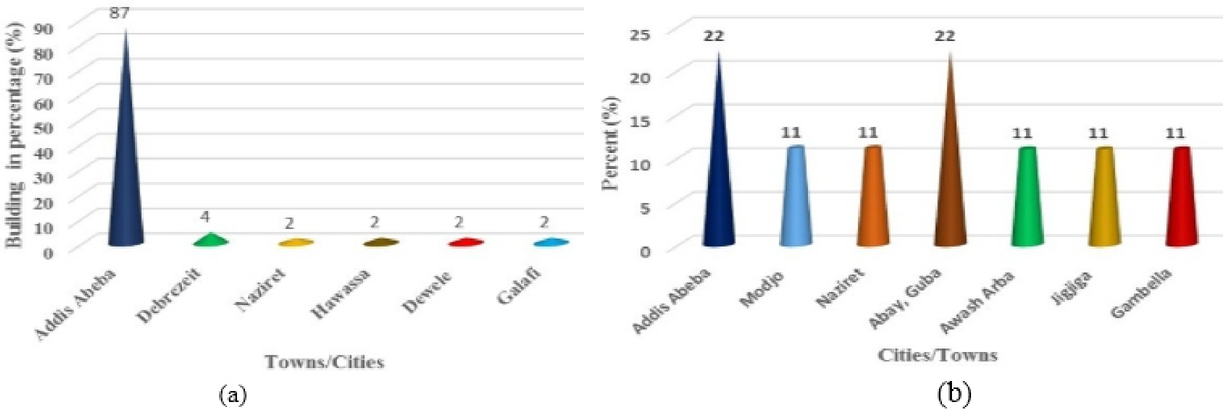
RESEARCH METHODOLOGY

The research area focuses on two of prefab building factories that are found in Addis Ababa: Prefabrication Building Parts Production Enterprise (PBPPE) and Ybel Industrial plc. One is governmental and the other is private. The areas were chosen by considering the experience and availability of prefab buildings factories. A descriptive case study method was used to address the stated objectives. Descriptive case study is a kind of research method that is more suitable to study as it exists at present and past. Such studies usually go deep into the causes of things or events using very small samples [15]. In this study, both primary and secondary data sources were used. Primary data were collected by direct communication with respondents through personal interviews, focus group discussions with professionals and field observation on the prefab factories. The secondary data were collected from both PBPPE and YBEL industrial reports, proposals, filed documents, magazines, web sites and other available documents.

RESULTS AND DISCUSSION

Expansion of prefabricated buildings in Ethiopia

Prefabrication technology is not new in Ethiopia. However, the development of the technology was not widely distributed to the other regions except some cities they are near to the factory. The following graph (graph 1) shows the expansion of prefab buildings in Ethiopia. The result revealed that (graph 1a) the highest percent (87 %) of prefab buildings were constructed and concentrated in Addis Ababa. This means that the distribution or expansion of the technology was restricted in a specific area. The second (4 %) were found in Debrezeit and the least (2 %) were found in Nazeret, Hawassa, Dewele and Galafi. This implies that the expansion of PMC in the other cities of the country was extremely limited. When the distances increase from the factory (AA) the distribution of prefab building to the regional cities decreases due to the transportation and logistics problems. That is one of the problems to limit the expansion of this technology in the country.

