Systems for standardized precast concrete elements: The case of the Larsen & Nielsen system

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Abstract

Many systems for large-scale industrialized building in precast concrete were developed in the beginning of the post-war period after the Second World War. One of the most important systems was constructed by the Danish company Larsen & Nielsen.

Thanks to intensive development work, it was possible to switch to industrial construction of houses in just 15 years to an annual output of built square meters quadrupled compared to pre-war figures.

This innovation involved not only the use of new technology but also a complete transformation of organizational forms, company constellations, education, public administration, and financial management. This development was supported by courageous politicians.

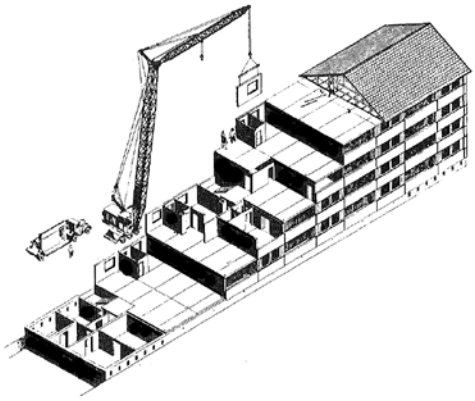
The L&N system became one of the leading building systems for houses in Denmark, and since 1956 the company has held export to and production licenses in many other countries. The export first went to nearby countries and later to Asia, America, and Africa.

The use of large-scale elements had some weak points. One was a vulnerable construction and the construction fraud of unskilled workers on skyscrapers, as seen with the Ronan Point accident in Great Britain in 1968. Another was the need for steadily high production volume to keep the production facilities alive. This was lost due to energy crises and the collapse of state administrations in many countries, and the company went out of business in 1997.

Industrialized building systems

Production in large quantities takes place by industrial production of standardized elements. Bricks and timber with fixed dimensions have been used for centuries in the construction industry.

However, the assembly of these relatively small elements was costly and often carried out on the construction site by skilled workers. It was laborious and thus expensive. A new generation of businesspeople after World War II saw that one could learn from the manufacturing of cars. Houses could be built on assembly lines if parts of the assembly work moved to an industrial production plant. This happened with the manufacture of doors and windows, and for the more significant constructions came entire staircases cast in concrete and long elements for flooring.

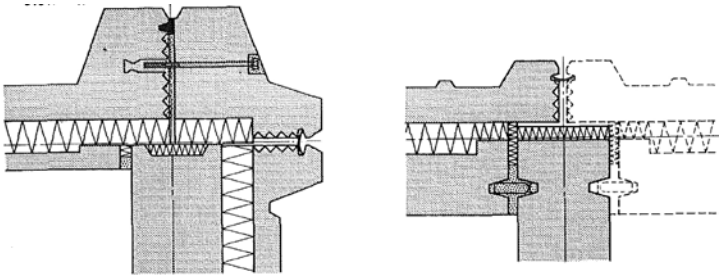


The over 400 m long Vesterbo building in Værløse created an international breakthrough for LN in 1959. Many countries were impressed by the LN-BO system, including the delivery of elements with everything mounted (Nissen 1984, p. 283).

France became the leading country in industrial building, as it had long been with other pioneers in the field of concrete, after the engineer Raymond Camus developed a complete building system. He had experience from the car factory Citroen, and he developed a building system based on prefabricated concrete elements. He applied for a patent in 1948, and his ideas were realized quickly. Houses were not built in France alone. In 1977, a census showed that 350,000 apartments were built in 20 different countries. Of these, 300 factories existed in the USSR inspired by his ideas and some based on his approximately 42 patents.

This article mentions another of the important developers of building systems, the Danish company Larsen & Nielsen (LN), Copenhagen (in some English literature spelled Larson & Nielson). The civil engineers R.A. Larsen (1905-1983) and Axel Nielsen (1906-1989) established the company in 1931. It started using elements in the facade when building a hospital in 1948, and after a few years of experience it developed a complete system for assembly construction.

