Concrete matter: building the Bruges submarine pens (1917-18)

Willem Bekers & Ronald De Meyer
Ghent University, Ghent, Belgium

ABSTRACT: Starting in August 1917, a large submarine shelter was erected in the German-occupied port of Bruges. Its construction completed a transition from mixed steel-and-timber shelters to all-concrete bunkers in this area. The new *Gruppenunterstände* prefigured many of the typological, technological and logistic key features of the iconic submarine pens from World War II, when lessons learnt from the Bruges prototype were to be pushed to extremes. The case of the Bruges submarine pens exemplifies the scientifically managed construction site and hints at the underexposure of experimental military concrete technology in architectural construction history. It is argued that the conflict period, rather than forming a gap in an otherwise continuous evolution of building practice, created certain opportunities for a modern and experimental attitude towards building typology and construction.

1 INTRODUCTION

In his book *Concrete and culture: a material history*, Adrian Forty (2012) acknowledges the shift of reinforced concrete from the realm of vernacular experiment to that of industrialized construction as being instrumental in concrete's association with modernity. This shift from 'mud' to 'modern' took place around the turn of the twentieth century, when calculation methods, building codes and standards for reinforced concrete were developed, after some decades of trial-and-error construction in different fields. While most attention in this respect goes to the proprietary systems developed by civil entrepreneurs, the military pioneering work in reinforced concrete remains somewhat underexposed. Nonetheless, military academies were among the first to integrate courses on concrete calculation or to install experimental concrete laboratories, for instance at the Belgian Royal Military Academy (Van De Voorde 2011, 134-153). When the war eventually broke out in 1914, the pairing between military thinking and emerging industrial trends, such as Taylorism and Fordism, created a unique breeding ground for experiment in the field of construction.

Figure 1. Partial view of the group shelter in the northern port of Bruges, 1919 (KLM-RMA).

In the following sections, we will explore some of the mechanisms behind these insights. Starting with a short description of the adoption and dissemination of reinforced concrete in the military context of the Western Front, we then move on to the building program of the *Marinekorps Flandern* and more in particular that of the *Kaiserliche Marinewerft Brügge*. The construction of the large group shelter for submarines in the northern port of Bruges (Fig. 1) will be treated in depth, as an example of a scientifically managed building site, before tracking continuities in submarine shelter designs into the 1940s.

2 CONCRETE AND THE MILITARY

The rapid evolution of artillery technology during the second half of the nineteenth century forced military engineers to continuously reconsider permanent fortification design and construction. The introduction of the rifled barrel around 1860 drastically increased the range and accuracy of siege artillery, which in turn resulted in new defense concepts that relied on rings of detached forts in advanced positions. For its part, the development of the explosive shell, between 1885-90, heralded the replacement of brick and masonry by mass concrete as the preferred construction material for the casemates that protected fortress artillery (Mallory and Ottar 1973, 13).

However, during the military construction boom before the outbreak of the First World War, the resilience of mass concrete against modern artillery was somewhat overestimated, resulting in poor execution of site-cast plain concrete in many cases. Little attention was paid to an appropriate aggregate selection or cement content of the concrete and the homogeneity of the concrete was often compromised by interruptions during the casting process. The failures of such poorly executed plain concrete, when confronted with contemporary artillery, became evident from field trials at the French fort Malmaison in 1886 and from the siege of Port Arthur during the Russo-Japanese war of 1904-05 (Mallory and Ottar 1973, 29). In 1912, the Russian army, in the presence of Belgian and French military observers, constructed a mock-up fort on the island of Berezan in the Black Sea to test the effects of artillery fire on different construction methods. The results of these tests clearly demonstrated the advantages of reinforced over mass concrete, but they came too late to influence the design of most prewar fortifications (Gils 2014, 36-43). Eventually, the upcoming war would accelerate the implementation of such insights.

As it was, permanent fortifications along the Western Front in 1914 displayed a variety of construction methods, including hybrid structures of brick and concrete (such as the Antwerp forts), plain concrete (such as the Liège and Namur forts) and reinforced concrete (such as some of the Verdun forts). German intelligence was quick to assess the effects of shellfire on captured Belgian and French concrete forts. The failure of the heavy German siege artillery to destroy the fort Douaumont in the Verdun sector had been entirely on behalf of the fort's construction in reinforced concrete with a high cement content and the implementation of certain novelties, such as an additional shell-bursting slab on the roof. Such innovations would resonate in the interwar design and construction programs of permanent fortifications in the 1930s.

