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Environmental Pollution in Construction Sites and Corresponding Green Construction Measures

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ABSTRACT

Many construction projects have been completed in the urbanization process in China. Long construction period and large-scale and complicated processes are the most prominent characteristics of construction projects. Construction projects are sensitive to many factors and cause enormous environmental pollution. Effective green construction measures can control potential environmental pollution. To analyze types of environmental pollution in construction sites, some environmental protection measures based on the philosophy of green construction were proposed. In this study, existing studies on environmental pollution in construction sites and green construction around the world have been reviewed. Types of environmental pollution caused by architectural construction and the principle and control keys of green construction were summarized. Research results demonstrated that noise pollution, light pollution, water pollution, solid waste pollution, and dust pollution were the major types of environmental pollution in construction sites. The core of green construction is to control existing and potential pollutants in construction sites throughout the project. Finally, some green construction measures were proposed, including establishing an environmental management system, strengthening environmental supervision, perfecting construction environmental management, and determining environmental technological management rules. Research conclusions provide positive references to understand types of environmental pollution in construction sites, establish green construction environment, save energies and reduce consumptions during construction, and protect the construction environment.

INTRODUCTION

The recent gross output of construction increases yearly due to the increasing quantity of construction projects in China (Fig. 1), where increasingly prominent environmental pollution problems arise in construction sites. In particular, the construction wastes damage not only the surrounding water, air, and soil, but also the normal life of surrounding residents. The use of poor quality of construction materials and unqualified detection technology causes tremendous potential environmental pollution problems in construction projects. Furthermore, paints with excessive heavy metals may cause serious heavy metal pollution in the construction process, and building materials with heavy metals pollute surrounding animals and plants. The construction supervision department lacks strict control on pollution behavior in construction engineering and neglects the full-process supervision of construction wastes. Some construction engineering enterprises fail to implement scientific recycling and harmless treatment of construction wastes and set acoustic lining for noise control, yet they blindly pursue engineering schedules. Given the above mentioned causes, construction has caused serious impacts on the surrounding natural ecology and residential environment.

STATE OF THE ART

Many studies on environmental pollution caused by construction and environment-friendly sustainable construction measures have been reported. With respect to environmental pollution caused by constructions, Ghandour et al. (1982) analyzed the current atmosphere pollution caused by construction in the Helwan industry park and pointed out that heavy metal dust produced by construction is the major reason of atmospheric pollution. Cole et al. (1992) evaluated various energy consumptions and air pollution of different construction materials. Theurer (1999) studied how different construction distributions in three cities in southwest Germany influence the concentration of air pollutants. Zhang et al. (2008) introduced an evaluation system of dust pollution in a construction site. An empirical study emphasized that this evaluation system provides reasonable results, which are conducive for construction planning. Jang et al. (2001) accomplished a sampling analysis of wastes in soils during the construction and dismounting process in Florida and assessed the environmental risk of these recovery soils. Houthoofd (2010) believed that using recycled materials in buildings can realize coordinated development between the construction industry and environ-

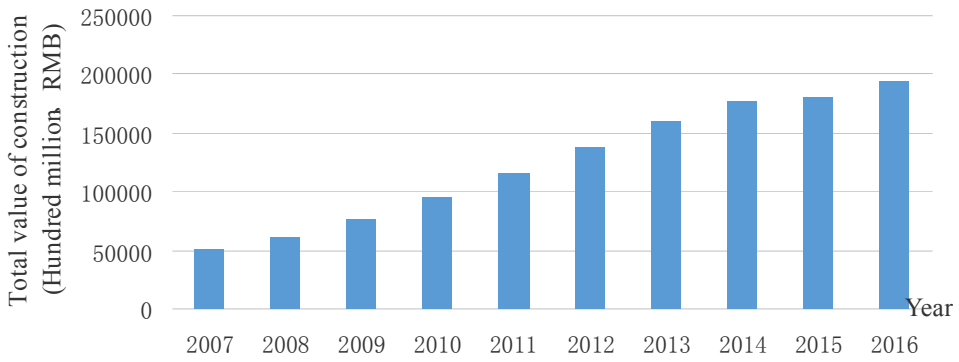

Fig. 1: Gross output of China's construction during 2007-2016. [Data source: China Statistical Yearbook (2008-2017)]