Larsen & Nielsen's first system and its subsequent improved systems had a great advantage. Columns could be avoided by letting walls bear the building. Many other systems had facades as a load-bearing element, but the systems from LN had the advantage that only the internal transverse walls carried the building. This gave the architects a more significant opportunity to unfold their abilities to decorate the facade, which could otherwise become monotonous through the constant repetition of similar elements and small windows.



The assembly of elements was continually improved. On the left is an assembly of a corner from the Hareskovvej building in 1958; on the right is an assembly from Bellmansgade from 1962 (Nissen 1984, p. 47).

Povl Egon Malmstrøm (1917-1985) helped, through his own consulting engineering company, several companies plan almost all the most important Danish assembly systems (Photo: The Royal Library).

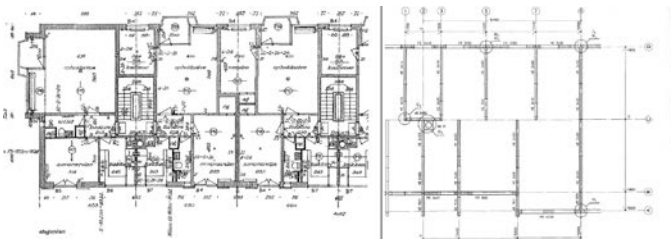
In total, LN designed more than 25 factories around the world, and the company's worldwide importance in spreading expertise within the industry was significant. In total, the company entered into 53 licensing agreements in 25 countries.

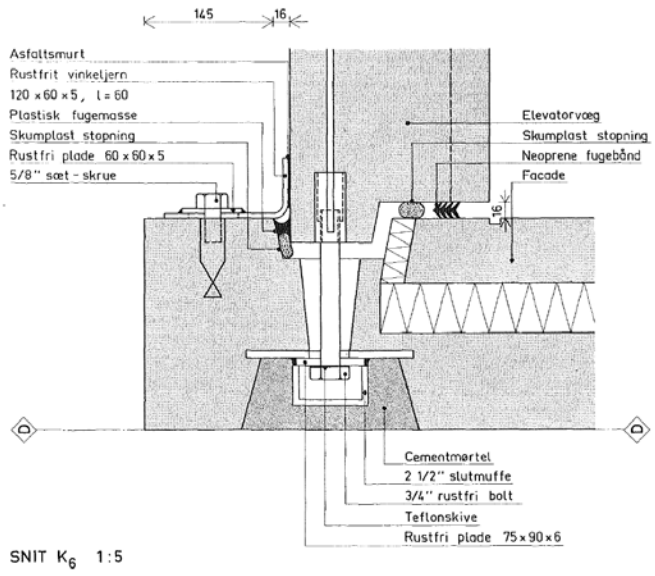
The company had many competitors. In 1965 at least 120 building systems for industrialized construction existed on the English market; however, probably only 40 were usable. A simultaneous description of systems for the heavy panel concrete buildings counted 71 systems. Most systems were developed in countries where World War II had created a great need for renewal. In the English inventory, 19 were British, 11 French, and 10 German. In fourth place came Scandinavia with eight systems.

In Denmark, LN had competition from two companies. One was Jespersen & Søn, a system that ended up being licensed in 1980 at 14 factories in seven different countries, and more than 80,000 homes were built according to the system. Jespersen & Søn used a so-called open system, to which other companies could also supply elements. Thus, 80% of its construction was done by tire and wall production standard components.

Another important Danish company was Højgaard & Schultz, founded in 1918. It had already established a cement foundry in 1950. It also became one of the country's huge companies, and its systems also developed towards an open system.

Construction with elements changed the drawings at the workplace. At left a drawing from traditional construction with information for all subjects, while in element construction, it was only a drawing of the assembly (Nissen 1984, p. 152 and 154).





Horizontal section in joint between facade and exterior elevator tower in the LN-BO system. Many parts had to be mounted accurately to avoid later construction damage. Poorly instructed unskilled workers and failing control was the weakness of industrialized construction (Nissen 1984, p. 301).