At the same time, the stalemate on the Western Front sparked a massive building campaign of fieldwork fortifications. In 1915, the Germans were the first to use reinforced concrete for the construction of shelters and dug-outs, and from 1916 on, its use was preferred, if not compulsory (Mallory and Ottar 1973, 45). Reinforced concrete gradually became the standard material for the shell-protection of a wide variety of strongpoints, personnel shelters and observation posts at the front. The casting of concrete under hazardous working conditions presented many difficulties. Concrete aggregates needed to be fetched over long distances, the supply of clean water for concrete preparation was problematic in many occasions, and crucial concealment of the building sites proved difficult to maintain (Oldham 2011, 43; Vancoillie and Blieck 2016, 264-268). As a result, it became standard practice to prepare a dry concrete mixture behind the lines, before transporting it by hand to the building site. This, of course, had a negative effect on the overall quality of the used concrete (Vancoillie and Blieck 2016, 101-103).

The difficult working conditions at the front prompted builders to make maximum use of local opportunities, which in turn paved the way for a proliferation of building typologies that deviated from textbook standards (Mallory and Ottar 1973, 49). To overcome the difficulties posed by the front conditions, both Germans and British started to experiment with prefabricated concrete building blocks and turned towards standardized shelter designs, such as the renown Moir pill box (Oldham 2011, 43-67; Oldham, 2014). Even if prefabrication never found general application, by 1918 the tendency was firmly established (Mallory and Ottar 1973, 59).

The German-built coastal defenses along the shore of Flanders deserve some particular attention in this context. Much to their surprise, the Germans captured the Belgian coastal ports undamaged during their advance in 1914. These ports were to become the spearheads of the so-called *Kleinkrieg* strategy, adopted by the *Kaiserliche Marine* (Karau 2014, 1). This strategy aimed for a naval war of attrition, by attacking the vital traffic of commercial and military shipping in the English Channel with light naval units such as torpedo boats and submarines. The advanced and vulnerable position of the bases in Flanders was a constant concern throughout the war. To prevent the Allies from turning the German flank by landing behind the lines, the *Marinekorps Flandern* launched a massive building program. The entire occupied Belgian coast was reinforced with a continuous dispositive of concrete-protected coastal batteries. A defense line of concrete strongpoints, the so-called *Hollandstellung*, was established along the Belgian-Dutch border between the coast and the port of Antwerp. After securing the western part of Flanders, the *Marinekorps* turned its attention towards the construction of bombproof shelters for personnel, submarines and dockyard facilities in the "Triangle" ports of Zeebrugge, Ostend and Bruges (Karau 2014, 17-18). Here, working conditions were very different from those at the trenches, allowing for a more rationalized and systematized approach towards design and construction of reinforced concrete structures. The design briefs in this context also specifically demanded for larger roof spans, thus favoring building typologies that could make good use of innovations made in civilian concrete technology before the war. We will look deeper into this in the following sections.

This short overview of construction methods and applications in permanent fortifications and fieldworks, gives an idea of the prolific use of reinforced concrete on the Western Front. Indeed, its widespread usage in 1914-18 was probably the first implementation of the material on such a vast scale (Mallory and Ottar 1973, 51). At the same time, the conflict established a firm association between reinforced concrete and warfare in people's minds (Forty 2012, 169-170).

3 IN SEARCH OF NEW TYPOLOGIES

The continuing deadlock of the Western Front marked a transition towards a full three-dimensional battlefield, characterized by overhead, underground and submerged warfare. The introduction of these new tactical layers radically disrupted the traditional spatiotemporal experience of conflict space and paved the way for new building typologies. For instance, the confrontation between strategic aerial bombing and unrestricted submarine warfare, is condensed in the construction of bombproof shelters in the German occupied Belgian ports, together forming the *Kaiserliche Marinewerft Brügge*. The *Marinewerft* comprised the ports of Bruges (principal seat), Zeebrugge and Ostend (advanced dependencies) and further disposed of shipyard facilities in the ports of Ghent and Antwerp. The inland harbor of Bruges, linked by canals to the coastal ports of Zeebrugge and Ostend, housed the headquarters of the *Unterseebootsflotille Flandern*, that would operate around the British Isles and even as far as the Bay of Biscay. This flotilla's increasing success in commerce raiding and minelaying turned the *Marinewerft* into a rewarding target for strategic aerial bombing. To keep pace with the ever-growing intensity and destructivity of aerial attacks, successive submarine shelter designs were developed throughout the war. Apart from some particular one-off designs, most shelters predating the large group shelter in the northern port of Bruges can be seen as one of two types (BA-MA RM 120/97).

