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Integrated Approach as Sustainable Environmental Technique for Managing Construction Waste: A Review

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Abstract

The construction industry was reported as a major consumer of natural resources worldwide. Almost 60% of the natural resources consumed by this industry have caused a lot of environmental impacts on humans and the environment. Among the impacts were the disruption of human water sources, changes in the biological ecosystem and disruption of the food supply chain among biological factors. Countries around the world have enforced several laws and regulations. Apart from that, waste management technologies were formulated by government agencies and the world's researchers were among initiatives to minimise the waste generation rate. Several technologies, such as recycling and recovery technologies were highlighted to be very efficient in minimising the waste accumulation rate. This paper discussed an integrated concept for managing construction waste in a sustainable manner. The integrated approach has adopted the reuse method, central sorting facilities, recycling facilities, thermal treatment facilities and disposal facilities. Implementations of these integrated approaches were able to save the world's raw materials and natural energy sources as well as reducing the impacts of pollution on the environment.

Keywords: Waste management facilities, Pollution, Sustainable

1 Introduction

The construction projects have increased tremendously in conjunction with Malaysia 2020 Plan. The increases in the number of construction projects are due to population demand which has led to harmful and negative impacts on the ecosystem in terms of waste materials handling. The management of construction waste materials, particularly in the Malaysian building industry, has become a major environmental issue in recent years. Although this issue has been discussed by the media, efforts towards minimising the waste generations are still few since landfill is the most common waste disposal method in the Malaysian construction industry. This causes serious impacts to the environmental platforms, such as water, air and residual [1, 2].

As the largest consumer of natural resources, the construction industry produces large amounts of waste materials into the waste stream [3]. Most of these waste materials are either during the construction process or at the end of a building life (EoL) which contains hazardous substances. These include brominated flame retardant (BFRs) in electronic plastic waste, copper in wires and cables, asbestos in walls and ceilings, mercury in light bulbs and fixtures, lead paint, wood preservatives and cement-based materials that contain heavy metals. Hazardous contaminants in these waste materials will be released into various environmental platforms, such as water, soil and air when they are disposed of by dumping or simple landfill [4, 5]. This is supported by [6] which stated that hazardous substances present in construction wastes might lead to serious health and environmental risks if they are not properly managed. When these materials come in contact with water from the rain, surface water or groundwater, the hazardous elements may be leached [6].

On the other hand, attitudes and behaviours regarding waste management practices among construction parties might influence the impact towards the environment. Based on a study conducted by [7] the contractors' attitudes and behaviours regarding waste management practices in Malaysia tended to differ according to the grouped size of contractors which significantly affected the waste management practices. Most construction wastes were disposed of at landfills and the contractors did not practice

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source separation, source reduction, reuse or recycling at their construction sites. Moreover, the research stated that some contractors disposed of their construction wastes at illegal dumpsites due to the distance between site locations and designated landfills, which were too far for them to travel, consuming some transportation costs and affecting their profit margin [2]. Therefore, the enforcement of law and regulations with a proper waste management framework might urge these contractors to comply with the legislation and make use of the established framework to understand the right ways of managing wastes. Proper waste management is not possible without having the proper awareness and knowledge in waste management [8]. This paper will discuss the integrated concept for managing construction wastes in a sustainable manner.

1.1 Construction Waste

The Malaysian construction industry recorded a total of 28.6 tonnes of daily construction wastes in 2015 [9]. In general, construction wastes can be divided into two forms, which are physical wastes and non-physical wastes. Examples of physical wastes are concretes, aggregates, sands, timbers, metals and plastics that are generated from various construction activities. Meanwhile, for non-physical wastes time and cost factors are counted [2, 10]. However, [11] stated that waste materials from construction activities were made of inert and non-inert materials. Examples of inert waste materials were soil, earth and slurry while non-inert mixtures were metal, timber and packaging wastes, as agreed by [12]. In addition, [13] mentioned that construction waste materials were made up of any building materials that needed to be reused or recycled due to damages, non-use, excessive or noncompliance with the approved specifications for construction.