mental protection through life cycle assessments. Wu et al. (2015) investigated the dust control status caused by construction in China and proposed suggestions, such as formulating targeted regulations, constructing appropriate charging systems, and developing feasible monitoring systems. Belayutham et al. (2016) emphasized that water pollution in construction site not only influences surrounding environment, but also affects economic and social welfare. He enlisted in-site water pollution into the concept based on prevention, which was conducive to the simultaneous implementation of construction and environmental protection. An explicit definition of green construction in China is provided. Internationally, it is generally called sustainable construction. Hill et al. (1997) proposed a multistage framework for environmental evaluation and environmental management system of sustainable construction. Rohracher (2001) believed that construction brings great ecological loads, but the philosophy of sustainable construction is in favor of construction innovation. Abidin (2010) accomplished a field investigation, survey, and interview in two cities in Malaysia, and research results demonstrated that only large-sized real estate enterprises are concerned about sustainable construction. He believed that actions are necessary to improve the sustainable construction behavior in the industry and increase associated knowledge in all levels of developers. Robichaud et al. (2010) reported that influences of buildings on construction, maintenance, and running should be determined based on energy demands and pollutant loads. He focused on the affordable loads of the environment on the basis of warming, hot water, electricity, and annual energy consumption per unit kilometers. Tan et al. (2011) reviewed sustainable development of the construction industry, as well as the relationship between sustainable performance and competitiveness of enterprises. In addition, a framework that can implement the sustainable construction and improve competitiveness of contractors was proposed. Raut et al. (2011) believed that recycling of industrial or agricultural solid wastes is a feasible solution to pollutions and an economic choice of green construction design, and it provides a potential sustainable solution. Govindan et al. (2016) constructed an evaluation model of optimal sustainable construction materials based on the sustainable indexes. This model was used to test a specific situation in the United Arab Emirates (UAE) through the multiple criteria decision-making (MCDM) method. Ong K. C. G. (2017) suggested the use of green construction design, construction methods, and materials and sustainably supplied materials and resources in construction projects in Singapore. According to existing literature, environmental pollution caused by construction is minimal in developed countries, which is attributed to the perfected construction site management system. In particular, many developed countries have improved the engineering quality and environment-friendly performance of construction projects through the philosophy of sustainable construction and modernized construction mode. They advocated the large-scale application of new energy-saving and emission-reduction technologies in construction sites, controlled environmental pollutants in construction projects strictly, and paid close attention to real-time discharge data of pollutants in the construction field, which conformed to the construction requirements of environmental protection. Recently, environmental pollution caused by construction has occurred in developing countries, which has attracted the attention of relevant government departments. For example, China supervises all environmental pollutants strictly through various control measures in construction projects in advance and achieves certain environmental protection effects in specific construction projects. In this study, targeted environmental protection measures for construction projects were proposed considering the types of environmental pollution and the philosophy of green construction.

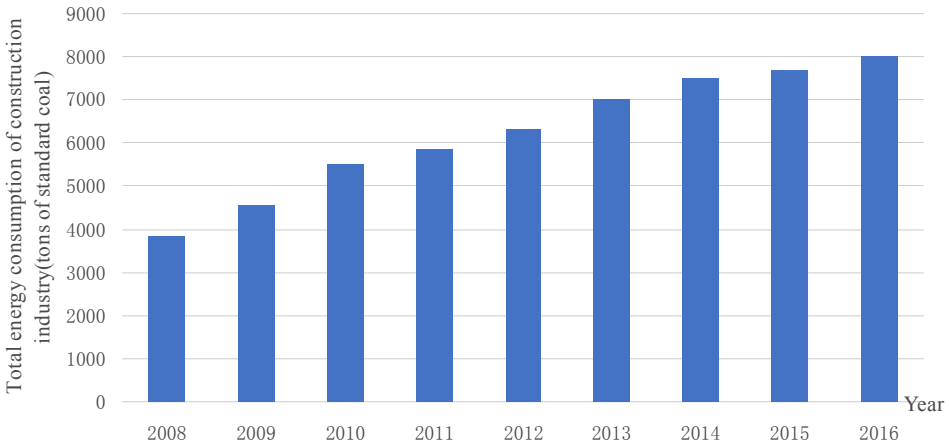

Fig.2: Energy consumption of China's construction industry during 2008-2016. [Data source: China Statistical Yearbook (2008-2017)]