Cantilevering canopies (*Kragunterstände*), attached to the existing quaysides constitute a first type. They come in a variety of construction methods, mostly using a combination of metal trusses and corrugated steel. However, examples of timber structures are also known. The *Kragunterstände* are counterbalanced by containers filled with concrete or sand, or anchored directly to the quay. Incidentally, the roof is doubled to create a hollow explosion chamber, or to integrate an impact-absorbing layer of clay bags. In some instances, the upper roof is covered with steel armored plating, whereas in other cases a thin slab of reinforced concrete is used for this purpose. The resilience of these constructions against aerial bombing is questionable, indicating an intended use for concealment rather than protection (Fig. 2).

The second type is the so-called *U-Bootsstall* (U-boat shack), a small covered dock that is excavated between metal sheet pile walls. Part of the removed earth is used to create a protective dike around the contour. The dock itself is covered by a roof composed of timber supports, steel girders and corrugated steel plates. Bomb proofing is attained by absorbing sand layers separated by a slab of reinforced concrete (Fig. 3).

The proliferation of typologies and construction methods up to this point indicates an empirical approach towards shelter design. Often, pragmatic reasons or local conditions, such as the load bearing capacity of existing quay walls or the increasing lack of steel as a construction material can explain particular design decisions.

Figure 2. *Kragunterstand* in the west dock of the port of Bruges, 1919 (KLM-MRA).

Figure 3. *U-Bootsstall* in the northern port, 1917 (BA-MA).

Following a peak in aerial bombing activity in the summer of 1917 (a direct consequence of the renewed unrestricted U-boat campaign in April) the German navy command planned a new group shelter for the submarines of the *Flandern* flotilla. Realizing the flaws in earlier shelter designs, the engineers of the *Hafenbauabteilung I Brügge-Nordhafen* conceived a new typology of juxtaposed covered wet docks that relied almost entirely on the use of reinforced concrete (Fig. 4). The choice for concrete added the potential of maximum protection to the advantage of reduced steel consumption, at a time when this had become scarce as a building material (Vancoillie and Blieck, 274-276). Shelling of mock-ups, constructed to assess the resilience of different construction methods, further tipped the balance in favor of reinforced concrete (BA-MA RM 104/234). Such use of a model-based approach towards design and engineering is a recurrent theme in the context of the World War I conflict (Bekers and De Meyer 2017).

Based upon the experiences in Flanders, a similar, but smaller submarine shelter was erected in the German port of Emden (BA-MA RM 104/237). In Pula, Croatia, the construction of nine submarine shelters of an unknown type was started in 1918, the latter remaining unfinished by the end of the war (DMA FA 010/060).

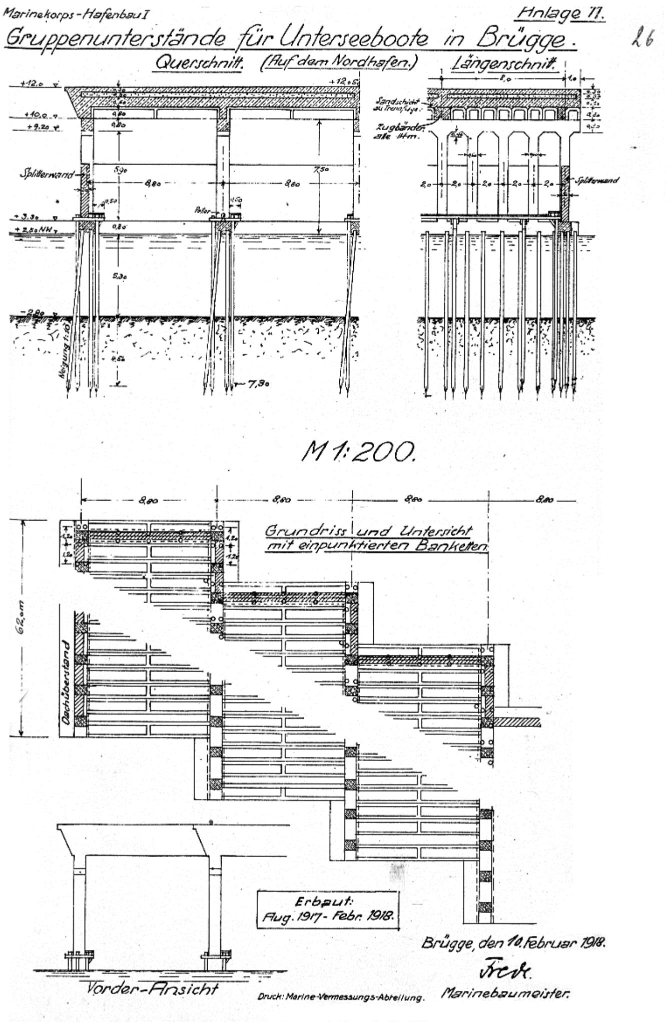

Figure 4. Plan, sections and facade of the *Gruppenunterstände*, 1918 (BA-MA).

