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Authors: Massimiliano Fanzaga, Design Manager, Permasteelisa Group
Zhihong Liao, Communication Manager, Permasteelisa Group
Marc Zobec, Regional Principal Engineer, Permasteelisa Group

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Marc Zobec


Massimiliano Fanzaga


Zhihong Liao

Authors

Marc Zobec, Design Manager[1]
Massimiliano Fanzaga, Communication Manager[2]

Permasteelisa S.p.A.
viale E. Mattei 21/23
31029 Vittorio Veneto
Treviso
Italy

t: +39 0438 50 5000
f: +39 0438 69 4509
e[1]: marc.zobec@permasteelisagroup.com
e[2]: m.fanzaga@permasteelisa.it
www.permasteelisagroup.com

Zhihong Liao, Regional Principal Engineer

Permasteelisa Asia Hub
Josef-gartner Curtain Wall (Shanghai) Co. Ltd
Floor 11, City Point Building
1600 Zhong Hua Road
Shanghai 200021
China

t: +86 21 6329 9988
f: +86 21 6329 8668
e: liao.zhihong@gartner-pgroup.com
www.permasteelisagroup.com

Marc Zobec
Marc is Permasteelisa's Technical Support and Design Manager. He has worked on numerous tall building projects particularly related to blast enhanced façade engineering, design and testing, such as Hearst Tower NY, HSBC Headquarters London and Goldman Sachs NY and leads the safety and security research group.

Massimiliano Fanzaga
Massimiliano is the Group Communication Manager of Permasteelisa and is in charge of the entire corporate image worldwide, supported by a team spread in every geographic hub where Permasteelisa operates.

Zhihong Liao
Zhihong Liao is the Principal Engineer in Building Physics for the Asia and Australia Business Hub of Permasteelisa. She specializes in detailed thermal analysis and building physics of advanced façade design in the Asia and Australia region.

China's tall buildings are taking their place in the international pantheon of distinctive tall buildings, in part due to landmark façades that define the towers and create efficient interior environments. Beyond aesthetics, façade systems are addressing the unique needs of China's climate and geography.

China is playing a leading role in the global development of tall buildings. Together with other Asian countries, such as South Korea, China represents the largest market in the world for the tall building industry. Within this process, the social role of tall buildings is broadening. Chinese cities are building a variety of towers; from the high-profile iconic "landmark" supertall building to those serving the daily needs of a population of 1.3 billion people living in the fastest-growing economy in the world (World Bank 2010).

Chinese tall buildings frequently have mixed-use occupancy, including residential, hotel rooms, corporate headquarters and public offices. Several Chinese cities are venturing to build the first true "vertical communities" in the world. The skylines of many metropolises, particularly coastal cities, are frenetically evolving and the profile of hundreds of residential skyscrapers is interspersed with emerging, landmark towers.


Figure 1. Taipei 101 © Lieser / Permasteelisa Group

The first impression created by this new generation of tall buildings, either from afar or at street level, is the façade that encompasses the building, defining both its geometry and volume. Façades play a crucial role, not only in the function of a tall building, but also in its overall quality. Often termed the "skin" of a building, façades provide a controlled internal environment filtering the external elements. The façade, particularly of a tall building, is often more important than its volume, as it creates both the image and functionality.

Developing China's Defining Style

In China, façades are playing a key role in defining buildings and cities. The Jin Mao, Taipei 101, Shanghai World Financial Center and Two International Finance Center in Hong Kong are international buildings but also distinctively Chinese as they embody national and regional cultural features. For example, the skin of the 508-meter-tall Taipei 101, completed in 2004 and designed by C.Y. Lee and Partners, embodies the pagodas of the "genius loci" of that region (see Figure 1). The tapering façade elements, superimposed one above the other, and their double-pitched corners, create a modern replica of the typical building silhouettes, while the bright green glass of its double glazed façade is inspired by the color of bamboo. The glazed curtain wall also plays a fundamental role in the energy efficiency of the building. The glass used for the building reflects more than 50% of the solar radiation, which helped the Taipei 101 become the tallest LEED-Platinum awarded building in the world.