TYPES OF ENVIRONMENTAL POLLUTION IN CONSTRUCTION SITES

Noise pollution: Large-scale application of construction machinery is the fundamental cause of noise pollution during construction, such as improperly installed construction machines. Construction machines that can produce loud noises are placed away from regions sensitive to sound, such as residential areas, schools, and hospitals to relieve influences to the surrounding environment. Many loud-noise equipment placed close to the potential affected objects produces noise pollution. Meanwhile, technicians do not monitor noises. The absence of "people-oriented" production mode is the leading cause of noise pollution.

Light pollution: In a construction site, light pollution is mainly caused by the excessive use of illumination devices at night. In the construction process, some procedures are often implemented. Illumination devices used at night are all high-strength illumination devices. Lights emitted from illumination devices run through glasses of residential houses close to the construction field, thereby disturbing residents.

Water pollution: Water pollution is mainly caused by random emission of sewages from construction, such as sewage produced by concrete stirring, curing, and pouring pipes; sewage from some hydrostatic test; and domestic sewage of construction workers. In some construction sites, abundant solid wastes are discharged into the sewer line, without considering the construction quality of sewer pipelines, seepage failure in drain line, sewage seepage in pipelines, and pollution of groundwater source. Moreover, rainfall runoff causes serious urban inland inundation and groundwater recession. Abundant pollutants dumped in construction sites are associated with surface runoff, which intensifies urban water pollution.

Solid waste pollution: Solid wastes are inevitable in the construction process. Construction wastes from the demolition of the original buildings or structures in construction sites, such as waste bricks, waste cement, outer packages of construction materials, and household wastes of workers, impact the surrounding environment and daily life of residents.

Dust pollution: Dust pollution is an important source of atmospheric pollution. It is characteristic of a large pollution source, uneven spatial distribution, random emissions, and great control difficulties. Dust pollution arises in many construction procedures, including dismantling of buildings, flatting of construction field, earth-rock engineering, loading and unloading of bulk construction materials, and transporting of construction wastes. Dust pollution can cause various respiratory diseases, transmit viruses, and threaten physical health of residents in nearby communities.

PRINCIPLE OF GREEN CONSTRUCTION AND CONTROL KEYS

Principle of Environment-Friendly Construction

The guideline for green construction issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in China provides an explicit definition to green construction. Green construction is an attempt to save energies and materials and reduce environmental influences in the construction process by management and technological measures in consideration of environmental factors. Green construction focuses on the protection of the original ecology to realize the effective protection of survival environment and facilitate the sustainable development of economics and society. It requires necessary concern on the protection of ecological environment, full utili-

zation of resources, and comprehensive implementation of people-oriented philosophy in the construction process to assure sustainable development of the construction industry.

People-oriented principle: The ultimate goal of human production activities is to create better survival conditions and development environment. Therefore, these activities must center on the goal of adapting to and protecting nature and realize the sustainable development of human beings by using the growth of material wealth as the driving force. Green construction targets resource saving and protecting the survival environment of human beings, renders human factors at the core position, and focuses on the negative effects of construction activities on production and life, including negative effects on construction workers, surrounding population, and society. Moreover, respecting and protecting people, reflecting on the people-oriented principle, and realizing the harmonious development between construction activities and nature are suggested.

