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BIM-Integrated Construction Safety Risk Assessment at the Design Stage of Building Projects

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ABSTRACT

The construction industry has a higher rate of work accidents than other industries. As a proactive approach to safety management, Construction Hazard Prevention through Design (CHPtD) can significantly eliminate or reduce construction safety risks. This method consists of three indices namely Likelihood, Consequence and Exposure. Likelihood and consequence index of 19 construction jobs using 2018 injury and death data. Only 4 types of work are shown in this case. The findings conclude that the index of relative mortality frequency (RFI) of roofers (47-2180) and the index of relative frequency of day-going injuries (RDAIFI) of construction workers (47-2060) are relatively high. In addition, construction equipment operator relative day-to-day injury severity (RDAIS) rates (47–2070) are 3.3 times that of roof operators (47–2180). These results validate that using plug-ins in Revit can quickly calculate the construction safety risks of various design plans in a very short time and show that the plug-ins developed have very good engineering application value.

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1. Introduction

The Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) indicated that 734 construction safety accidents and 840 deaths occurred in 2018, which is an increase of 6.1% and 4.1%, respectively. The US Department of Labor's Bureau of Labor Statistics (BLS) indicates that the average death rate in the construction industry in 2017 was 9.5 deaths per 100,000 workers. However, the mortality rate for all workers was 3.5 deaths per 100,000 workers during the same year. A report on construction statistics in the UK revealed 30 deaths among workers in 2018/19. The worker mortality rate is 1.31 deaths per 100,000 workers while the average death rate is 0.45 deaths per 100,000 workers across all industries.

Construction safety performance has become a recognized issue in the construction industry. Risk assessment in the design stage, as an important content of safety management, can fundamentally reduce risks at source (Zhang et al., 2019). identified potential fall hazards and found that placing guardrail posts at the edge of the slab in the design phase would reduce the fall hazard in case projects. Golabchi et al (2018) shows that many interventions exist to reduce construction risk in the design phase, including workplace design, task sequencing design, shape and size design, human action design, and other interventions (Puteh, 2022).

Integrating these designs can improve safety in the construction process. construction process and safety risks required to conduct CHPTD. Only 3.2% architects and 9, 8% of structural designers stated that their company has guidelines for reviewing the CHPTD. The main reason for this is that the technical issues underlying CHPTD to help architects and structural designers perform CHPTD better have not been addressed. A safety risk assessment in the design phase is required to perform CHPTD. The construction industry has a higher rate of work accidents than other industries. As a proactive approach to safety management, Prevention of Construction Hazards through Design (CHPtD) can significantly eliminate or reduce construction safety risks. However, this concept is not applied effectively in practice because the technical issues underlying the CHPTD have not been addressed. This paper proposes a new method of quantitative construction safety risk assessment for building projects at the design stage. This method consists of three indices: Likelihood, Consequence and Exposure. These indices are calculated using accurate and objective data on occupational accidents, fatalities and specific construction planning. Plug-in connecting building information modeling (BIM) with safety risk data developed at Autodesk Revit, which can automatically calculate construction safety risks to help architects and structural designers quickly select design alternatives. A case study is presented to demonstrate the feasibility and effectiveness of the proposed method.

2. Methodology

This methodology includes a theoretical framework and developed plug-ins. Building Information Modeling is a system or technology that includes some important information in the Design, Construction, and Maintenance process that is integrated in 3D modeling. The proposed theoretical framework includes data collection, data mapping and data analysis, which are used to calculate construction safety risks quantitatively on a job basis, as shown in Image 1. The developed plug-in implements the proposed theoretical framework and serves as a platform for automatically calculating construction safety risks. The theoretical framework can be seen in Figure 1.

2.1. Data Collection

This data collection as a visual modeling tool, BIM can provide the information needed in the planning, design, construction and operation stages. However, BIM lacks data regarding safety risk assessment. Safety risk data must be captured systematically in the data collection phase. Therefore, two databases integrating all the data for risk assessment were only built at the data collection stage: the Injury and Death Database and the Construction Planning Database. The database previously recorded casualty information and job size for each construction job. The latter collects data on specific construction processes, unit hours worked, and required labor resources. All information collected in this database is based on the US construction industry.