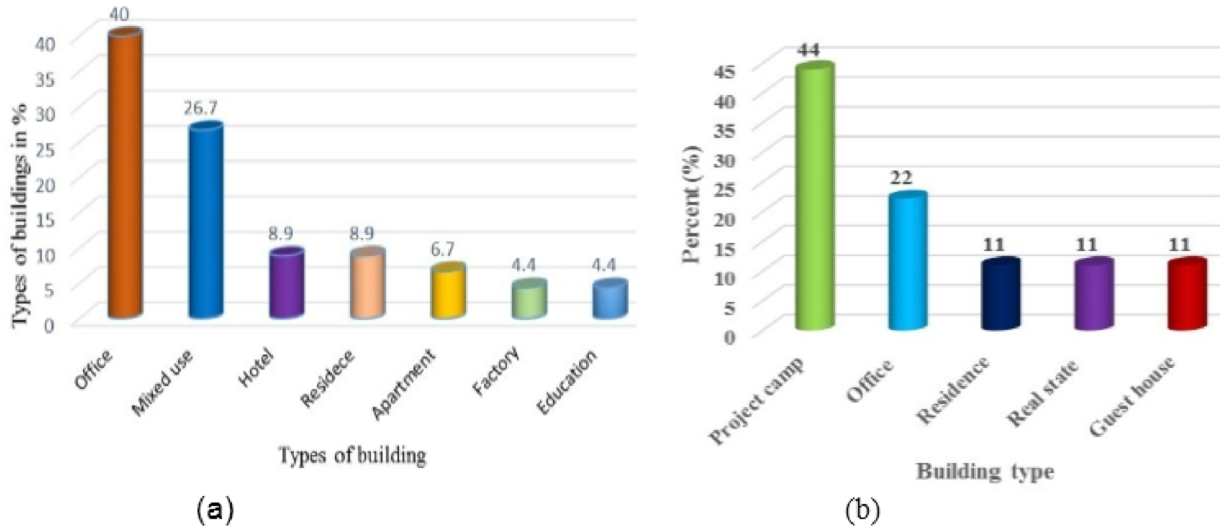


Graph 1. Expansion of concrete based(a) and Agrostone & steel based (b) prefab buildings

Light weight steel structure and agro-stone panel prefabrication technology are newer than concrete prefab in Ethiopia. However, the development of the technology were increased and distributed in good status to the other regions. The following graph shows that the distribution of LWSS and agro-stone panel prefab buildings constructed by YBEL industrial in Ethiopia. The graph shows (graph 4.8) that, about 22% of prefab buildings are in Addis Abeba and Abay, Guba and the rest 11 % are found in Modjo, Adama, Awash Arba, Jigjiga and Gambela. This implies that, the expansion of Ybel is widely distributed than the PBPPE.

Types of prefabricated building

The study result shows that PBPPE constructed different types of buildings (see graph 2a.) such as offices, mixed use, hotels, residence houses, Apartments, factories, school, etc in different part of Ethiopia.The study result (graph 2a.) shows that, about 40 % buildings were office and 26.7 % were mixied-use buildings. Education center takes the least percent (4.4%). Nevertheless, in developed countries, health and education centers take 49% and 42% respectively while the other manufacturing constitute (42%), low-Rise office (40%), public (40%) etc [16]. However, in Ethiopia PMC is very low when compared with the other countries. The graph shows that (graph 2a) out of past prefab buildings, the appartment housing takes only 6.7%. But now a days in Ethiopia the government plans to construct more than 75,000 condo houses during the GTP II using PMC. This implies that there is a huge gap on implimenting PMC on house building program.