4 BUILDING THE SUBMARINE PENS IN THE NORTHERN PORT OF BRUGES

Close reading of several archival documents provides a rather complete insight in the construction site of the Bruges group shelter. Aerial pictures taken with roughly three-week intervals show the building progress (KLM-RMA Aerial Picture Archive; BA-MA RM120/97). A photographic intelligence survey of the abandoned construction site by the Belgian army in 1919 complements this information with eye-level information (KLM-RMA Image Archive). Details on the design could be derived from German military reports on building progress at the *Marinewerft* (BA-MA RM120/97).

The new bunker was planned in the northern port of Bruges, at the end of the partially excavated side dock (*darse*) No. 1, whose construction had been commenced before the outbreak of the war. From the initially planned 11 covered docks, only 8 bays were completed by the end of the war, each measuring around 8.80 by 62 m. To save time-consuming excavation works, the bunker was built on the water. At the same time, this solution would overcome the lack of steel sheet piles for retaining walls, a notable disadvantage when constructing the aforementioned *U-Bootsställe*. A total number of 1200 timber piles, measuring over 10 meter long were driven in the bottom of the dock by floating steam pile drivers (Journal de Bruges 1951, 2).

The overall layout of the bunker followed the outline of the dock, resulting in the irregularly stepped floorplan that characterizes the building. The main structure was conceived as a framework of piers, columns and beams in reinforced cast-in-place concrete. To avoid extensive scaffolding and formwork over the water, the roof was composed of lined-up U-shaped precast concrete elements. Concrete ties, placed at regular intervals in between those elements, further ensured the horizontal stability and determined the location of expansion joints in the roof. Similarly to the *U-Bootsställe* or the French forts at Verdun, this loadbearing structure was then topped with a blast roof, in this case a double reinforced concrete slab, followed by an elastic layer of gravel and on top an impact layer of double reinforced concrete. Its effectiveness was never assessed, the only account of a direct hit being three aerial bombs that ricocheted off the roof during an aerial bombardment in June 1918, without doing any further damage (BA-MA RM 104/221). To protect the base of the facades from bomb damage, protruding eaves were cast along the contours of the roof. Besides the office space in the back of the building, which was cladded with a timber

Figure 5. Aerial picture of the construction site, 1917 (BA-MA).

curtain wall, the voids between the facade columns were filled with blast walls in brick masonry, leaving only small openings for access and natural lighting.

It is tempting to consider the layout of the construction site (Fig. 5) as an assembly line against the backdrop of emerging managerial trends, such as Taylorism and Fordism, which made an enormous impact on American and later also on European industry, particularly in Germany (Guillén 2006, 55-63). The principles of scientific management, as formulated by Frederick Winslow Taylor (1911), involved the methodical analysis of the work process and its subsequent division into atomic tasks, the selection of the appropriate work force for such tasks, the separation between conception and execution of the process and the creation of an incentive system for workers. Taylor (1905) had also applied this model to the production of reinforced concrete and the organization of the building site, thereby emphasizing the importance of the appropriate degree of standardization and mechanization. Shortly before the war, German contractors started to take a keen interest in the possibilities that the scientifically managed American building site could offer: faster, cheaper and more efficient construction through the use of mechanical transportation systems, building tools and production facilities. The result was a transnational knowledge transfer that would add American building technique and organization of concrete construction sites to European technological and theoretical expertise in reinforced concrete (Stegmann 2016).

The ideology of scientific management appealed to contractors, engineers and designers alike, but unsurprisingly also captured the imagination of the military. Feedback concepts, such as systematic testing during design phase were early on adopted in military engineering and were considered paramount in the idea of standardization in Taylor's theories. The very origins of Fordism can even be traced back to the military arms industry of the nineteenth century. In turn, the managerial experience gained in military circles during the war had its legacy in postwar civilian enterprise (Smith 1985, 1-39). The effects of a scientifically managed approach towards construction became evident in numerous examples throughout the war. One example at the *Marinewerft* would be the construction of a steel hangar over an existing dry dock in the port of Ostend, whose frames were fabricated by Lehman in Düsseldorf and subsequently put together in place (BA-MA RM 3/7507). A similar approach was used for the fabrication of the UB-I and UC-I submarines that would use the group shelter in Bruges as a hideout. They were constructed in roughly fifteen pieces in German naval yards and transported in eight railway cars to Antwerp. Once assembled, they were towed via the inland canal system towards their coastal home ports in the west (Karau 2014, 42-43).