Similarly, the 421-meter Jin Mao is very popular among Shanghai residents, as it combines modern construction techniques with the traits of older Chinese architecture (see Figure 2). The shape and the façade of this 15- year-old high-rise designed by

Figure 2. Jin Mao Building – detailed view. © Phillip Oldfield

Skidmore, Owings & Merrill (SOM) is inspired by the superimposed structures of Chinese temples, making the Jin Mao a case study for the reinterpretation of vernacular examples in modern buildings. The façade, designed to withstand earthquakes and Shanghai's extreme weather and pollution conditions, has a number of intricate filigree features that were considered innovative for the Chinese market at the time. First, in order to achieve the stepped back façade synonymous with ancient Chinese pagodas, the system was unitized as opposed to conventional stick systems of that time. The unitized approach created a higher quality system by ensuring that critical façade joints and interfaces were prefabricated and sealed in the factory rather than relying on standards of site labor to ensure effective weather seals. The use of façade modules instead of stick technology also enabled the panels to handle greater inter-story movements caused by earthquakes, absorbing movements between the panel joints rather than glass-to-frame joints.

When the construction of its curtain wall began in 1998, the German technology used by Gartner GmbH in Jin Mao's façade was a novelty on the Chinese market and it raised the bar of façade performances and construction quality in the region. To deal with Shanghai's aggressive maritime climate and the high level of air pollution, external façade features included stainless steel spandrel panels, 50 millimeter-thick stainless steel rods and anodized aluminum fins. In addition, careful detailing and engineering of the external features ensured that joints were completed to high tolerances. Fifteen years after completion the Jin Mao still maintains the design quality and system performance.

Building Efficiency

Performance is essential to modern tall buildings in China. Official data shows that in 2008, building energy consumption accounted for 27.5% of China's total energy consumption (Zhu Neng 2009). Last year China published its energy conservation "white book" as part of the 12th five-year plan, in which the central government set goals for different regions. For Beijing and Shanghai, the energy consumption is planned to be reduced by 17% and 18% respectively, which will result in a cumulated energy saving of 32.01% and 34.4% compared to energy consumption in 2005.

China also published the document – ***GB50189: 2005: Design Standard for Energy Efficiency of Public Buildings.*** Compared to the current European energy conservation regulations, such as the ***UK Building Regulation, Approved Document Part L 2010 - L2A,*** GB51089 sets much more stringent requirements. For Beijing climate, GB 51089 requires that, for an individual elevation, when the window-wall ratio is between 50 to 70%, the U-value of the curtain wall vision area shall be no higher than 2.0 W/m^{2}K and the U-value of the opaque area shall be no higher than 0.6 W/m^{2}K. This is equivalent to a U-value 1.3 –1.58 W/m^{2}K for a curtain wall overall with 50–70% window-wall ratio respectively, while according to UK Building Regulation Part L the compliance value is 2.2 W/m^{2}K for curtain walls (Fridley et al. 2011).

Increasingly stringent regulations imposed in recent years mandate the adoption of high performance façades in new construction and encourage the substitution of existing-low performance envelops in older tall buildings.

The results are now evident both in terms of environmental performance and architectural impacts. Single-glazed, fully transparent façades that were common in the first 20 years of the "curtain wall" era, have evolved into the complex double-skin, multi-layered façades of current buildings, which characterize the visual image of many skyscrapers. Though such examples represent an important opportunity for architects and engineers, higher performances can be attained with the adoption of high-performing materials applied on simpler envelope systems.

This is the case with many high-rises that feature a single-layered façade system but still achieve good results in terms of energy efficiency. The most important example, other than the above-mentioned Taipei 101, is probably the new 7 World Trade Center, New York, designed by SOM and completed in 2006 (see Figures 3 and 4). Here, the fully glazed curtain wall system (including framing) achieved an overall U-value 1.6 W/m^{2}K; enabling the tower to become the first New York office building to achieve LEED Gold rating. The thermal performance was achieved using floor-to-ceiling neutral

"Increasingly stringent regulations imposed in recent years mandate the adoption of high performance façades in new construction and encourage the substitution of existing-low performance envelops in older tall buildings."