Several factors are causing the generation of construction wastes, particularly in the Malaysian construction industry. Among the factors are improper handling, stacking, cutting and storage of building materials, lack of attention being paid to measurement of product used, lack of awareness about construction during design stage activities and lack of interests among contractors. Normally, about 1% –10% of purchased materials at sites, depending on the category of materials, are left at the sites as wastes [14].

1.2 Hazardous Components in Construction Wastes

The European Waste Catalogue (EWC) has classified construction wastes into 38 subcategories. Out of these subcategories, 16 were classified as absolute or minor hazardous entries [15]. Several types of hazardous entries were found in cement-based waste material samples. Among the hazardous entries or heavy metals presented were chromium (Cr), lead (Pb), arsenic (As), zinc (Zn), mercury (Hg) and vanadium (V). Among all presented heavy metals, the concentration of Zn was observed as the highest in both construction and demolition waste samples. The hazardous nature of these waste materials greatly depended on the source of the formation area [16,17]. Specifically, it could be seen that concrete wastes, which were made up of cement, sand and aggregates, were the major waste materials that contained hazardous substances, followed by electronic and steel wastes.

2 Directive, Policy and Regulation

2.1 International Directive, Policy and Regulation

In most developed countries, construction wastes have always been a huge contributor to environmental problems. In conjunction with the higher generation rate of construction wastes, the European Union is exploring to reduce waste materials that will be hazardous to the environment and establish certain laws and regulations which provide major directions in waste management practice and the use of a certain chemical was prohibited. Therefore, the concept of waste management hierarchy was developed by the European Union Waste Directive and the European Commission's Community Strategy in 1975. The waste management hierarchy concept was made up of several stages, such as prevention as the priority option, followed by reuse, recycling, recovery and finally, the least priority was waste disposal. The most desirable option in this concept was waste prevention and the main standpoint of this concept was to fully utilise all parts of a product and generate the lowest amount of waste possible, especially on the increasing number of construction wastes around the union [18]. In South Africa, problems related to construction wastes were faced since the past few decades. With an increase in the population number, demands for building construction were increased and resulted in a higher waste generation level [19]. The amount of construction and demolition waste generation in this country was accounted for as the second highest, next to the non-recyclable municipal waste [20]. Therefore, the Government of Africa has created the National Waste Management Strategy which was later known as the Waste Act, 2008 under the National Environmental Management. This legislation was in-charge of eliminating the usage of virgin materials, ensuring sustainability at the product design stage, resource efficiency and prevention of waste materials. Moreover, the Government of Africa will review the Waste Act at least once in every five years to maintain with current transformation and enhancement of laws and regulations [21]. Every party that was taken into the Waste Act, 2008 and Act 108 of 1996 by the Republic of South Africa, such as waste generators, transporter of waste materials, construction parties and landfill managers, need to comply with the legislation and follow the roles and responsibilities that were entitled [21].

With the huge transformation of the construction industry in 2012, the Environmental Protection Department (EPD) of Hong Kong reported a total of 13,844 tonnes of daily construction wastes being dumped at landfills. These were due to unpopular on-site waste sorting and common practices of contractors in Hong Kong who directly dispose of their waste materials at landfills [22]. Several ordinances were declared by the Government of Hong Kong in realising the seriousness of environmental impacts caused by the disposed waste materials at landfills. Among the ordinances were Waste Disposal Ordinance (1980), Water pollution Control Ordinance (1980), Environmental Impact Assessment (EIA) Ordinance (1998), Noise Control Ordinance (1989) and Air Pollution Control Ordinance (1985) [23].

It can be concluded that these directives, policies and regulations of developed and developing countries in managing construction wastes are using an approach that prevents and minimises the generation of wastes, optimises recycling and recovery of wastes and the practice of safe disposal for the construction wastes.

2.2 Local Directive, Policy and Regulation

Being among the worst type of environmental pollution contributors, the construction industry has used up a significant amount of virgin materials as input for several building processes to produce outputs and solid waste materials. Based on the estimated result of the solid waste production rate in Kuala Lumpur, the trend showed that the generations of solid wastes were increasing at 2% on a yearly basis. By considering this issue, the Malaysian Government has announced the Solid Waste and Public Cleansing Management Act (Act 672) on 30 August 2007. This act was enforced on 1 September 2011 as a medium to control, reduce, recycle, recover and dispose of solid wastes in the right manner without affecting the surrounding environment and local communities [24, 25, 26, 27].