The example of the construction site of the *Gruppenunterstände* affirms such insights. The size of the group shelter allowed for a semi-industrialized construction process, facilitated by the presence of three-phase electric power in the port, at a moment when electricity in the city center was available only in a few private buildings and hotels (Bilé and Trips 1973, 85-86). Materials were delivered directly on the site by train or via the dock, where a jetty provided immediate access to a purpose-built concrete plant. Sand originating from earlier excavation works of the dock was directly available in large quantities. The mixed concrete was raised to a casting tower and gravitationally distributed over the building site through a rotatable casting arm (Fig. 5). Similar vertical transport systems, predating the invention of the concrete pump in 1927, were documented in the US by German contractors prior to the war (Illingworth 1972, 131-132; Stegmann 2016). From the pictures, it could not be determined whether the concrete was ready-mixed whether dry-mixed before entering the casting tower. Additional narrow-gauge tracks on the roof and at the building yard at the back of the construction site complemented this transport system. The stretch of land behind pen No. 7 housed the production line for the precast roof beams, sufficiently large to cast the roof elements for an entire bay (Fig. 6). Timber gantry cranes displaced the finished elements to the end of this line, where they were hoisted by an identical roof-mounted crane. In turn, this crane would run on tracks over the columns to place the elements on their final position over the pens (Fig. 7). Similar crane track systems had been used before by the *Marinekorps* for the placement of large caliber guns in the coastal batteries (Ryheul 2015, 240-241).

The delivery of materials, the mixing of the concrete, its dispatching to the prefabrication site and the mechanized transportation of mixed concrete and prefabricated components were all combined into a single and compact assembly line. In doing so, the layout of the building site in the northern port considerably reduced construction time. Work started in August

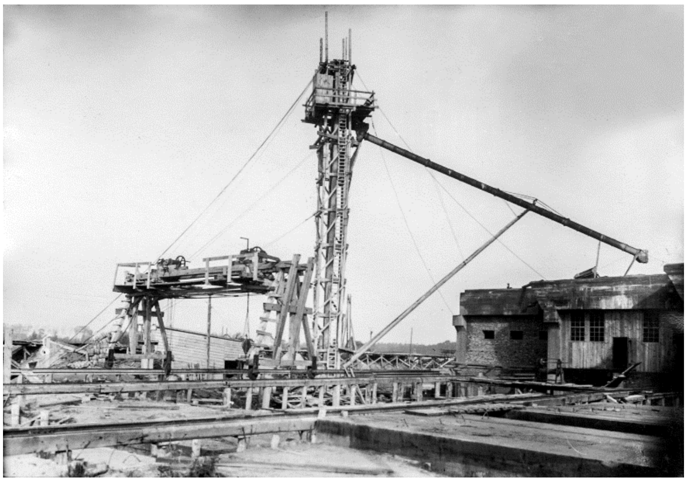

Figure 6. Precast concrete production line, casting tower and gantry crane, 1919 (KLM-RMA).

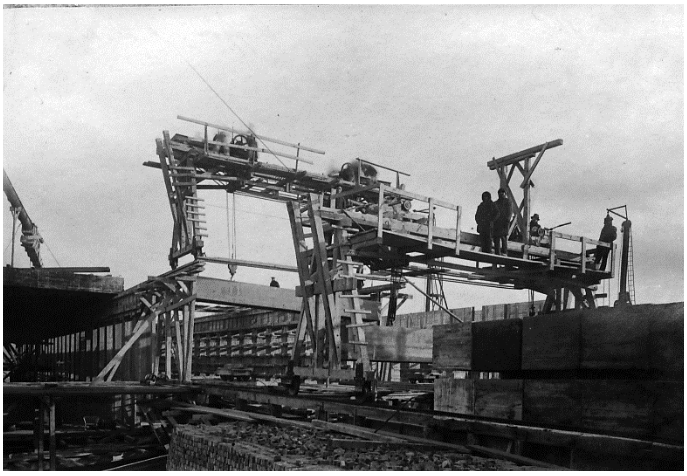

Figure 7. Detail of timber gantry cranes, 1917 (BA-MA).

1917 with the installation of the concrete plant and the pile foundation of the northern bay No. 8. By the end of the year, two bays had been completed, followed by six more in the first half of 1918. In late February 1918, the first finished pens were put into service. No further building progress was made after the end of July 1918, days before the start of the allied campaign that eventually would end the war (KLM-RMA Aerial picture archive).