Figure 3. 7 World Trade Center, New York.© Chuck Choi Architectural Photography

Figure 4. 7 World Trade Center – façade detail. © David Sundberg/ESTO

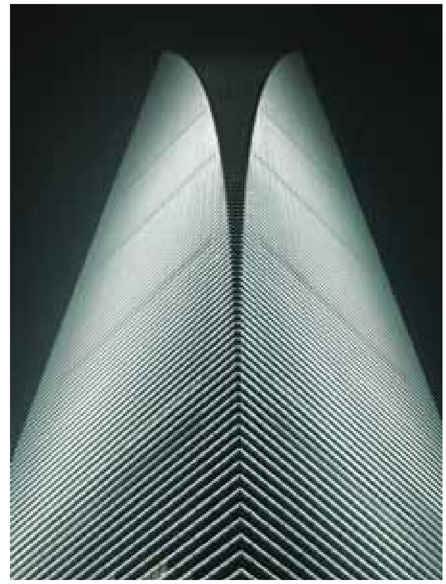


Figure 5. Shanghai World Financial Center – sloped façade. © KPF

high-performance glazing that maximizes both natural daylight and views of the World Trade Center area and upper Manhattan.

China's Challenges

The desire for building owners and architects to maximize transparency and natural daylight in order to reduce energy from artificial lighting, while achieving high thermal performance and occupant comfort, poses something of a design paradox. Maximizing glass surface areas to reduce the use of artificial lighting has greater impacts than many simple energy saving techniques. Over two thirds of energy generation in China is coal fire power based (Rosen 2007). A reduction in the use of artificial lighting has a substantial impact on carbon emissions. While increasing glass surface areas enhances natural daylight use, glazing contributes to the highest heat loss element in a façade. Therefore, more advanced climate responsive integrated façade systems are required to cope with severe external environmental conditions in order to achieve occupant thermal and visual comfort. From this aspect China is a challenging country encompassing several broad climate zones. The North-East region experiences very cold winters (up to -40°C, in Harbin) and hot summers. Further inland there are large seasonal temperature variations with very hot summers (37–40°C) and cold winters (-10°C, such as in Shanghai); while the south area is hot year-round. These climates, coupled with the extremely high levels of air pollution, require buildings with responsive and technically advanced façades, which can reduce energy consumption and the CO_2 footprint while improving internal conditions.

In the last ten years, the development of low emissivity, spectrally selective glazing has resulted in a dramatic reduction in energy consumption in buildings. Building owners realize that for future energy compliance building façades will need to be adaptable for retrofitting and refurbishment. Sustainable design of buildings not only deals with energy reductions but also affects life cycle design and replacement of façade components. One such building in Shanghai that encompasses life cycle component design is the iconic Shanghai World Financial Centre. The design of the façade allows glass replacement to be carried out from within the building, not only providing maintenance and safety advantages, but enabling upgrading and modernization of the building in line with advancements in glazing technology and energy code requirements. The system allows the simple and rapid replacement of components with minimal cost and operational impacts on the building.

Another challenge for the Shanghai World Financial Centre project was Shanghai's high seismic risk zone. Multi-faceted sloped surfaces (see Figure 5) require special engineering detailing in order to accommodate seismic movements without the risk of large glazed panels "locking up" and rupturing; presenting a potential hazard to the public. The sloping nature of the façade and large glass surfaces required specialized fixing brackets that allowed rotational movement in all planes.

New Ideas for China

In recent years, developments in glass coating technology alone have been outpaced by the introduction of increasingly stringent energy codes and the architectural trend to maximize glass surface areas. To meet these requirements, advanced "active" multi-layer façade systems developed and in use in Europe over the last decade have become more prevalent in China. While these systems can be integrated with the building control system to regulate functions such as blind settings and ventilation, the depth of the system for maintenance access and ventilation requirements resulted in the loss of effective net-rentable area, far exceeding the cost of the initial investment of the system. In order to address these concerns, new façade strategies are required.

The latest innovation in façade technology recently introduced in China is termed the CCF (Closed Cavity Façade) or Mfree-S® (as the second generation of this façade has been named). The closed cavity façade provides all the advantages of a naturally-ventilated double skin façade without the need for opening elements, deep façade cavities for effective ventilation or the risk of interstitial condensation. The Mfree-S® closed cavity façade, as the name suggests, consists of an internal double (or triple) glazed unit and external single glazing with an intermediate blind system.