Under the Act 672, the 3Rs (reduce, recycle and recover) practices are mandatory for every construction party. Severe penalties of non-compliant with regulations were stipulated under the act, especially in avoiding solid waste segregation. The solid wastes under this act were categorised into different types of groups, such as construction solid waste, household solid waste, industrial solid waste, institutional solid waste, imported solid waste, commercial solid waste and public solid waste [28,29]. Even though this act mentioned construction solid waste as part of controlled solid waste management, the scope of proper construction waste management as a whole is not enough and comprehensive. There is an urgent need to come out with a proper framework for each stage of construction waste from cradle to grave that can minimise the release of pollutants into the environment.

3 Construction Waste Management Technologies

In the world of rapid modernisation, the concern of the population has moved from the point of efficiency towards environmental impact. It is undeniable that the construction industry is among the major waste contributors to the nations, causing serious environmental impacts [30, 31]. Some of the waste materials that are generated through this industry hardly to be recycled since these materials are highly contaminated during the process of formation and assembly. Therefore, with the advancement of technologies, these highly contaminated waste materials can be treated in some other methods, such as reuse and thermal treatment [30, 31]. The following subtitles of this paper further elaborate on each of the management option and technology.

3.1 Reduce and Reuse

[32] introduced another construction waste management technology in terms of the barcode system by using the incentive reward programme (IRP). Workers will be rewarded according to the number of construction materials they have saved from the site activities. Through this barcode system, the movement of materials will be recorded and workers will be rewarded based on the amount of construction materials that are returned to store after their usage at site, without leaving them as waste materials and be considered for future usage, such as the half bag of cement, remaining reinforcement bars, nails, half-cut woods and half-cut bars that can be used for short columns instead of slab [32]. Therefore, it is believed that by using the barcode system, the amount of construction waste generation at the site can be reduced, even until more than 50% and site parties are advised to adopt this method for better site management [32]. However, studies claimed that the usage of IRP barcode system is consuming a lot of time since all material movement details in and out of the store are manually recorded. Besides, the workers' attitudes and carelessness influence the material recording system [32].

In accordance with issues on time and workers' attitudes, [33] suggested the integration of geographical information system (GIS) and global positioning system (GPS) with the barcode system. In detail, GIS is a computer-based system while GPS is based on the movement of a satellite around the orbit [33]. This system works by the visual information captured by GPS on the movement, usage and balance of construction materials on-site in the form of triangular or particular shape programmed and transmitted into GIS to be stored. The GIS data will be analysed and displayed on the amount of materials usage and balance that should be returned to the site store. The gathered data through GIS and GPS systems will be compared with the IRP barcode system on materials received and scanned back to the store [33]. The implementation of GIS and GPS systems are proven to be more efficient in terms of cost and time as compared to a single barcode system. However, the initial costs for setting up the GIS-GPS-Barcode integrated system are higher, but the costs are gradually decreasing with further system utilisation [33].

3.2 Recycling

Tonnes of glass wastes generated in the construction industry are being recycled throughout the world. The United Kingdom (UK) has recorded a total of 400,000 tonnes of recycled glass wastes which can be used for many applications in the construction industry. For example, recycled glass wastes can be used as glass fibres to enhance material properties in terms of strength. In detail, the Japanese government practices the usage of recycled glass as glass fibres to increase the strength of cement, gypsum and products that contain resins [34]. The usage of glass fibres will also enhance thermal and acoustic insulation properties, particularly for the industrial and commercial building constructions. These insulation properties are very much needed on the mechanical aspects of a building, such as pipe covers, ceiling boards and finishes for the auditorium, which can be obtained through a recycled glass in the form of glass fibres [34].