One question remains unanswered: who built the *Gruppenunterstände* and was there any involvement of German or local contractors that might explain the advanced mastering of concrete construction and building site organization? Archival documents only offer indirect answers to this question. The construction process was overseen by the *Hafenbauabteilung I* of the *Marinekorps* and was supervised by its chief engineer *Marinebaumeister* Georg Frede, himself detached from the Imperial Shipyard in Wilhemshaven. The example of the aforementioned dry dock in Ostend further demonstrates how civil contractors in Germany were pressed into construction programs by the *Marinewerft*. At the same time, German authorities were reluctant to call upon the services of Belgian subcontractors, the quality of whose work they occasionally esteemed rather low (BA-MA RM 104/236). There was always the risk of sabotage or espionage and moreover, local companies were urged by the Belgian government in French exile not to cooperate with the German occupiers.

Because of its particular strategic position, the Belgian coastal region or *Marinegebiet*, had been put under the extremely severe administrative regime of the *Marinekorps*, whereas most of occupied Belgium remained under control of the German *Generalgouvernement* (Karau 2014, 16). This situation gave the *Marinekorps* unrestricted control over the civilian population and allowed for the installation of an organized program of forced labor in the *Marinegebiet*, more in particular for the purpose of military construction (Thiel 2007, 132-136). The *Hafenbauabteilung* thus disposed of a contingent of requisitioned laborers, whose number is estimated between 5000 and 14,000 (Karau 2014, 22-23; Bilé and Trips 1970, 84). Even if German firms were involved in construction work in the *Marinegebiet*, they were not allowed to employ unskilled German laborers, as to prevent the draining of such workers from the homeland economy (Thiel 2007, 132-136). As it seems, the pairing of military logic and Taylorism pushed the principles of scientific management to extremes. Dictated by conflict conditions, the division between high-skilled engineering and unskilled labor, which initially seemed so promising for the development of reinforced concrete, was twisted into a perverse system of forced labor under military control, possibly assisted by the expertise of contracting firms.

5 DESIGN CONTINUITY

As early as 1920, an article published in the Journal of the Royal Institute of British Architects claimed that “certain structures erected by the Germans in Belgium during the war period, ... on account of their scale and peculiar construction, may not be without interest to architects”. The article continues with a detailed description of the large submarine shelter, of which the author states that “in its simple truthfulness of construction it has something of the greatness of a classic temple” (Murrell 1920). From a construction historical perspective, the design of the submarine shelters occupies a singular position within military concrete construction. Here, design constraints, such as large spans, excavation works, deep foundations and building site organization, most closely relate to civil construction design issues. Even if the interwar evolution of technology sparked a dramatic increase in scale of the submarine pens that would be constructed in World War II, those basic conditions would not change between both world wars.

The March 1942 issue of the periodical *L’Illustration* (1942) proudly announced the completion of the concrete submarine pens in Saint-Nazaire. Interestingly, the article also included a picture of the bunker in Bruges and the text identified the *Gruppenunterstände* as the ancestor of the new submarine pens, a point of view shared by Neitzel (1991, 9-15) and Mallory and Ottar (1973, 69-70). Indeed, the juxtaposition in *L'Illustration*, by then a magazine under the supervision of German propaganda, is a strong indication that the shelter in Bruges was used at least as a starting point for later designs. This seems to be confirmed by the fact that officials of the Krupp Germania submarine shipyards in Kiel photographed the ruins of the Bruges shelter in March 1943, just weeks before the start of the construction work on the Konrad submarine bunker, located next to the Krupp premises in Kiel (WLB; Neitzel 1991, 93-96).

It is beyond the scope of this text to provide a full account of Second Word War submarine bunker construction, but some recurrent issues will be treated in more detail, departing from a comparison to the *Gruppenunterstände*: building typology, roof spans, excavation and foundation works and construction site management.

Typological resemblances between the submarine pens in Bruges and the projects of the 1940s are obvious, for instance in the juxtaposition of the covered docks and the protruding eaves to protect the foundations and outer walls. But essential differences also exist. The shelter in Bruges, for instance, did not dispose of the workshop facilities that were integrated in later designs. Moreover, its primary structure is composed of a concrete framework, while the examples of the 1940s, with the exception of the submarine bunker in Helgoland, feature solid concrete walls and disposed of the masonry blast walls. The Helgoland bunker, built in 1940-41 but conceived in the late 1930s, bears most resemblance to the Bruges submarine pens and constitutes a missing link between both wars (Neitzel 1991, 97-99). It shares some of the trademark features of the bunker in Bruges that were completely abandoned in later projects, such as the skewed plan, the construction on the water, the concrete framework or the beveled eaves.