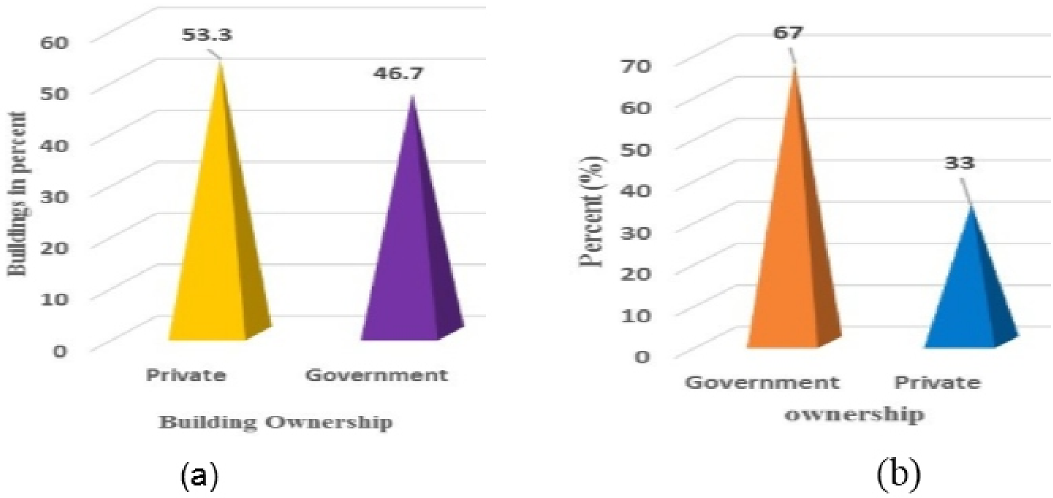


Graph 2. Types of concrete based (a) and Agrostone & Steel based (b) prefabricated buildings

The study result shows that YBEL industrial constructed different types of buildings as shown on graph 2b such as offices, mixed use, hotels, residence houses, apartments, factories, school, etc in different part of Ethiopia. The factory were carrying out the construction work using prefabricated steel, mechanized agro- stone panel and light gauge steel. The above graph (graph 2b.) showed that, 44% of agrostone prefab buildings were constructed for construction project camp housing and the second 22 % were for office building. Finally 11% of buildings were constructed for residence, real satate and guest hose buildings. The result implies that, LWSS housing method is more applicable in housing projects espcialy for project camps.

Ownership and Story level of prefab buildings construct by PBPPE

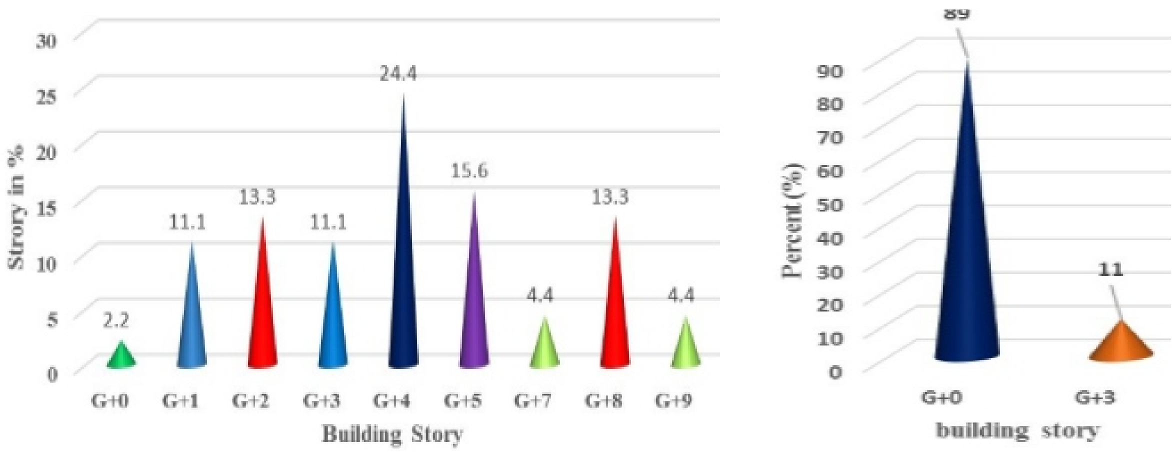
The PBPPE factory constructs prefab buildings for both private and government sectors. However, the study result shows that (graph 3a.) over half (53.3 %) of the past prefabricated buildings were constructed for the private sector. This denotes that there is a good awareness and acceptance on private sectors than the government on the effectiveness of prefab technology. The government sector follows by 46.7 %. When we compare with private sector, the government sector was weak to implement the technology.



Graph 3. Ownership of concrete based (a) and Agrostone based (b) prefab buildings in percent YBEL industrial is constructing different types of buildings in different areas of Ethiopia for both private and government projects. Based on the study result (graph 3b) most of (67%) steel prefab buildings were construced for governmental projects while only 33 % accounts for the private projects. This implies that, for governmental projects houing and for temporary and permanent camps construction LWSS method of construction is more preferable than concrete prefab buildings.