The Government of Hong Kong has shown interest in the development of recycling technology for recycled glass aggregate as a paving block in the road and building infrastructure construction [34]. The usage of recycled glass aggregate has numerous advantages in the construction processes as this material provides an attractive reflective surface upon finished with polishing, decreases the water absorption rate for concrete block, particularly at water prone areas and provides good resistance for breakage under compression [34]. However, the disadvantages of using recycled glass aggregate for the paving blocks are lack in stability and reaction between alkali-silica. Normally, the problem can be resolved with the presence of pulverised fly ash to improve the quality before being applied in road and building constructions [34]. On the other hand, glass wastes at construction sites can be used as a fine aggregate in the proportion of concrete for building structures. Apart from cement, sand and coarse aggregates, the addition of fine glasses in the form of micro-filler for concrete production were proven to improve the concrete properties [34]. Sweden has adopted this method as an effort to reduce the accumulation of glass wastes in the country. The collected glass wastes from the construction sites are washed and dried before being shaped into the required specification, depending on the concrete grade and size of particles. The added micro-filler into the concrete batch tends to improve the quality of mixing either in the fresh or hardened state [34].

Furthermore, ferrous metals are among waste materials that have the highest possibility to be recycled. Ferrous metal recycling is considered as a highly developed market worldwide as it is most profitable and could achieve 100% of the recycling rate [34]. Even the recycled ferrous metals from construction sites can undergo several recycling processes and can be reused many times to form a scrap metal, such as aluminium, copper, brass, iron and steel. Since the demands for ferrous metals are increasing yearly, the construction industry has widely accepted the usage of scrap metals as some of these metals can be used directly to the construction activities and can be easily transformed into other forms of products through melting and shaping [34]. The country of the Netherlands has adopted the usage of recycled scrap metal around 80% to the local construction projects and the wastages from scrap metals usage are fully expected to be repeated by recycling at a rate of 100% with direct usage at the same or different sites and through melting if it failed to be used directly. Besides, the scrap metals are well occupied with a higher percentage in the formation of steel reinforcement and almost 25% of steel segments are built up from recycled scrap [34].

In terms of concrete wastes, the most common recycling technology is through crushing the waste into smaller portions as a natural aggregate substitute for the new concrete batch in residential and non-residential construction projects [34]. The crushed concrete is well used as a sub-base layer, backfilling, foundation materials, protection for embarkment and as paving stone, depending on the size of crushed concrete for the construction activities. The by-product of crushed concrete, usually in the form of powder, is used as a filler for asphalt concrete and soil stabilisation [34]. The rapid global developments that took place in the past few decades have opened proficient replacement of concrete ingredients with other materials of the similar nature and properties, with considerable strength and durability [35].

3.3 Waste to Energy

Furthermore, waste to energy (WTE) conversion as a waste management technology in various sectors has gained some attentions among environmental researchers. These researchers were stressed by the demand for energy around the world due to population growth and economic developments [36]. They claimed that the world's energy consumption might increase by 25%–34% in the next 20 years. Therefore, it is advised to promote the WTE conversion technology, particularly in the construction industry because this industry is believed to generate a huge amount of waste materials which could be a source for WTE processes [36, 39]. WTE conversion is linked with several adjoining technologies, such as incineration, anaerobic digestion and pyrolysis. For incineration, it is a well-known technology as a substitute for landfill disposing activities. This technology is believed to be suitable for almost 90% of the waste materials generated worldwide [36]. The amount of thermal energy produced through incineration processes can be supplied to high fuel consumption industries, such as coal mining, power generation plants and automobile manufacturers [41]. However, studies found that apart from thermal energy producers, the usage of incineration technology is generating a certain amount of emissions into the environment. Based on this statement, [36] stated that the toxic emissions that are released into the environment can be reduced to an acceptable level by installing a flue gas cleaning system in chimneys.

On the other hand, for anaerobic digestion technology, the presence of temperature of around 65°C with a low amount of oxygen could induce a biochemical reaction in waste materials, which reduces the amount of waste significantly [37]. Throughout this process, some bio-gasses are expected to be produced as a by-product which can be used for power generation plants, but provided with some treatments and modifications [36]. Besides, for pyrolysis waste management technology, the waste materials have undergone a thermal decomposition in an environment with free oxygen supply. The presence of heat energy indirectly to the surface of waste materials transform it into three different states, such as solid, liquid and gas based on the range of temperature from 300°C to 850°C [38]. With higher temperature used for the decomposition process, the end product would be in gas state, while at lower temperature the end product would be in liquid to solid state [39].