Since the cavity is closed, there is a reduction in the number of surfaces requiring regular cleaning and maintenance. Careful research and development has been carried out to develop blind systems that have been extensively tested for durability through intense cyclic testing, as well as heat built up within the cavity. Such testing has led to the development of proprietary blind systems with increased durability and reliability.

In order to prevent condensation within the cavity, controlled low volume/low pressure dry air is introduced into the cavity. The flow rate is an engineered balanced design that ensures condensation risk is eliminated by using the minimum level of energy for the dry air system.

Figures 6 and 7 shows the impact on annual building energy consumption taking into account heating, cooling, ventilation, artificial lighting and hot water service requirements, as well as internal heat loads such as occupants and IT equipment. For comparison purposes, building energy consumption is expressed as kW/m^2 of façade surface area for different façade typologies on the south elevation Shanghai climate. Comparing the same glass coating, the energy consumption of an internally ventilated "active" double skin façade is 127 W/m^2/year, while for the Mfree-S® closed cavity façade; it is 114 W/m^2/year. This is due to the different ventilation rate of the cavity between the inner and outer skins.

The Mfree-S® closed cavity façade doesn't require the tedious cleaning and maintenance work within the cavity caused by heavy pollution or dust. The system also eliminates the risk of interstitial condensation, as well as a significant increment in acoustic insulation due to the outer glass layer being effectively closed, mitigating sound paths. The difference in acoustic performance between various façade typologies is shown in. The low dry air volume in the cavity guarantees a quiet double skin façade. This is another important characteristic compared to standard internally ventilated façades, where thermal performance is achieved by the air exchange volume in the cavity.

Compared to standard internally ventilated double skin façades, An Mfree-S closed cavity façade can eliminate the need for internal opening panels required for cleaning and maintenance, increasing the effective usable floor area.

The first project in China to use this new technology is a relatively small building that will host offices and a demonstration area for an important and highly innovative lighting manufacturer company in Wu Jian, Jian Su (see Figures 8 and 9). The client requested a façade reflecting the high-tech image of their company, providing a "slinky," neat appearance, and higher level of occupant comfort, as well as energy efficiency and operational cost savings.

The 2,200-square meter of Mfree-S closed cavity façade can provide high thermal performances, dramatically lowering heating and cooling demands. In addition, users get

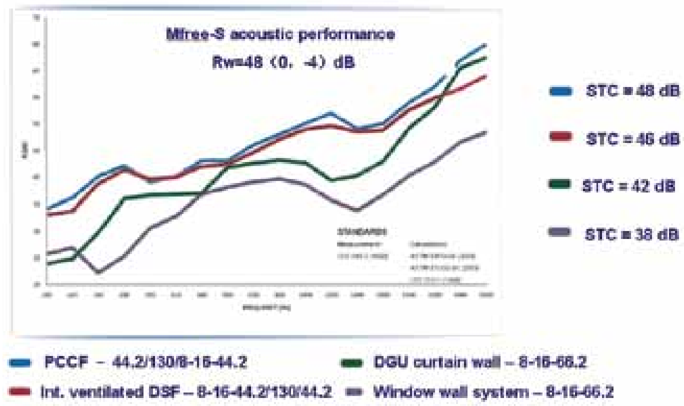
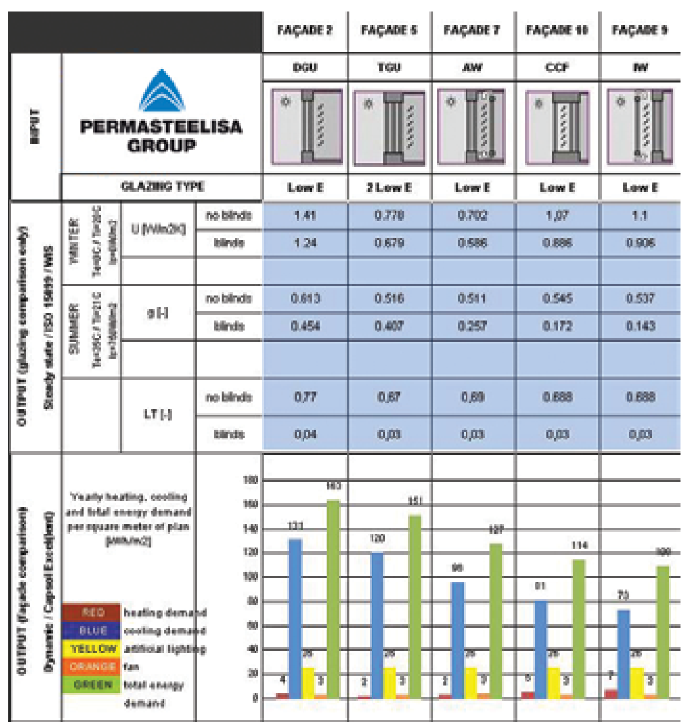