Story level of prefab buildings

The PBPPE was constructing buildings in different stories from G+0 up to G+9. This shows that, there were a capacity to implement the prefab technology in multi-story building construction in the country. Based on the study result (graph 4a.) the highest percent (24.4%) of prefab buildings were G+4 followed by G+5 (15.6%). The other (G+2 and G+8) and (G+1 and G+3) and (G+7 and G+9) prefab buildings were taking %, 11.1 % and 4.4 % respectively. The least percent (2.2%) corresponds to G+0 prefab building. This implies that, the technology was mostly implemented on multi story buildings than ground buildings. It encourages the effective usage of our land resources properly. If the factory goes as a beginning, now a days it is possible to build a high rise buildings. Based on the field observation, the past prefabricated buildings are interesting, beautiful and accurate in their surface, shape and quality and also there is no defects on the structure like cracks, (Personal observation).



(a) (b)

Graph 4. Story level of concrete based(a) and Agrostone based(b) prefab buildings in percent

Ybel industrial is constructing buildings in different stories from G+0 up to G+3. This shows that, there were a capacity to implement the technology in multi-story building construction. The result reveal that (graph, 4b.), in contrary to concrete prefab building, about 89 % of the buildings using steel prefab building are G+0. However, the other 11% (G+3) building shows that it is possible to construct story buildings using LWSS system.

Some of the prefabricated buildings in Ethiopia

(a) (b) (c)

Figure Hotel (a), Public School (b) and Apartment (c)

CONCLUSIONS

The concrete based prefab building development (PBBPE) were dramatically declining and the expansion was also limited in the capital city of Addis Ababa. The agro-stone panel and light weight steel prefab building development (YBEL) showed a reasonable increment and the expansion was widely spread to other cities beyond the capital city of Addis Ababa. Attention is not given to the prefab technology and its development in the country is not growing as it was in the beginning. The using of prefabricated building elements in Ethiopian building industry are limited to non-structural elements such as: precast beam, PVC openings, blocks and Agro-stone panels for wall and partion. However, condominium houses are easy for PMC due to the uniformity of design for the repetitive production and standardization process.

RECOMMENDATIONS

Public awareness is also a strategic function (either in government or private) if the prefab construction process needs to be changed. A bridge must be built between the customer and house manufacturer to render the market chain more efficiently and to expand PMC to the regional level. A universities should done academic and industry based research works in the area to better understand how PMC adoption and implementation can add real value to the construction process and improve the sector. Further study on supplementation of building element production with locally available material may improve the adoptability and reduce scarcity of material to solve the housing problems of the community. Visionary leadership is also required to see the current and future problems within the industry, challenges and plan towards achieving integration of available technology, innovation, and project development process. Finally, there should be a concerted effort by relevant government bodies, professionals, private investors, financing institutions, and the general public in solving the problem radically and improve the well-being of the society and the country as well.

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Applications of Ferrocement in Construction

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ABSTRACT

Ferrocement or Ferro-concrete is a system of reinforced mortar or plaster applied over layers of metal. It had been concluded from this study how ferrocement is better than conventional types RCC, PCC etc and how it perform good against lateral displacement, fire resistant etc economically without required any skilled worker. Ferro concrete is relatively a new material and has good strength and resistance to impact. It provided better resistance to fire, earthquake, and corrosion than traditional materials such as wood, adobe and stone masonry. It is used in construction as well as repair material. The main purpose of the paper is a try to introduce new technology like ferrocement and its applications by literature study using various references.

Keywords - Ferrocement, Mortar Matrix, Fibers, Mesh Reinforcement, Rcc, Servicibility, Durability, Ferrocrete.