The need for housing

At the liberation in 1945, the housing situation in Denmark was critical. House construction had stalled and in the following years the redevelopment properties of the big cities deteriorated further due to a lack of materials.

The influx of apprentices to the construction trades was minimal during the limited construction of the war years, and with continued limited construction in the post-war years the number of skilled masons continued to decline. Seasonal unemployment was high. For example, 17,000 out of the nearly 53,000 (32%) unskilled construction workers were unemployed in January 1950.

Therefore, desire rose to spread construction throughout the year. Here, element construction had many advantages: it could be completed in a very short time when elements were cast in parallel with earthworks and load-bearing foundations. It was possible to build during the winter period, as the elements could be installed in almost any weather, and with the house under one roof, the other craftsmen had controlled working conditions.

Wood was especially in short supply, which was a problem when an average of approximately 10 m^3 of wood was used for an apartment around 1950. The former major producers, the Soviet Union and the Baltic countries, supplied almost nothing, which is why Denmark introduced strict restrictions.

The best solution was to completely replace wood with factory-made concrete building elements. Elements for floor separations could be the basis for casting a cement floor. Unskilled people could assemble many of the elements, which was an advantage with the lack of skilled workers. These were all reasons behind the desire for prefabricated construction.

The nature of the element factories

It took many years to learn how to use concrete for building houses. Only a few building parts were cast at the many concrete foundries across the country, which otherwise mainly supplied road tiles and sewer pipes.

Entire houses were cast in concrete as early as 1900. Although the first element houses were assembled in the United States in 1918 and in Germany in the 1920s, the first many years were spent casting in the traditional way: carpenters built a form of wood, and in this formwork the load-bearing walls or columns were cast.

As early as the 1940s, the City of Copenhagen made plans for pilot building, but it took some years before construction on the high-rise buildings at *Bellahøj* began (words in italics are names of important building projects). LN built some of the high-rise buildings erected using climbing formwork, while partitions were cast on site.

A large number of forces worked together to rationalize the construction: a new Ministry of Housing was established in 1947, and a new state research institute for construction got started and worked with the Engineers' Association, the Standardization Council, and many private companies. The work of rationalizing the construction also came to include the standardization of building elements. The initiative was taken by the Engineers' Association's Rationalization Committee, which published a report on the simplification of construction in 1951. In it, a "vertical modularity" was proposed, with a ceiling height of 280 cm, which was introduced as a requirement for state-subsidized housing construction in 1953.

Element construction was not yet mature, but it gave LN an opportunity to work, as the Danish military had to build extensive barracks buildings. It received such large orders that it was worthwhile to build a permanent element factory in a suburb of Copenhagen, Glostrup, in 1951, thanks to support from Marshall Aid. In the first years, 20,000 tons of items per year were produced by 60-70 men. The factory was expanded in 1954 in connection with delivery for construction for the City of Copenhagen. In 1954-1961, production increased to 50,000 t/year. In its best year in 1971, production exceeded 200,000 tons.

Much development work took place in the offices of the rapidly growing company. However, one person should be mentioned in the development of LN’s systems: P.E. Malmstrøm. He not only helped LN but also helped develop other Danish companies' building systems.

LN’s first building system

The first building system, LN-BO, was a closed system. "Closed" means that the geometric

configuration of the elements was brand-specific. The connection detail was unique for the company, where one element of one system was incompatible with those of other systems.

It was a complete system because all elements and components for an entire building were included in the package. The design and construction process was included.

Reinforcement bars and hooks that facilitate transporting, handling, and joining the panels were provided beforehand, as well as frames for doors and window openings.

The moulds were the bottleneck of an element factory. They were expensive to manufacture and had a limited life. Eventually, they were made of steel, but were expensive and therefore had to be used many times. For the first building systems a dwelling type consisted of approximately 60 different concrete elements, which could then be assembled into four or five different apartment types.