3.4 Landfill

Since waste disposal activity at landfill is a very common method worldwide, several countries have adopted the waste landfill technology and system in managing disposed wastes. In Japan, landfills are classified into several types which include inert landfill, controlled landfill and isolated landfill. The types of the landfill would be chosen based on waste material classification [40]. For example, waste materials that are classified as harmful waste which contain heavy metals, such as arsenic, lead, mercury and cadmium that has potential to affect the environment and surrounding populations, are designated to the isolated landfill. The structure of an isolated landfill does not permit movements of leachate and rainwater since it is build-up with high corrosion-resistant materials [40]. On the other hand, waste materials that are categorised as harmful wastes are designated to the controlled landfill since it has some possibilities to affect water bodies, such as public and underground wastes which act as human water sources. Meanwhile, for the inert landfill, the waste materials, which include construction wastes with little potential impacts to the environment such as rubber and metal debris, ceramic, glass and brick, are disposed. These waste materials are believed to be biochemically stabilised through inert landfill processes and will not affect the water bodies [40].

Apart from isolated, controlled and inert landfill technologies, the Japanese researchers have developed a semi aerobic landfill technology for managing waste materials from broad categories, such as domestic and construction wastes. In this technology, the concept of isolated landfill technology is adopted and added with some features for better management of waste materials [40]. Among the features are leachate collecting pipe and movement of natural air into the system for aerobic purpose. In detail, the leachate collecting pipe is made up of two compartments for the movement of leachate out from the system and flow of oxygen into the system where it occurs at the leachate regulation reservoir or also known as open-pit [40]. The main aim of natural air movement into the system is to induce the aerobic decomposition of waste through microorganisms, which allow for quick waste stabilisation and minimise the generation of carbon dioxide and methane, which act as the main source for global warming. Since the seriousness of methane was accounted as 21 times to carbon dioxide generation in the global warming issue, this technology is believed to be more environmentally friendly as compared to the conventional methods [40]. Besides, landfill sites that are adopted with semi aerobic technology tend to stabilise quickly after its role as landfill and it can be reused for some other purposes, such as an open field for sports and recreational parks. For example, a landfill site in Hokkaido, Japan was used for waste disposal activity between 1979 and 1990 was transformed into recreational parks for tourists and communities after the landfill stabilisation period [40]. It can be concluded that waste management technologies are plenty around the world. It is advisable to choose the right technology by considering the aims, cost of implementation, end products that we would gain and the level of emissions towards the environment.