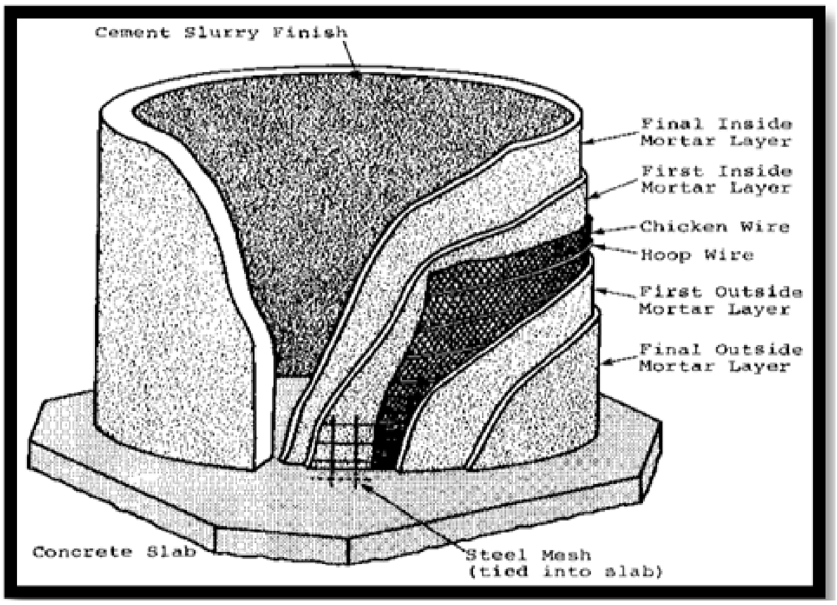
I. INTRODUCTION

Ferrocement is a composite material used to form thin section, it is composed of a mortar, reinforcement include light steel fabrics and meshes. Ferro cement originated in the 1840 in France and used for the construction of a rowing boat and after this a reinforced concrete was invented. Ferro cement cover the wide range of applications due to the low self weight, economic, lack of skilled workers, no need of frame work etc.

Ferrocement used in sewage pipes

Walls constructed with a help of Ferrocement can withstand against 0o temperature to 1700o and after that the damage is negligible and can be repaired. The expansion in Ferrocement due to fire is negligible and no cracking or splitting is occurred & bond being very high. A Ferrocement reinforcing can be done over any temporary frame work in any desired shape and mortar can be applied. All the studies on Ferrocement reported that it has performed well under almost all the loading conditions weather it is tension, compression, flexure, shear, torsion, fatigue, impact or dynamic loading.

On the other hand when we compare Ferrocement with RCC (Reinforced Cement Concrete) it perform better against crack, because wire messes that were used in Ferro cement will cover the macro part of Ferro cement structure and avoid cracking, and in RCC structure there is a possibility of crack due the attack of aggressive chemical like Cl-SO4.



Detailed View of Ferrocement Construction

II. DEFINATION OF FERROCEMENT

Ferrocement is defined in different ways by different organizations.

1) According to United Nations High Commissioner for refugees (UNHCR), ferrocement is defined as 'A thin walled construction, consisting of rich cement mortar with uniformly distributed and closely spaced layers of continuous and relatively small diameter mesh (metallic or other suitable material).' (reference-UNHCR-Large ferrocement Water tank Manual July 2006).
2) ACI committee-549 describes it- 'Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh and/or small diameter rods completely infiltrated with, or encapsulated, in mortar. The most common reinforcement is steel mesh' (reference – ACI 549.1R-93- Guide for the design, construction and repair of ferrocement)

III. BASIC METHODOLOGY OF FORMING FERROCEMENT MEMBERS

A ferrocement structure is formed by fabricating the mesh reinforcement to the shape and size of the structure first and then mortared and cured. Method of forming a ferrocement element is as follows:

1) Welding skeletal steel framework.

A skeleton of steel bars is welded to the exact geometrical shape and size of the structure. This provides a rigid framework of the exact shape and size with correct line and level.

2) Tying mesh reinforcement tightly over it to form cage.