Principle of lean construction: Lean construction can decrease mistakes and rework in the construction process, reducing resource wastes. Hence, green construction should be centered on the principle of lean construction. On the basis of refined planning, refined management, strict standardization, construction optimization, improvement in construction technologies, and strengthened dynamic monitoring of constructions, the construction mode shifts from traditional high consumption-extensive and labor-intensive mode to the resource, intelligence, technology, and management-intensive mode, thereby practicing the principle of lean construction gradually.

Principle of environmental protection superiority: The natural ecological environmental quality directly determines the physical health of humans. It influences human survival and development. Protecting the ecological environment protects the survival and development of human beings. Construction activities can considerably affect the surrounding environment. Green construction should follow the principle of "environmental protection and limited resources" to control pollutants (smoke, dust, and solid wastes) and pollutants that stimulate organs (vibration, noise, and strong light) in the acceptable range. This principle is a direct manifestation of "green" connotation in green construction.

Principle of high-efficiency resource utilization: Sustainability of resources is the major guarantee of the sustainable development of human beings. In the future, as a typical resource consumption industry, construction shall maintain long-term large demands, which will consume abundant resources. The basic goal of green construction is to change the traditional extensive production mode. Efficient utilization of resources should be considered. In addition, green construction shall remain to save resources, use resources efficiently, and develop renewable resources in construction activities to facilitate the continuous increase of engineering construction in China.

Key Controls in Green Construction

Save construction materials and water resources: Construction materials and equipment in housing construction projects account for about 60%. Thus, material resource saving technology is an important aspect to study green construction technology. Research on material saving technology focuses on the efficient utilization of material resources and full use of cast-in-place concrete technology, commercial concrete technology, preparation and transmission technology of reinforcement, support framework technology, and technology to reduce construct wastes and improve waste recycle. China is one of the countries with the poorest average water resources. Water-saving construction and full utilization of water resources are technological difficulties that have to be solved. Water-saving technology needs to be considered in green construction technology. Technologies related to the efficient utilization of water resources, high-performance concrete and concrete water-free curing, and utilization of pit rainfall should be considered.

Save energy sources and lands: Energy-saving and utilization technology is one aspect that green construction technology should focus on. To reduce energy consumption, increase energy utilization, and develop renewable resources in the construction process, technologies should be studied. In Fig. 2, energy consumption in China's construction industry remains high and increases yearly. Heat source, pipe network, and passive energy saving of buildings must be considered systematically to facilitate energy saving of construction projects. Other steps include selecting and using renewable resources first, increasing heat-insulation performance and energy utilization of temporary buildings in a construction site, selecting construction machines with high environment-friendly performance, and increasing load factor of machines to save energies and resources at a maximum extent. Land resource protection technology should focus on the protection technology of temporary lands, reasonable layout, and scientific utilization of construction lands. In addition, the utilization of temporary lands in construction sites shall be improved at a maximum extent.

Increase human resource investment and improve technologies: Experts suggest improving the operation condition of construction projects; reducing labor intensity; utilizing human resources efficiently; reconstructing construction sites, working, and living conditions; reducing labor

wastes through studies of management technologies; improving the heavy labor activities in construction sites by improving mechanization and assembly level; and strengthening labor protection measures. New technologies, materials, and equipment conforming to the philosophy of green construction should be studied, promoted, and applied extensively, including the preparation and delivery technology of rebar finished products, bare concrete template technology, modular steel structural framework assembly and hoisting technology, heat supply measurement technology, construction industrial technology, and BIM information construction technology.

ENVIRONMENTAL PROTECTION MEASURES IN CONSTRUCTION PROJECTS

Establish the environmental management system and strengthen technological prevention: A health, safety, and environment (HSE) management system is established. The environmental management system is a component of engineering management. In addition, implementation of the environmental management system is vital in the prevention and control of pollutions. Given specific situations of construction enterprises and characteristics of the project, the construction administration department should establish an environmental management system to control environmental pollution effectively and maximize the system. In engineering construction management, a perfect construction environmental management system shall be established in consideration of national mandatory provisions on pollution control and environmental protection in construction sites, existing industrial technologies and standards, quality standards of construction materials, and other relevant quantitative indexes. This system can analyze important causes of environmental pollution in the construction process, adopt targeted pollution prevention measures from the pollution source, and reduce environmental pollution effectively.