The application of prefabricated roof elements for large spans was repeated in most of the 1940s examples. A distinction can be made between the bunkers in France (Brest, Lorient, Saint-Nazaire, La Rochelle and Bordeaux) and those constructed later in Germany and Norway (Helgoland, Bremen, Hamburg, Kiel, Trondheim and Bergen). The French bunkers relied on the use of on-site assembled steel trusses (called *Melan-Träger*) with infills of corrugated steel as a permanent formwork. German examples made great use of prefabricated trusses in prestressed concrete, placed side by side and embedded in concrete, much like the example in Bruges. One probable explanation for this difference would be the increasing steel shortage as the war evolved, prompting engineers to look for less steel-consuming options. Another account however involves legal disputes between German engineers (such as Hoyer or Weiss & Freitag) and French pioneer Freyssinet about patent infringements, resulting from the use of prestressed concrete on French soil (Grote and Marrey 2000, 42-97). The principle of the shell-bursting slabs in Bruges would be further expanded. As the intensity of strategic bombing steadily increased, many bunker roofs would subsequently be equipped with additional layers of hardened reinforced concrete, relief chambers or bomb-protection grating. Such ideas were derived from the British air-space theory as developed in World War I pill box design (Mallory and Ottar 1973, 59). One exception is, again, the submarine bunker in Helgoland, where the entire roof was executed in cast-in-place concrete, using an intricate system of movable formwork, itself made of reinforced concrete.

Another issue, with greater impact on building speed than any other was the necessity to limit excavation and foundation works. As pointed out earlier, similar considerations determined the choice to construct the Bruges submarine bunker on pile foundations in the water. Only the bunker in Helgoland followed this example. Later bunkers would try to avoid pile foundations for being too susceptible for damage by ground-penetrating bombs and being unable to take on supplementary loads after construction. Wherever possible, the 1940s bunkers were built directly on the solid soil or bedrock. This approach often required the installation of temporary cofferdams and added considerably to the excavation time. The limitation of excavation work for wet docks was one of the reasons for building most of the Lorient bunkers away from the waterfront and to introduce a slipway and carriage system for the overland transport of submarines to their pens.

The organization of the different construction sites followed the example of Bruges in the installation of on-site concrete plants, now using large-scale concrete pump networks and mechanized distribution of concrete through gravity slides, lorry slopes and elevators. A railroad system, laid out over the construction site ensured easy evacuation of excavated earth and rock. *Melan-Träger* were put in place by roof-mounted tower cranes, whereas a scaled-up version of the Bruges gantry cranes moved back and forth over the roof to install prestressed concrete trusses.

A major innovation in comparison to the World War I example involved the administrative organization of the construction sites. The Organisation Todt, a consortium of governmental administration, private building companies and labor resources could operate with substantial autonomous powers, thus opening the door to an even greater program of systematic forced labor in which most of Germany's big building companies were involved.

6 CONCLUSION

During the First World War, submarine shelters evolved from improvised mixed-material structures to all-concrete pens. The latter displayed an advanced mastery of concrete construction and building site management, when compared to other concrete structures built at the Western Front. The Bruges submarine pens anticipated, within the design constraints and technological framework of its time, many of the key features of the submarine bunkers from World War II and its typological, technological and logistic peculiarities did not remain unnoticed, even beyond military circles. It is uncertain to which extent expertise from German or local contractors was drawn into the specific project in Bruges. However, when observed in a wider context of battlefront construction, there are strong indications that a only a combination of military engineering, civil construction expertise and forced labor would have allowed for the semi-industrialized approach towards construction that came about in the case of the *Gruppenunterstände*.

The continuous search for new building typologies and construction methods as a response to evolving military technology, of which the Bruges shelter is just one example, demonstrates how the conflict significantly contributed to advances in design and building practice. Thus, the war was not only instrumental to the development, popularization and dissemination of reinforced concrete, but, through its global and industrial character, it also established a transnational knowledge transfer by which technological expertise and scientific management could meet. One could even argue that the military apparatus and its ability to push industry and engineering to its extremes would act as an incubator for such experiments. In this respect, the perception of the conflict as constituting a gap between prewar and postwar building practice becomes problematic. Rather, some sort of catalyst effect can be perceived, that in the 1920s would contribute to the interest in model-based and scientifically managed construction and engineering in the circles of emerging architectural modernism.

REFERENCES

“Abris Pour Sous-Marins.” L'Illustration, March 21, 1942.

Aerial Picture Archive, KLM-RMA. Royal Museum of the Army and Military History, Brussels.

Bâtiments militaires, Port de Bruges, 1934-1938. KLM-RMA 185/5320. Archives of the Royal Museum of the Army and Military History, Brussels.