Torveparken in Gladsaxe became the first of LN's buildings constructed by elements. In 1957 the company went ahead with hollow core elements produced in moulds with inserted tubes, which were pulled out the day after casting. This construction used less concrete and reduced the weight.

Completely finished bathrooms with all accessories - including toilet paper holders - were delivered in finished units. Initially, they presented a logistical problem with their weight of 6-7 tons, but later they were replaced by lighter constructions made of fiberglass-reinforced polyester.

LN's first type house was built on *Hareskovvej* in Copenhagen. It was the first eight-story building, which became the starting point for LN's multi-story type house.

The first large project with all parts manufactured at the factory was the *Vesterbo* building in Værløse, built in 1954-1959. Here, sandwich elements with insulation between two concrete slabs were used for the first time. The elements were even finished with glazed windows. The 400 m long house became Denmark's longest house. It was used for a long time as a reference when the company had to sell solutions abroad.

The experiences led to the development of a building system called LN-BO (bo means 'to live' in English). The was first used was on the *Søbækgaard* building in Espergærde in 1963.

A building was typically constructed with floor plates of 2.4 m broad elements, whereas most other Danish companies used 1.2 m. The hollow cover elements were laid on the 15 cm solid load-bearing transverse walls of unreinforced concrete. The decks, normally 18 cm thick, were usually sufficiently rigid for the limited spans of up to 4½ m. Non-load-bearing walls were 6.4 cm thick with solid, unreinforced elements supplemented with carpentry walls around cabinet sections. Non-load-bearing partitions were traditionally carried out of wooden partitions with sheet metal

cladding. They were replaced by 64 mm concrete elements with surfaces ready for painting work. The painting work was also rationalized, as it was reduced to a spray treatment of ceilings and walls, as the majority of the furniture and installations were supplied with finished surfaces.

Kitchen furniture and cupboards went through a long development from semi-finished products that were processed and assembled on the building to fully finished components ready for installation in the raw house.

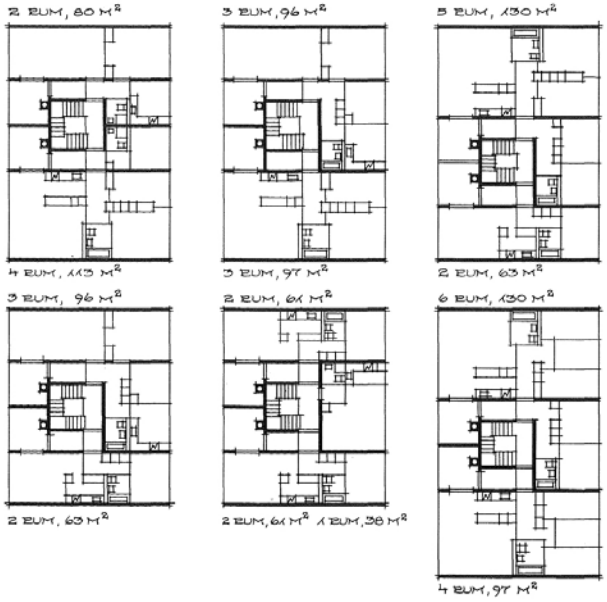
This system became a success. More than 9,000 apartments of this type were built in Denmark in 1980.

New systems

There was constant development in the industry, and LN continuously improved its systems. Production techniques were developed at the company's element factory in the 1960s, so tolerances were reduced. This meant that joints could be made without giving jumps and unevenness in the surface during assembly.

A new system, LN-NYBO (NY-BO = new live), was introduced in 1969. Slabs of 23 cm thickness were delivered in spans of 6.6 m, which gave a much freer division of the area between the load-bearing transverse walls.

The new type was not developed for a specific building, but rather made after commercial and production considerations, as well as on a large resident survey (later translated into English by the Canadian Building Research Institute, as it was the only survey of its type at that time). The series length was at least 4,000 apartments, with a minimum of 100 apartments.