Weld mesh and fine wire chicken mesh is tied over this welded skeleton by stretching and tying technique. 'Tightly tying meshes' is the key point in

3) Impregnating the mesh cage with rich cement mortar, finishing and curing.

The stiff cement mortar is filled in the mesh layers by pressfill method. In pressfill method, the mortar is to be pressed inside the meshes from both the sides. All these steps in construction are to be followed in sequence. On large size constructions, one can work simultaneously on all the three operations.

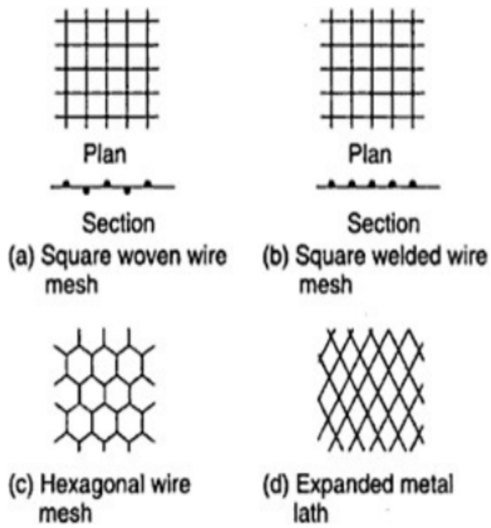
IV. CONSTITUENT MATERIALS OF FERROCEMENT

A. Cement
B. Fine Aggregate
C. Water
D. Admixture
E. Mortar Mix
F. Reinforcing mesh
G. Skeletal Steel
H. Jointing compounds

Reinforcement Details

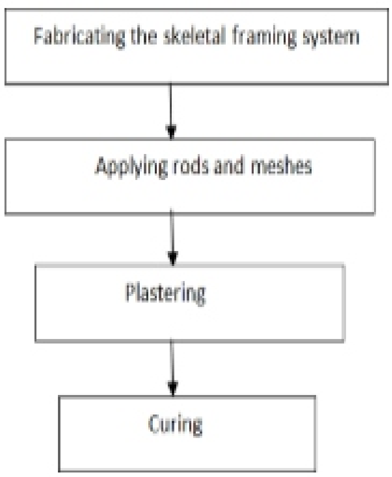
- The reinforcing mesh (with mesh openings of 6 to 25 mm) may be of different kinds, the main requirement being flexibility. It should be clean and free from dust, grease, paint, loose rust and other substances
- The volume of reinforcement is between 4 and 8% in both directions, ie between 300 and 600 kg/m3; the corresponding specific surface of reinforcement ranges between 2 and 4 cm2/cm3 in both directions.

- Hexagonal wire mesh, commonly called chicken wire mesh, is the cheapest and easiest to use, and available almost everywhere. It is very flexible and can be used in very thin sections, but is not structurally as efficient as meshes with square openings, because the wires are not oriented in the principal (maximum) stress directions
- Square welded wire mesh is much stiffer than chicken wire mesh and provides increased resistance to cracking. However, inadequate welding produces weak spots.
- Square woven wire mesh has similar characteristics as welded mesh, but is a little more flexible and easy to work with than welded mesh. Most designers recommend square woven mesh of 1 mm (19 gauge) or 1.6 mm (16 gauges) diameter wires spaced 13 mm (0.5 in) apart.
- Fibers, in the form of short steel wires or other fibrous materials, can be added to the mortar mix to control cracking and increase the impact resistance.
- Expanded metal lath, which is formed by slitting thin gauge sheets and expanding them in the direction perpendicular to the slits, has about the same strength as welded mesh, but is stiffer and hence provides better impact resistance and better crack control. It cannot be used to make components with sharp curves.



Types of Steel Reinforcement used in Ferrocement

V. PROCESS OF FERROCEMENT CONSTRUCTION



VI. SOME EXPERIMENTAL WORK DONE IN MERI INSTITUTE

The ferrocement subject was introduced in MERI in 1975. Some research was already carried out by then officers in MERI.