Construction industry data taken from the 2018 IIF BLS Program was used in this study. Specifically, holiday injury data was collected from the Occupational Injury and Disease Survey (SOII) of the IIF program. Mortality data were collected from the Census of Fatal Occupational Injuries (CFOI) of the IIF program. The BLS SOII only collects data from the private sector, while the CFOI BLS collects data from the private sector, government employees and the self-employed by industry. Therefore, data from the private sector is used in this study for consistency. Nineteen construction jobs were selected for analysis in this paper based on the 2010 Standard Occupational Classification (SOC) system. The total number of workers employed in the private sector was compiled from the BLS Employment Statistics (OES). RSMeans is a mature construction cost database owned by the Gordian Company; The database contains the most comprehensive data on unit materials costs, unit labor costs, unit equipment costs, labor sources, municipal cost indexes, equipment rentals, location factors and other information on construction projects in North America. Therefore, only these three types of data are obtained separately from RSMeans to be integrated into the Construction Planning Database.

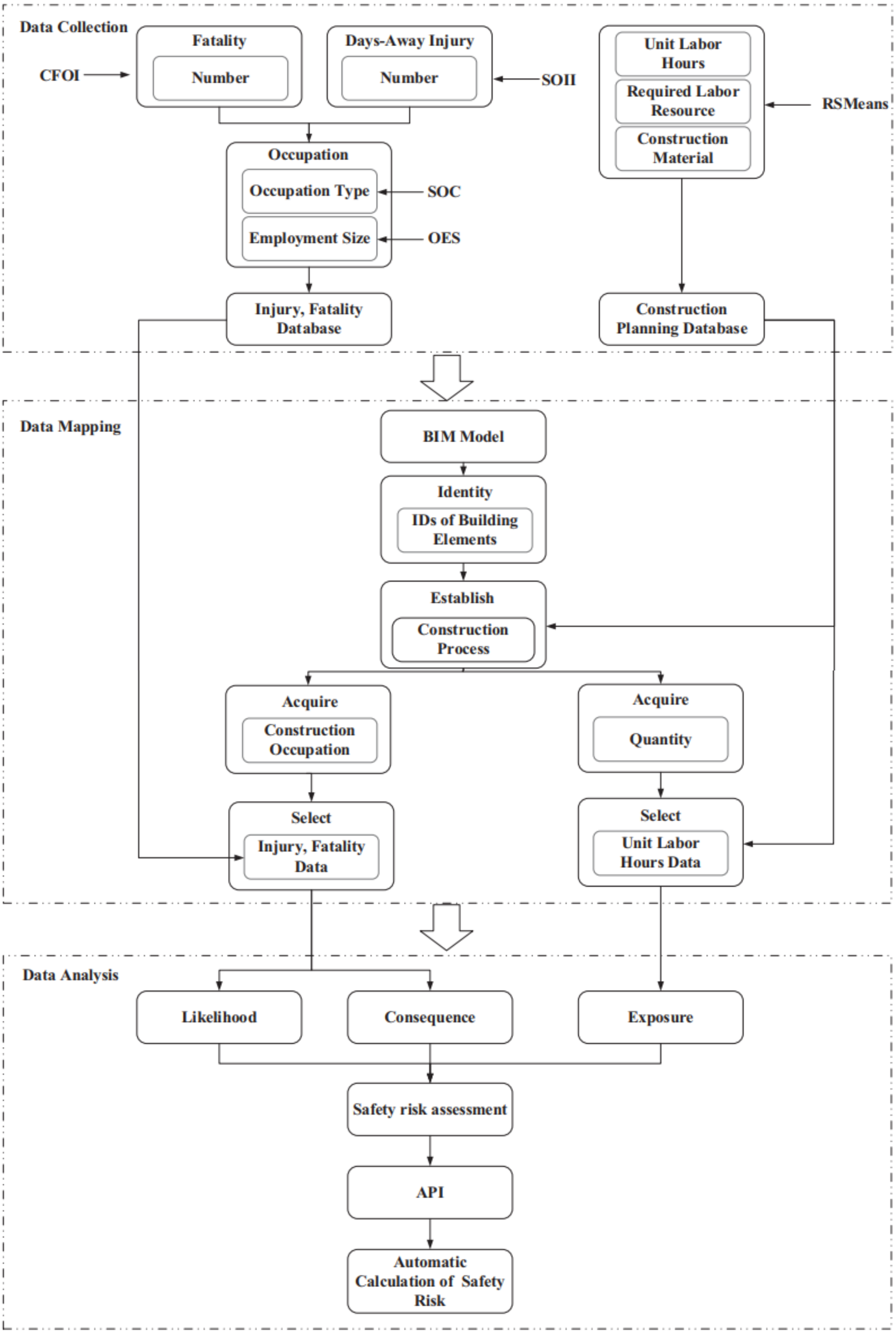

Figure 1. Theoretical framework

2.2. Data Mapping

BIM is a family of object-oriented modeling techniques. By building a library of custom families from basic building components, more dimensional information can be integrated beyond dimensional information. Families are divided according to the construction process. The two databases mentioned earlier are linked to BIM, and DB Link is applied to extract and update the data. The data mapping process includes two steps. First, the required labor resources, required job IDs, and unit hours of each construction process stored in the Construction Planning Database are mapped to the Revit family object extension parameters. Second, the required job IDs obtained from the first mapping are mapped to the Injury and Death Database. Then, Likelihood and consequence indices of the corresponding work can be obtained. The amount of construction materials is automatically calculated in Revit. The exposure index can be calculated according to the number and units of hours worked.