A new developed system, LN-NYBO, was launched in 1968. Its apartments had improved facilities, elements with even more installations built-in, and there were 14 possible combinations of apartments with a net area of 33 to 117 m^2 (Nissen 1984, p. 289).

The planning for the element factory in Glostrup in the 1970s was based on the goal that LN-NYBO ran on the two production lines. The third production line ran at a new element factory in Taastrup, which was to run *Brøndby Strand* since it was a "foreign project" and not based on one of the company's series.

The company expected to develop new housing types based on a planning period of three years. However, a new project, LN-73, was hit by the Ministry of Housing in 1972 when it demanded a decline in the cost of new social housing. The quality had to deteriorate and the maximum size of the apartments was reduced to 80 m^2 on average. It was announced in a circular, popularly called the "Tiled stove Circular". The average LN apartment in social housing in 1966 was 74 m^2, while it had risen to 100 m^2 by 1971. At the same time, equipment and materials were improved with more built-in cabinets, flooring from extra-flamed beech to ash or oak. The refrigerator grew from a 125 l to 350 l fridge and freezer. At the same time, there was better ventilation and double-glazed windows. In addition, there were many improvements outside the apartment with more and larger hobby rooms; the playground equipment increased as well. Parking spaces were increased from 1 to 1½ per. apartment. Traffic segregation had been introduced, and more was sacrificed on gardens.

The desire for the sharp cuts meant the LN-BO system had a revival, and 2,000 apartments were built with certain modifications.

However, the time of the high-rise building was over, and thus the efficient mass production also stopped. It became low-density buildings instead. A new system was launched in 1974, LN-Hylde Bo, which was first used for the residential development *Hyldespjælde*t in Albertslund. The current demand for low-density buildings meant a new development. The insulation layers were nine cm thicker, and PEX hoses were used for water pipes. It was a heavy construction with large elements on spans for up to 6 m. The load-bearing elements weighed more than 5 t, and tires even 5.7 t.

In the period 1962-1974, 7,751 LN-BO type apartments were manufactured. During the same period, one-off projects were built on 9,286 apartments, of which included *Brøndby Strand*, *Valby Gasværk*, and *Stjernen*. In *Brøndby Strand*, LN's design department was only involved as an assistant in the planning. The planning period was ten years, which is why it was not easy to plan an optimal production rate at the element factory.

Element export

During periods of surplus capacity at the element factories, employment could be maintained through the export of elements. Although the transport costs naturally amounted to a fairly high extra cost, it could pay to bid on construction projects far from Denmark.

Hamburg was in dire need of housing after a flood disaster in 1962, and finished elements were delivered on 1,000 *Bellmansgade*-type apartments. The great need meant that a dispensation was granted from the strict German building regulations.

Many elements for Germany were also supplied by an element factory in Hjallese on Funen, which was produced under license. The railway in Funen had a direct connection to Germany, so the elements did not have to be transported to ships along the way, as was the case with the occasional deliveries to Sweden and Norway.

In 1966 it was delivered to Berlin in connection with the start-up of a new licensed factory in Berlin.

Institutions, office buildings, and, as here, the factory hall type LN 02 were a large part of LN's building activities. Despite standard types, the customers' individual wishes reduced the possibility of a significant system export (LN archive, Danish National Archives).

Commercial buildings, schools, etc.

Construction of factories, offices, and warehouses was also on LN's building program based on typified, prefabricated projects. The majority of the constructions were in the Nordic countries and England. It was a rational construction with a high degree of completion. It also developed into type houses, although there was rarely mass construction, as in the case of large construction projects, but often tailor-made projects for each company's fabrication based on one type.

However, warehouses were produced in large numbers in two types. One type had a main girder across the neck vessels, while the other type had main girders with roofing sheets between the facade and the main girder in the centreline of the building.