Bekers, Willem, and Ronald De Meyer. 2017. “War on Scale: Models for the First World War Battlefront.” In *The Intellectual Response to the First World War: How the Conflict Impacted on Ideas, Methods and Fields of Enquiry*, edited by Marysa Demoor, Sarah Posman, and Cedric Van Dijck, 185-201. Eastbourne: Sussex Academic Press.

Bilé, Elie and Eduard Trips. 1970. *Zeebrugge, Een Haven in De Branding*. Brugge: Brugsch Handelsblad.

Bombensichere Unterstandsbauten für U-Boote. BA-MA RM 120/97. Bundesarchiv-Militärarchiv, Freiburg i. Br.

Forty, Adrian. 2012. *Concrete and Culture: A Material History*. London: Reaktion books.

Gils, Robert. 2014. *Antwerpse Forten 1914*. Tielt: Lannoo.

Grote, Jupp, and Bernard Marrey. 2000. *Freyssinet, Prestressing and Europe*. Paris: Éditions du Linteau.

Guillén, Mauro F. 2006. *The Taylorized Beauty of the Mechanical: Scientific Management and the Rise of Modernist Architecture*. Princeton: Princeton University Press.

Illingworth, John R. 1972. *Movement and Distribution of Concrete*. London: McGraw-Hill.

Image Archive, KLM-RMA. Royal Museum of the Army and Military History, Brussels.

Karau, Mark D. 2014. *The Naval Flank of the Western Front: The German Marinekorps Flandern, 1914-1918*. Barnsley: Seaforth Publishing.

“L'extension Du Port.” Journal de Bruges, October 10, 1951.

Mallory, Keith, and Arvid Ottar. 1973. *The Architecture of War*. New York: Pantheon Books.

Marinearchiv, Bibliothek für Zeitgeschichte, WLB. Württembergische Landesbibliothek, Stuttgart.

Marinewerften und Arsenale der Kaiserlichen Marine: Kaiserliche Werft Brügge. BA-MA RM 104/216-252. Bundesarchiv-Militärarchiv, Freiburg i. Br.

Militärbauten. DMA FA 010/060. Deutsches Museum Archiv, München.

Murrell, H.F. 1920. “German War Construction: Submarine Shelters and Zeppelin Sheds.” *Journal of the Royal Institute of British Architects* Third series, Vol. 27, no. 20 (October 23): 485-90.

Neitzel, Sönke. 1991. *Die Deutschen Ubootbunker Und Bunkerwerften: Bau, Verwendung, Und Bedeutung Verbunkerter Ubootstützpunkte in Beiden Weltkriegen*. Koblenz: Bernard & Graefe.

Oldham, Peter. 2011. *Pillboxes on the Western Front: Guide to the Design, Constructon an Use of Concrete Pillboxes, 1914-1918*. Barnsley: Pen & Sword Military.

Oldham, Peter. 2014. “From Extemporised to Engineered: Advances in Concrete Technology During the First World War.” *Journal of Concrete research* 66, no. 1: 8-17.

Ryheul, Johan. 2015. *The German Marine Corps in Flanders 1914-18*. Stroud: Fonthill Media.

Smith, Merritt Roe. 1985. *Military enterprise and technological change*. Cambridge: MIT Press.

Stegmann, Knut. 2016. “Globalizing Building Technique: A Case Study on the “Centennial Hall” in Wroclaw.” In *Objects in Motion: Globalizing Technology*, edited by Bryan Dewalt and Nina Moellers, 2-21. Washington, DC: Smithsonian Institution Scholarly Press.

Tätigkeitsberichte der Werften. BA-MA RM 3/7507. Bundesarchiv-Militärarchiv, Freiburg i. Br.

Taylor, Frederick Winslow. 1905. *A Treatise on Concrete, Plain and Reinforced: Materials, Construction, and Design of Concrete and Reinforced Concrete*. Norwood: Plimpton Press.

Taylor, Frederick Winslow. 1911. *Principles of Scientific Management*. New York: Harper.

Thiel, Jens. 2007. *“Menschenbassin Belgien”: Anwerbung, Deportation Und Zwangsarbeit Im Ersten Weltkrieg*. Essen: Klartext.

Vancoillie, Jan, and Kristof Blieck. 2016. *Bouwen Aan Het Front: Loopgraven, Schuilplaatsen En Betonbunkers Van Het Duitse Leger Aan Het Ieperfront 1914-1918*. Zonnebeke: Memorial Museum Passchendaele 1917.

Van De Voorde, Stéphanie. 2011. “Bouwen in Beton in België (1890-1975): Samenspel Van Kennis, Experiment En Innovatie.” PhD diss., Ghent University.