2.3. Data Analysis

Likelihood and consequence index of 19 construction jobs using 2018 injury and death data. Only 4 types of work are shown in this case. The findings concluded that the relative death frequency index (RFI) of roofers (47-2180) and relative day-away injury frequency index (RDAIFI) construction workers (47–2060) is relatively high. In addition, relative day-go injury severity (RDAIS) construction equipment operators (47–2070) is 3.3 times that of roof operators (47–2180).

The results of the automatic calculations obtained from the plug-ins validate that using plug-ins in Revit can quickly calculate the construction safety risks of various design plans in a very short time and show that the plug-ins developed have very good engineering application value. The final results obtained from the plug-in developed from this case show that plans A and B have the same total holiday injury risk (TDAIR), but plan A has a lower total death risk (TFR).

3. Results and Discussion

This case is a three-storey private building mainly used to analyze the construction safety risks involved in roofing works. Roofing work includes tasks such as cutting, aligning and gluing plywood sheets, asphalt felts, shingles, fitting to roof structures. According to the US Institute of Construction Specifications quantity calculation rules, the quantity of construction materials is calculated based on the actual data. In a BIM environment, the amount of construction materials can be calculated automatically. In this case study, the quantity of wood frame is presented by the number of types of material. The amount of plywood, moisture proofing and metal shingles of the roof elements is calculated by the roof surface area of one floor. The design can be seen in Figure 2.