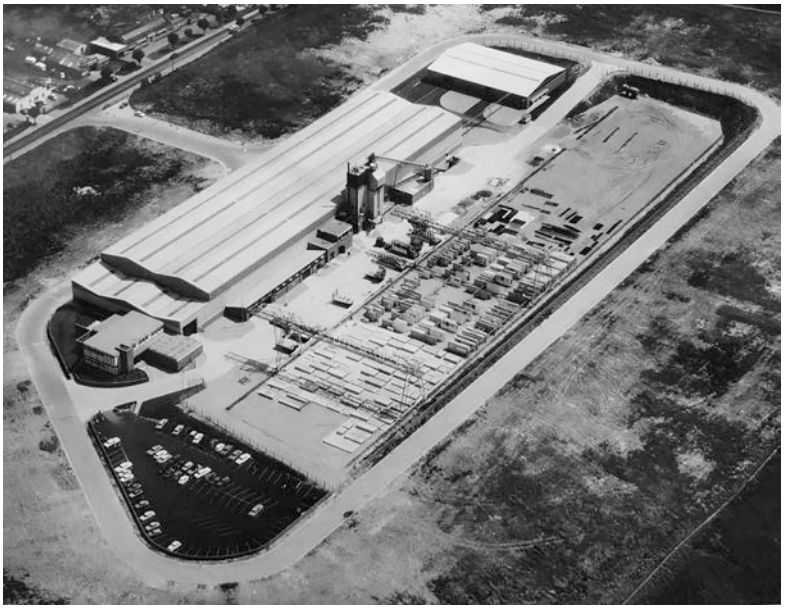
Similarly, types were also developed for schools, care centres, and skating rinks. Schools became somewhat widespread based on a type first built on Funen in 1963 (hence the Funen Plan). A number of architects set up a design studio in collaboration with a number of schools, the "Central

Office for Practicing Architects on Funen". The state supported the construction, and in the first years more than 100,000 m^2 of schools were built. In 1983, a total of 110 schools were built with a total floor area of 477,000 m^2 in Denmark. The construction was based on 12 different building types.

The company tried several times to produce single-family houses, but it was usually only for a few experimental houses. Among other things, a villa was built in Switzerland.

Purchased licenses for manufacturing abroad

The first licensing agreement occurred in 1956 with Ungdomsbyg in Oslo, Norway; the first contracts followed in Sweden, Germany, the Netherlands, and England soon after. These agreements were with existing companies that wanted to mechanize and systematize their housing production.



One of the factories based on license was opened in 1965 in Sunderland, Great Britain, by Taylor & Woodrow – Anglia (LN archive, Danish National Archives).

No guarantees were given in relation to the quality of the construction, but the licensees could see the quality from the factory in Glostrup and from the finished homes in Denmark. The agreements went on a percentage charge of future sales.

Demand abroad grew, and in 1966 a special department was set up to take care of sales abroad: Larsen & Nielsen Consultor.

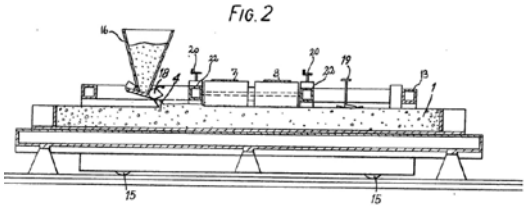
In Hungary and Czechoslovakia, factories were built with a desire for a high production rate. LN supplied Europe's largest element factory to the state-owned construction group, Stavebni Zavody Praha, in Czechoslovakia. The Malešice factory had seven production lines for horizontal moulds.

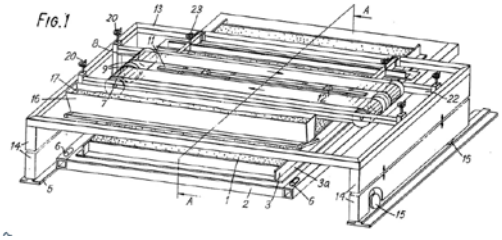
Here, LN had to guarantee a production capacity of a promised quality. Governments did not trust a local licensee to provide this service.