MERI has conducted many tests and experiments on ferrocement. A water tank and partition wall was constructed using ferrocement, which is still available for observation. 2 boats were constructed in MERI using ferrocement. The boats are still available for inspection. The rain water is collected in one of the boats but there is no leakage seen in these boats.

In Canal Lining, ferrocement lining was taken on experimental basis in 2014-15. Tapi Irrigation Development Corporation has executed 100 meter length of Punand Right Bank Canal near Kalwan. The canal had heavy leakage in this portion. After completion of the ferrocement lining the leakage was completely stopped. (The report is under finalization).

Water tank built in MERI Nashik in 1988

A boat built in MERI Nashik in 1980

VII. ADVANTAGES OF FERROCEMENT

Ferrocement has following basic advantages over RCC

1) Increase in bond strength:

The transfer of load from steel to concrete and vice versa takes place through bond between the two materials. The bond depends upon the bond-stress of concrete and the area of contact between the steel and concrete. Bond stress of concrete depends upon the grade of concrete. It is hardly 6 kg/cm2 for M15 concrete. The bond can be substantially increased if the contact area between steel and mortar is increased. For Ferrocement, it is achieved by use of small diameter wires and mortar.

2) Bond area increase:

Increase in bond area will result in more adhesion between steel and mortar, making it behave more like a homogeneous material and which has become very strong in tension due to increase in bond.

3) Dispersion of steel wires:

Ferrocement is formed by tying together a number of layers of continuous wire meshes. Volume of steel percentage is very large, may be up to 8 percent. Also the mortar cover over the meshes is hardly 3 to 5 mm. Hence, throughout the body of the composite, the wire reinforcement is fully dispersed. This leads Ferrocement to become more homogeneous. It results in improving the properties of Ferrocement in tension, flexure, impact resistance and crack resistance.

4) Crack control:

Meshes are fully bonded to mortar and spaced very near to the surface of Ferrocement. Such closely spaced fine wires, very near to the surface of Ferrocement, act as crack arrestors.

5) Equal strength in both directions:

The continuity and placement of equal mesh reinforcement in both directions make Ferrocement to achieve equal strength in two directions and to become strong in resisting diagonal tensions due to shear.

6) Containment of mortar matrix in mesh layers:

In Ferrocement, layers of wire meshes tightly tied together are impregnated with cement mortar. The matrix is held by the meshes in between and is contained by them.

7) Formless construction:

Tightly tied meshes in ferrocement can hold wet cement mortar when it is pressfilled in them. The consistency of cement mortar is very thick with very low water cement ratio. It won't come out of the meshes. Thus casting of Ferrocement does not need any formwork or shuttering. The other advantage of this aspect is no honeycombing will occur in pressfilling, as the mortaring is done in front of your eyes. If the mesh is tied loosely or water cement ratio is not maintained to thick consistency or over-sanding is done, the mortar will flow down and will not be held by the meshes.

8) Strength through shape:

Ferrocrete structures are thin walled and may be hardly 25 to 50 mm in thickness. Hence, to take care of slenderness and buckling, Ferrocement is shaped in different forms to achieve its strength.

9) Lightweight, homogeneous and versatile material Ferrocement structures have high equal strength in both directions. It can be moulded in any shape and size. Ferrocement is homogeneous, easy to work and can be made available in thin sections.

10) High strength to weight ratio:

Being a thin walled structure of high strength, strength to weight ratios in tension and compression of ferrocement are very high. Hence thin sections can take higher loads.

VIII. APPLICATIONS OF FERROCEMENT IN CONSTRUCTION

With Ferrocement it is possible to fabricate a variety of structural elements, may be used in foundations, walls, floors, roofs, shells etc. They are thin walled, lightweight, durable and have high degree of impermeability. It combines the properties of thin sections and high strength of steel. In addition it needs no formwork or shuttering for casting.

Ferrocement have applications in all fields of civil construction, including water and soil retaining structures, building components, space structures of large size, bridges, domes, dams, boats, conduits, bunkers, silos, treatment plants for water and sewage.