Figure 6. Impact in building energy consumption by using different types of curtain wall at south orientation for Shanghai climate. © Permasteelisa Group



				FAÇADE 2	FAÇADE 5	FAÇADE 7	FAÇADE 10	FAÇADE 9
INPUT	PERMASTEELISA GROUP			DGU	TGU	AW	CCF	IW
	GLAZING TYPE			Low E	2 Low E	Low E	Low E	Low E
OUTPUT (glazing comparison only) Steady state / ISO 15099 / WIS	WINTER	U [W/m2K]	no blinds	1.41	0.779	0.702	1,07	1.1
			blinds	1.24	0.679	0.586	0.886	0.906
	SUMMER	g [-]	no blinds	0.613	0.516	0.511	0.545	0.537
			blinds	0.454	0.407	0.257	0.172	0.143
		LT [-]	no blinds	0,77	0,67	0,69	0.688	0.688
			blinds	0,04	0,03	0,03	0,03	0,03

Figure 7. Impact in building energy consumption by using different types of curtain wall at south orientation for Shanghai climate. © Permasteelisa Group

> “While energy is an important design parameter, historically buildings have been primarily utilized for both protection from the elements and safety from external sources.”

the maximum from the usable space, due to the optimized thickness of the external wall, coupled with the fact that the internal glass cannot be opened, resulting in a very small loss of usable area. Therefore, furniture can be placed very close to the glass, without penalizing the living conditions of the occupants, who can still benefit from the full-height transparent glass.

The project is scheduled for completion in September 2012. The main challenges of this project came from the difficult tuning of the dissimilar components of this façade to cope with the specific climatic conditions of the area: a great level of humidity both in summer and winter season; relatively high solar loads with high external temperatures and a high level of air pollution, requiring technicians to test different solutions and mechanical components. Design and efficient economical sizing of the air compressor and dehumidifier was achieved using proprietary software to carry out hourly hygrothermal energy balance simulations of the humidity in the cavity specifically for the Shanghai climate. This enabled the dry air flow rate required in the cavity to be introduced at minimal volumes, eliminating condensation risks while minimizing energy use of the air equipment.

Meeting China’s Standards

In recent years, the term “sustainable design of buildings” has focused on reductions in energy usage and CO^2 emissions. While energy is an important design parameter, historically buildings have been primarily utilized for both protection from the elements and safety from external sources.

The performance of a curtain wall façade is determined by a range of parameters that are specified for both general and particular environmental conditions faced by the building. The façades of the two 216-meter-tall iconic twin towers designed by Arquitectonica for the Pujiang Shuanghui complex (Riviera TwinStar Square 1 & 2) in Shanghai (see Figures 10 and 11) are created to withstand the unique atmospheric forces acting in the region. Typhoons and heavy rains require the design of a relatively sealed façade, with Grade 3 or 4 water resistance (depending on the orientation and its exposure to predominant strong winds), and thermal transmittance less than 2.25 W/m^2K. The façade of this building is also designed and engineered for specific safety requirements. The use of laminated glass in lieu of tempered glass ensures retention of glass fragments in the event of breakage. Tempered glass, often called safety glass, has been eliminated due to the risk of spontaneous breakage from Nickel Sulphide (NiS) inclusions. One of the main material features of the façade is the use of natural stone. In the unlikely event of breakage, a safety mesh is laminated to the inner stone surface to prevent problems. These are the type of invisible safeguards against the impact of improbable environmental forces specifically required for this region.