Germany became the biggest market. The need was great, but tight and outdated local building codes prevented large success. By 1980, more than 24,000 homes were built under the LN system. The first licensee factory was built in 1959, and later element factories were built in Schleswig-Holstein, Hessen, Berlin, and North Rhine-Westphalia.

Collaboration with local licensees was necessary to handle, among other things, the many different local building regulations. Betonfertigbau West did it in Cologne with the complex Neue Heimat (LN archive, Danish National Archives).

In the United States, the RELBEC consortium in Puerto Rico was merged with the International Basic Economy Corporation and the Rexach Construction Company. The factory opened in 1972 after two years of preparation. One- and two-story single-family houses were produced, but only a few elegant high-rise buildings were built, and in 1975 a planned municipal housing development fell away, RELBEC went bankrupt, and the factory closed.





Patents were essential to LN for the company to maintain its position as one of the world's leading suppliers of finished element foundries. This casting machine for smooth slaps was patented in 1971 (patent GB1402317A).

Licensing in the first years was mostly based on 10-year contracts. In recent years, the contracts were based on the payment of direct services. All in all, however, the sale of licenses abroad comprised only a tiny part of LN's revenue.

LN never succeeded in developing international housing types. The building regulations and traditions of the individual countries were too different from the Danish ones. It also meant that no additional components could be sold.

In 1960s Spain a number of buildings were built in Barcelona with the Construccion Industrial de Edificios S.A. (CIDESA). However, the raw house was cast on-site and provided with prefabricated facades of concrete sandwich elements. In 1972, a new element factory was built near Barcelona to manufacture 100% LN constructions. Another factory was built in 1974 in the Alcala de Henares in the province of Madrid. As a result, the annual capacity was approximately 3,000 apartments.

The Anglo-Danish engineer Ove Arup arranged contact with one of England's largest construction companies, Taylor Woodrow-Anglian, and since 1963 a number of significant buildings have been built in the London suburbs. Later, construction continued in Sunderland.

One of the English buildings has become world-famous in a tragic way. The 1968 *Ronan Point* accident became a critical event for not only LN, but for the entire industry. Two months after construction, part of a 22-story high-rise collapsed after a gas explosion, and four people were killed after a cascading collapse. In England alone there were 600 buildings of that same type. Restrictions were immediately placed on the use of gas in high-rise buildings. The accident gave rise to a revision of building regulations around the world so that high-rise buildings were better equipped to withstand unforeseen events and strong winds. When new technical problems arose, investigations showed heavy construction fraud in the *Ronan Point* building, leading to nine high-rise buildings being demolished in 1991.

A gas explosion in a 22-storey house, Ronan Point, near London, showed that high-rise buildings were not designed to withstand extreme impacts. Building authorities worldwide then had to revise their building regulations (LN archive, Danish National Archives).

International technology transfer

LN was active in technology transfer. The company thus exchanged knowledge with the Soviet Union and other Eastern European countries, which had extensive experience in assembly construction. In 1966, a visit was arranged by a reciprocal visit with the Soviets. For 20 days a strong group of actors of industrialized construction studied assembly construction in Moscow, Leningrad, and Sochi on the Black Sea. Similarly, Russian engineers gained access to Danish factories and construction sites. The co-operation also took on a formal character in 1972-1973, when the government signed agreements with both the Polish and Soviet ministries on co-operation.

Outside Europe

Following the first licensing agreements in highly industrialized countries, LN sought customer potential for package-deal deliveries in middle-developed countries. The least developed countries were avoided as industrialized construction required a certain infrastructure level.

One of the first projects outside of Europe was realized in Asia. In 1966 a partnership was formed with Gammon Southeast Asia Berhad Ltd. to build housing for the city government of Kuala Lumpur in Malaya. An element factory was established in order to build 3,000 apartments. In 1969 the buildings were completed at a very modest price, which is why everything should be cheap in the 40 m^2 apartments. For example, there was no flooring.