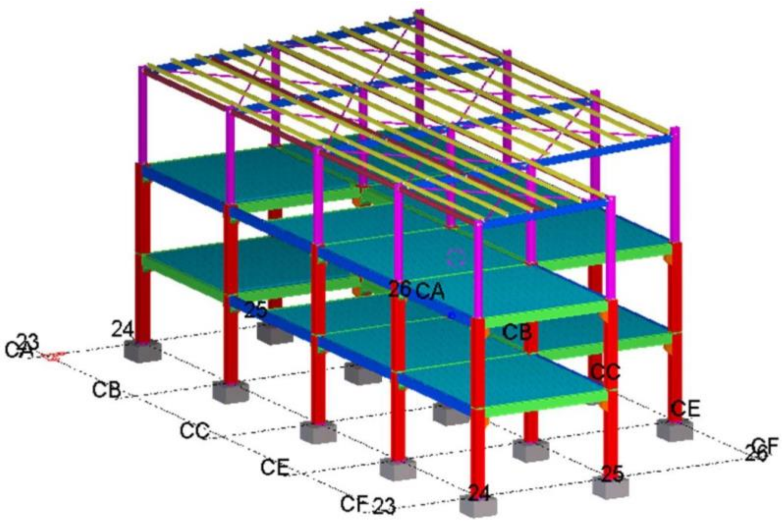

Figure 2. Modeling picture building

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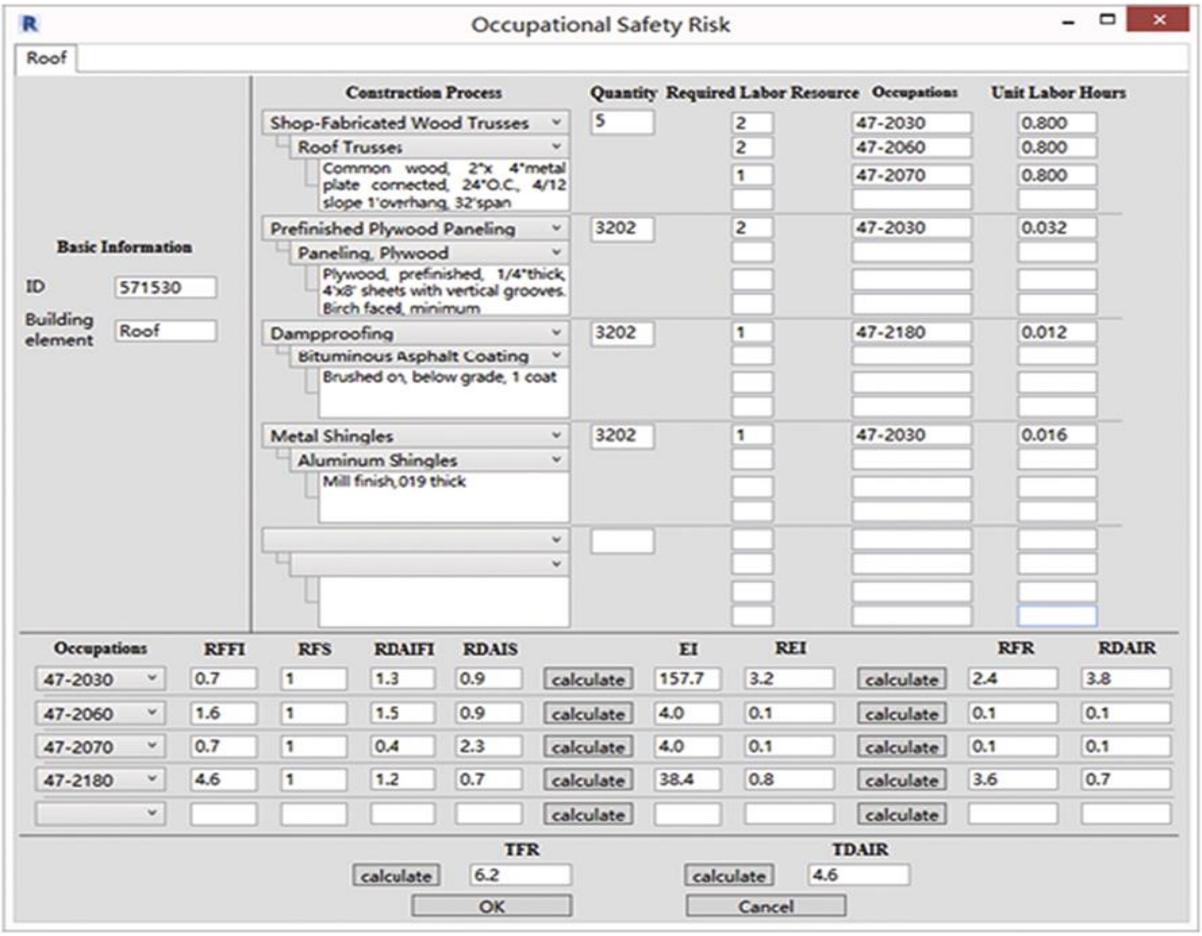

Figure 3. Automatic calculation results from plan A

Corresponding secondary development code mainly embodies the following functions:

1. Identify all these layers for calculations.
2. Determine the angle between the vector normal of each surface and the positive Z-axis.
3. Identifies all faces with an angle greater than 0, and
4. Add up the areas of all these selected surfaces

Likelihood and consequence index of 19 construction jobs using 2018 injury and death data. Only 4 types of work are shown in this case. The findings concluded that the relative death frequency index (RFI) of roofers (47-2180) and relative day-away injury frequency index (RDAIFI) construction workers (47–2060) is relatively high. In addition, relative day-go injury severity (RDAIS) construction equipment operators (47–2070) is 3.3 times that of roof operators (47–2180). The results of manual calculations are in accordance with the results of automatic calculations obtained from the developed plug-in. These results validate that using this plug-in in Revit can quickly calculate the construction safety risks of various design plans in a very short time and demonstrate that the plug-ins developed in this paper have very good engineering application value.