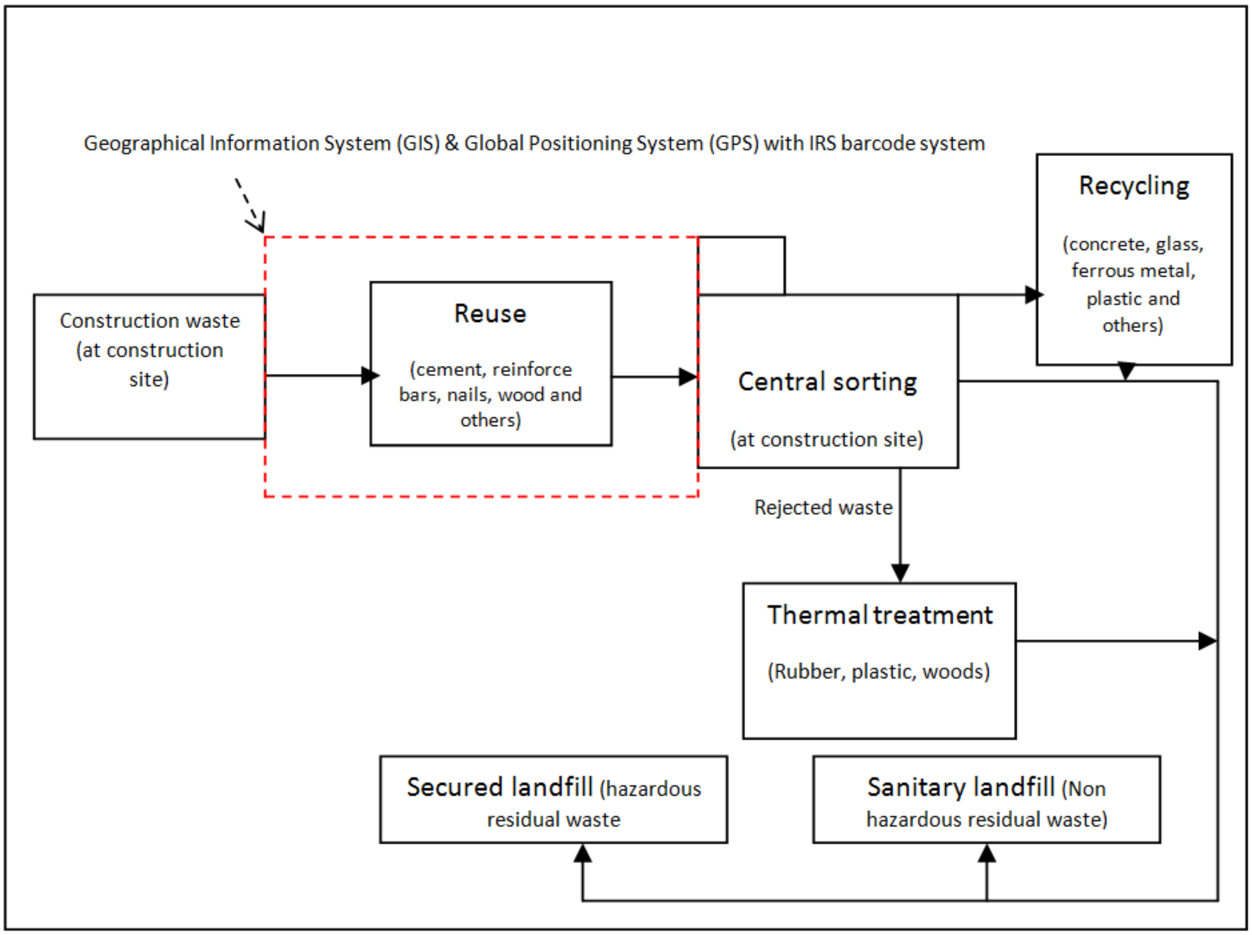

Figure 1: Flow chart of an approach towards integrated construction waste management

4 Developing an Integrated Construction Waste Management System

Figure 1 illustrates the flowchart of an approach towards the integrated management concept for construction waste management. Concerning Figure 1, the integrated approach from point of waste generated to the point of waste disposal will undergo four stages, namely waste reduction system, sorting system, raw material and energy recovery system and disposal system.

Generated construction wastes at construction sites should be minimised as much as possible by using the reuse method. Once the reuse method is implemented, the generated construction waste will go through a second phase, which is the separation of construction waste based on waste materials such as concrete, plastic, metals, electronic waste and others. Each landfill site should have facilities to separate the construction waste in an effective manner. After central sorting stages, the waste will go through the next phase, which is waste recycling to produce secondary raw materials as well as thermal treatment to generate electricity. Usually, inorganic construction waste such as cement, ferrous metal and glass will undergo recycling, while organic waste, such as wood, plastic and rubber, will undergo thermal treatment to generate electricity. The final phase is the disposal of residual waste from central sorting, recycling facilities and thermal facilities. Non-hazardous residual waste is disposed at the sanitary landfill site, while hazardous wastes are disposed of at a secured landfill disposal site. Fundamentally, an integrated approach to managing solid waste should have an interaction between facilities. Therefore, there is a need to improve waste management facilities such as central sorting systems at construction sites, recycling and recovery facilities, landfill facilities as well as transportation systems between each of the waste management facilities.

5 Conclusion

As a conclusion, this study comprises of managing a construction waste from the point of generation towards the point of disposal. The development of an integrated approach can be implemented in the construction waste management such as reuse, central sorting, recycling, thermal treatment and landfill, as an effort to substitute the traditional waste disposal method and reduce the final dispose rate at a landfill.

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no any conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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