Brøndby Strand became one of the country's largest construction projects between 1969-1974, with 2,850 apartments spread over buildings in two, four, and 16 storeys. Other firms carried out the work of engineers and architects. The oil crisis stopped LN's large projects in Denmark (Suburban Museum).

The oil crisis of 1973 dampened construction in Europe, and interest in construction exports grew in the industry. The trend was supported by various government measures through fund support and export credits. There were also a number of bilateral agreements with other countries in the form of agreements on technological cooperation and arrangements for construction symposia. These were mainly held with countries in Eastern Europe, the Middle East, and the Far East. LN hosted nine international congresses with broad exchanges of technical information during the 1970s and 1980s.
The Middle East became an important area of work for many years. Major construction projects resulted from a lengthy diplomatic effort by the Danish government. The foundation was laid when the Iranian shah visited Denmark in 1959, where he visited companies such as LN. In 1974, the Iranian finance minister visited the country and signed a series of supply agreements, including the construction of 20,000 homes a year for five years.
In a wave of enthusiasm for industrialization in the Middle East and Asia, there was great interest in receiving know-how. LN offered the Egyptian Ministry of Housing a staff member free of charge to thoroughly analyse the entire issue surrounding industrialized construction. The ministry established a department to assist the country's 11 element factories.
LN offered a total "package" to Egypt, Iraq, Saudi Arabia, and South Korea. In addition to the actual construction of a factory, training programs and management services were included. Until the mid-1980s, 12 of these packages were delivered. Despite the war between Iraq and Iran, LN continued to build a number of element factories in Iraq.

Conclusions

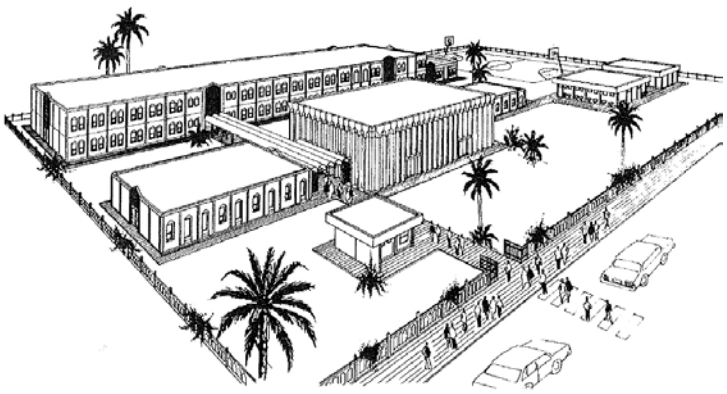
The construction company LN moved early into element construction and quickly gained a leading position in Denmark. When the state started supporting large construction projects in the 1940s, LN had the opportunity to become one of the most significant participants.

The technique was based on transverse walls as load-bearing elements, whereby the facades gave the architects an opportunity for creative expression. In this way, the technique had an advantage over systems , where the facade as a supporting element limited the architectural possibilities both aesthetically and spatially.

Establishing their own element factories in combination with the logic of element construction for planning all details and tight time management meant organizational change for LN. The company became a system supplier, and for many large building projects LN also became a total supplier with many permanent employed architects and engineers. It could deliver buildings at a fixed price and at the agreed time in a turnkey contract.

The construction method was rational in continuous production, and at the same time the transport of the heavy elements gave a natural boundary at a distance of 200 km between the factory and construction site. These conditions were met in the years after the war when the need for new housing was great. There was also a great deal of political attention at the same time, so public authorities provided conditions for the large number of new buildings.

Thanks to the good conditions in Denmark, the Danish company had developed good systems that were continuously replaced by improved versions. It provided exports to many European countries. The company's technology became important with production in 25 countries. In addition, the company was important through effective exchange of knowledge with other countries, e.g., in Eastern Europe.



LN built 216 schools in Baghdad on a total of 715,000 m^2 based on the model from the Danish Funen Plan. The project did not become a faithful copy, as conditions had to be adapted to local conditions and the possibilities of an existing element factory (Nissen 1984, p. 401).

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