Strengthen environmental monitoring and implement prevention measures: In construction site management, compound talents with multiple special skills related to environmental management shall be trained. The environmental management system shall be implemented by combining the quality management system and occupation health safety management system. Thus, the environmental management programs can be implemented depending on the requirements and supervised indexes of environmental goals of projects. Correction and prevention measures shall be adopted appropriately in environmental management, which can effectively prevent construction environmental pollution. In construction site management, important environmental factors shall be supervised by following the principle of "prevention-centered and continuous improvement". During the construction period, dusts and waste gas in construction sites should be detected and supervised by environmental monitoring instrument and equipment, such as harmful gas detector. The surrounding atmosphere, water, and soil environmental qualities are tested by a pH meter. On the basis of the above real-time monitoring measurements, the difference between surrounding environment and national environmental quality standards is assessed during construction to determine whether building pollutants reach national or local emission standards.

Perfect *in situ* construction environmental organization and improvement of environmental protection consciousness: An environmental post-responsibility system, environmental examination system, environmental education system, and environmental reward system are formulated to realize a standardized, labellized, and scientific environmental management system; enhance the rights and responsibilities of management; avoid mutual disputes; and increase management level and efficiency. All involved managers from the executive level to the basic level and constructors should know about environmental problems and environmental pollution in the construction process through education. Improving environmental protection skills and consciousness of all constructors is necessary. Environmental management staff must be familiar with relevant laws, regulations, and technological standards and master the use of relevant monitoring means and green construction skills. In addition, they shall accomplish a series of environmental protection education and promotion activities to improve environmental protection consciousness.

To establish the construction site management system and determine the management rules of environmental technologies: A general director for environmental protection shall be assigned for overall responsibility of technologies and construction. The general director shall decompose relevant problems of construction environmental protection layer by layer, divide the work, and assign special persons for specific problems. The project managers are the general directors of environmental protection and shall be held responsible for comprehensive environmental management in the construction site. The chief engineer is responsible for technologies and leads the entire construction pollution control group to supervise air, noise, wastewater, solid waste, light, and radiation pollution during the construction process. Different environmental protection measures shall be implemented. In addition, the chief engineer is responsible for advanced prejudgment of many potential environmental problems. The pollution source shall be classified, and many different prevention technological means are adopted, such as reducing dust pollution in atmosphere, timely cov-

erage of temporary soil pile, and setting automatic spraying system to reduce dust pollution. Construction works with big noises, such as pile foundation and concrete pouring, are performed in daytime. A special temporary storage of solid wastes in the construction site shall be established for classification. Wastes shall be classified, sealed up, and covered before transportation to prevent leakage and from being missing. A special pool for sedimentation of wastewater and curing wastewater in the stirring station is established to process sewage before discharging into the urban sewage system.

CONCLUSIONS

As an important pillar industry of national economy, China's construction industry drives relevant industrial development and consumes abundant natural resources. The enormous quantity of construction wastes produced by construction projects causes serious pollution to the surrounding natural environment and disrupts the daily lives of surrounding residents through water and air pollution. In this study, existing studies on construction-induced environmental pollution and green construction are reviewed. Types of construction-induced environmental pollution are summarized, and environmental protection measures for construction sites on the basis of the philosophy of green construction are proposed. Finally, principles and control keys of the green construction are summarized. Research results demonstrate that noise pollution, light pollution, water pollution, solid waste pollution, and dust pollution are major types of environmental pollution in a construction site. The core of green construction lies in the full-process control of existing and potential pollutants in construction sites. Finally, some green construction measures are proposed, such as establishing an environmental management system, strengthening environmental monitoring, perfecting the construction environmental organization, and determining environmental technological management rules. Further studies on sewage discharge control in construction projects, construction of reasonable management system of construction wastes, formulation of legislations and regulations of construction environmental protection, promotion and application of green construction materials, and quantitative assessment of construction environmental pollutions are suggested.

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