1) Housing and other Industrial and commercial.

a) Low cost dwelling house

b) Strengthening reinforced concrete element.

c) Strengthening masonry element.

2) Marine

Marine structure such as Boat, trawler, Barges, floating docs can be constructed with a help of Ferrocement and give better result than steel and wood and a good resistance of atmosphere.

3) Agricultural

The plates that are construct with a help of ferrocement can be used for :-

a) Construction of canal

b) Gates over dam

c) Cross-drainage work

d) Aqua-duct

e) Penstocks etc Ferrocement lining is good against abrasion

4) Anti corrosive Membrane treatment

A Ferro cement consist anti-corrosive membrane treatment hence no other treatment is required for protection against corrosion.

5) Tank container & silos

Every type of tank e.g. overhead, underground or at ground level can be manufactured with the help of Ferrocement and give a satisfactory service.

6) Floor & Roof

We can construct floor & roof various type of building e.g. residence, factories, office, sheds etc.

7) Waterproofing

By using Ferrocement membrane technique we can construct water proofing.

8) Manhole cover

Heavy duty and light duty manhole cover be constructed and are superior and durable than conventional once.

9) Wall cupboard

It consist no. of small holes in rectangular form with or without shutter used to store office record, factory material etc.

10) Ferrocement Duct

Ferro Cement ducts are suitable for circulation of cool or hot air.

11) Chemical Resistant Treatment

An overly of epoxy, bitumen, polyurethane, chlorinated rubber, lead lining and glass fiber will be an ideal chemical resistant treatment.

12) Rural Application

Ferrocement is applicable in rural areas for construction of cattle sheds, silos for storage of food grains. Low costs houses, community centres, well lining, gobar gas plant, lavatory block, water storage tank etc.

13) Elevation Treatment

Elevation treatment e.g. fins, projection curved, folded and hollow, sun shed to the building have been provided with advantages.

14) Fire Resistant Structure

It can resist fire upon 750O for a period of 48 hours.

15) Soil Stabilization

Ferrocement can be used for increase bearing capacity of soil for foundation of building, bridge, dams etc.

16) Pipes

There is corrosion problem using steel and iron pipes instead of these wire ferrocement pipes overcome the problem of corrosion.

17) Sewer Lines

Ferrocement in sewer line is necessary same as pipes.

18) Bridge

As per know Ferro cement is crack resistance and corrosion resistance and applicable to make girder plates.

19) Foot Bridge

Foot bridge with Ferrocement girder, decking, railing and roof is better than RCC and steel

20) Sulphate Resistant Cement Saving

During conventional concrete curing by using sulphate resistant ferrocement lining very cost effective and structure is safe against sulphate attack.

21) Pre-cast Ferrocement Structure

Pre-cast ferrocement structure are in light weight as compared with RCC and sometime pre stressed concrete structure, considerably reduce the cost hence ferrocement is most appropriate in pre-cast industry.

Parameters	Reinforced Cement Concrete (RCC)	Stones	Reinforced Brick Cement (RBC)	Ferrocement
Strength to weight ratio	Low	Very Low	Medium	High
Performance	High	Medium	Medium	High
Durability	High	Medium	Medium	High
Equipments for roof	Shuttering required	No Shuttering	Shuttering required	No Shuttering
Skills required	Skilled	Highly skilled	Highly skilled	Semi skilled
Cost range (Rs.) for 1 M span	450-600	400-500	400-550	375-450

Table : Comparative Analysis of Ferrocement and other Building Materials

IX. CONCLUSION

Ferrocement is a good material. Further modification in ferrocement can make it best materials in structure as compared to RCC or other type of material and also ferrocement is economical in nature and having a good performance against lateral load. Maintenance cost of ferrocement structures is almost negligible.

Considering its unique features, no doubt ferrocement will be one of the most important structural alternatives for RCC and a repair material in the future and thus has a great potential for developing and developed countries alike.

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