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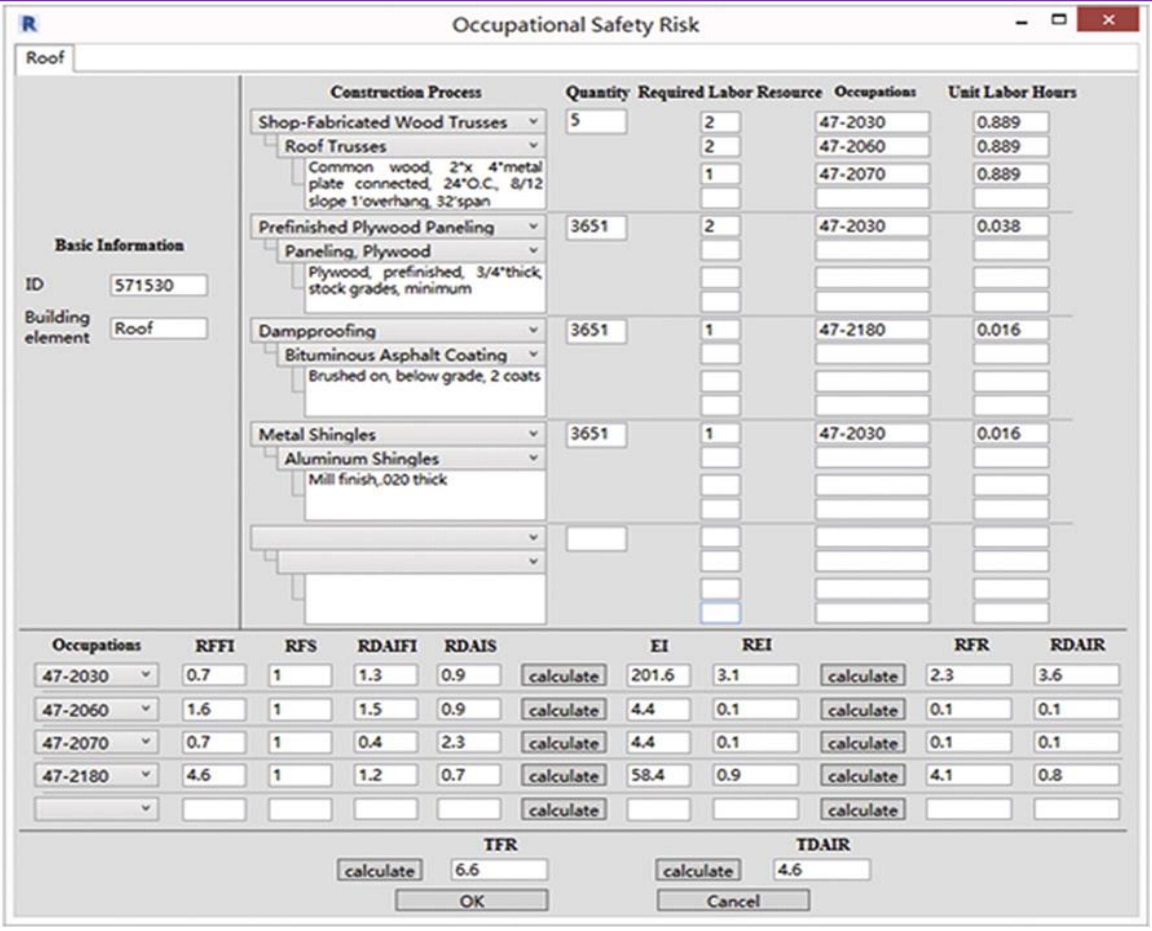

Figure 4. Automatic calculation results from plan B

Based on Figure 3 and Figure 4, the results of case study calculations cannot reflect the actual safety risk situation in countrie. The final results obtained from the plug-in developed from this case show that plans A and B have the same total holiday injury risk (TDAIR), but plan A has a lower risk of total death (TFR). Architects and structural designers should immediately select design plan A. Thus, architects and structural designers should focus on the construction work of carpenters and roofers. Effective shield design should be considered at the design stage.

4. Conclusion

As a proactive safety intervention to reduce construction safety risks, the use of CHPTD is recommended in practice. The technical problem underlying CHPTD is how to use risk-based methods to select design alternatives that optimize construction safety. This paper proposes a quantitative construction safety risk assessment method consisting of three indices: likelihood, consequence and exposure. This index can be calculated using accurate and objective data on occupational accidents, deaths and specific construction planning. These data are closely related to the design features of the building project. The technical problem underlying CHPTD is how to use new tools to improve the selection of optimal design solutions. Plug-ins that connect BIM with security risk data have been developed in Autodesk Revit. This plug-in can automatically calculate construction safety risks to quickly help architects and structural designers select design alternatives that optimize construction safety. This approach solves the problem that architects and structural designers cannot implement CHPTD in practice due to a lack of safety knowledge. In addition, a case study is presented to demonstrate the feasibility and effectiveness of the proposed method for construction safety risk assessment at the design stage.

The final case study results are presented to demonstrate the feasibility and effectiveness of the proposed method for construction safety risk assessment at the design stage.TFR). In plan A, carpenters (47-2030) and roofers (47-2180) have a higher relative risk of death (RFR) and relative holiday injury risk (RDAIR). Architects and structural designers may consider effective shielding designs for the construction work of carpenters and roofers at the design stage. Death and work accident data are collected by 19 construction jobs in this paper. For the same work, there is no further analysis of safety risks arising from different construction activities. Neither the BLS SOII nor the BLS CFOI provides risk data by cause of death or injury to construction workers with the same occupation. Using labor casualty data from different construction activities for further analysis after perfecting the statistical caliber makes more sense. Furthermore, in the traditional method of construction procurement, design-bid-build.

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