Threats to building safety do not always arise from environmental elements. Explosions in the immediate surroundings of a building can cause extensive damage to the building façade. In the event of explosion, either accidental or from a terrorist act, the primary cause of injuries is not due to the blast pressure wave itself but glass fragmentation (Norville et al 2001). The 1995 Oklahoma City bombing exemplified the indiscriminate outcome of a blast, whereby the majority of damage occurred indirectly to surrounding buildings within the vicinity of the blast. Recognizing this threat to safety and its close proximity to the Twin Towers site in New York, the Goldman Sachs Headquarters in New York (Pei Cobb Freed Architects) represents the state-of-the art in terms of façade security strategy.

Figure 8. Mfree-S project – Opple Lighting, Wu Jian, Jian Su, China. © Permasteelisa

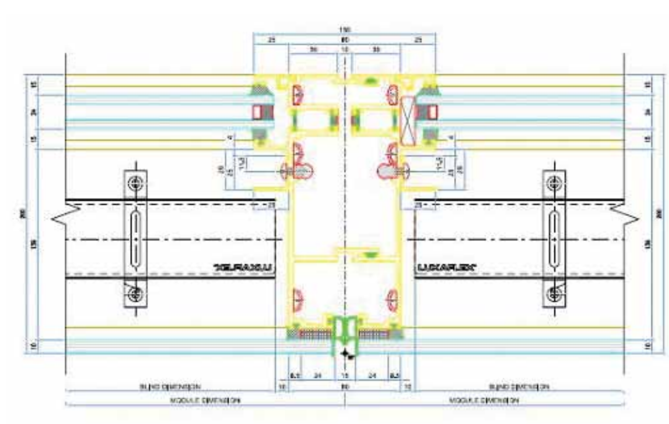


Figure 9. Mfree-S Project in China. © Permasteelisa Group

The façade of the building is engineered to withstand the force of a major explosion within the immediate surroundings. Acknowledging the economic as well as architectural constraints in using fully resistant glass, the façade was designed to dissipate rather than resist the energy of the blast wave. Elements such as the framing and brackets were designed to deform, while laminated glazing was sized to rupture and retain a majority of glass fragments. The ability of the cracked laminated glass membrane to progressively deform meant that the velocity of any detached glass fragments would be at a low velocity, ensuring minimal superficial damage. The deformability of the framing system required the design of special interlocking components to achieve the catenary transfer of forces and retention between façade units. The dissipative design resulted in a cost effective solution, reducing reactions to the main structure as well as achieving the desired architectural intent.

Security in buildings is an ever present concern for building owners and developers worldwide. Threats are often indiscriminate and often aimed at soft targets, such as commercial public buildings, designed to cause the maximum disruption to building occupants. Blast-enhanced façades are common in US and European markets but are increasingly being specified in Asia. Current security intelligence levels in China dictate that the "probability of threats" is very low, but national security can, and often does, change rapidly. The cost of blast enhancement is intangible in the sense that the cost of engineering and materials cannot be readily compared to the cost of human life.

Conclusion

The industrial and economic development of China in recent years has seen not only the quantity of commercial buildings increase, but also the quality. As a major global economy, China recognizes that the improved standards of living and competition have led to a greater energy demand. Energy demands though are increasing at a greater rate than sustainable supply and greater energy efficiency technologies in buildings are being applied. The thermal and energy performance of façades are becoming more stringent. The use of advanced façades with multi layers and shading systems that respond to the climatic needs of the building are increasingly embraced in China.

Figure 10. Riviera TwinStar Square 1 & 2, Shanghai. © Permasteelisa Group

Figure 11. Riviera TwinStar Square 1 & 2 – façade detail. © Arquitectonica

Careful building design addresses not only immediate energy use, but also the life cycle of materials and components, as well as the ability to upgrade buildings in the future with improved technologies. At the same time, an appropriate design utilizes as much of the existing longer-life components as possible. The recent application of new façade technologies in China is the result of the recognition of not only the need for greater energy efficiency but also reduced maintenance and operational costs.

Security and safety in buildings is an increasing design challenge, particularly seismic and fire. Seismic risks are well defined and engineered in the design and are being adapted to more free form and non-planar façade surfaces and buildings. Other threats such as fire are evolving in line with the use of lighter materials, as well as the use of active systems. Blast enhancement, although not a highly probable threat in China at present, is increasingly being specified in designs throughout Asia and significant security can be achieved cost effectively. Technology is not only a goal itself; it's a way to improve the quality of life. ■

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