

Nobel Center Architectural Competition

Statement of the Jury
Stage 2

Background

Ever since the Nobel Foundation was established in 1900, there have been plans for a Nobel Prize building where the Nobel Laureates and their achievements could be presented to the general public. Over the past two decades, discussions have taken place between the Nobel Foundation, the Swedish government and the City of Stockholm about where and how a Nobel Center might become a reality in Stockholm. During this period, the Nobel Museum was established in temporary premises in Stockholm's Old Town (Gamla Stan), while the Nobel Peace Center was built in Oslo.

In his will, Alfred Nobel wrote that he wished to give his prize to those who had conferred the greatest benefit to mankind. The Nobel Foundation's intention is that the Nobel Center shall operate in this spirit and build up its activities around the Nobel Prize's unique combination of disciplines – sciences, literature and peace. The Nobel Center shall be a unique place – the home of the Nobel Prize in Stockholm –with broad public activities, scientific conferences, meetings and events. A place that inspires, engages and arouses curiosity.

During 2011 a breakthrough occurred in the discussions about the Nobel Center. The Nobel Foundation and the City of Stockholm, after having made a joint effort to identify suitable locations, in December signed a declaration of intent to work jointly towards the creation of a Nobel Center. For this purpose, the City offered a site on the Blasieholmen peninsula next to Nybroviken – an inlet of the Baltic Sea – and the Nationalmuseum art and design museum building. This is a centrally located site that the City had long reserved for important public purposes.

One assumption behind its agreement with the City was that the Nobel Foundation would take responsibility for constructing and operating the future Nobel Center. The ambition was to finance the building through private donations. The Swedish government soon backed the project and promised operating support starting in 2018. Further, the intention is that the Center's future activities will be financed through its own revenue from such sources as entrance fees, a shop, restaurants, conferences and a garage as well as donations and support from partner organisations. In addition, the City of Stockholm will provide operating support.

In order to implement the project and manage the Nobel Center, the Nobel Foundation took the initiative to establish the limited liability company Nobelhuset AB in 2012. In August of the same year, the City allocated the Blasieholmen site to Nobelhuset.

Through Nobelhuset AB, in June 2013 the Nobel Foundation announced an architectural competition. The invitation was preceded by a process in which about 175 architects from all over the world were encouraged to participate. The 142 architects who expressed an interest were evaluated in an extensive process before 20 were invited to introduce themselves in Stockholm. Twelve of these were then selected and invited to participate in the competition. In the end, eleven architects participated.

The competition has been characterised by a desire for as open a process as possible. Both in the first and the second stages, the various proposals have been displayed at the Nobel Museum. Presentations of the architects and their proposals have also been organised by, among others, the Stockholm Association of Architects.

The current statement includes the jury's assessment of the three proposals that were selected in November 2013 for the second stage of the competition. After the competition, it is the Nobel Foundation's ambition – with the help of Nobelhuset AB – to refine the winning

proposal in such a way that it can serve as the basis for the City's work with a new local plan and eventually be built on the Blasieholmen site.

Assuming that construction begins late in 2015 as planned, the new Nobel Center can open in December 2018.

The jury

The competition jury was appointed by Nobelhuset AB after a dialogue with the Nobel Foundation. It was given a broad composition, including representatives of the Swedish prize awarding institutions (Karolinska Institutet, the Royal Swedish Academy of Sciences and the Swedish Academy) and the Nobel Foundation as well as experts on construction and real estate matters, architecture, city planning and museum activities.

Juhani Pallasma (Helsinki), Professor and Architect, SAFA, has served as a special advisor to the jury. In addition, a number of experts have assisted the jury with cost estimates, calculations of energy and environmental performance, spatial estimates and programme fulfilment as well as with assessment of issues related to the urban setting, landscapes and cultural environments.

The members of the jury

Lars Heikensten, Ph.D., Executive Director. Nobel Foundation (Chairman of the Jury)

Olov Amelin, Ph.D., Museum Director, Nobel Museum

Lars Drangel, M.Sc.Eng, Ramsbury Property

Elizabeth Hatz, Architect, SAR/MSA, AA Diploma, RIBA II, Senior Lecturer, Royal Institute of Technology (Stockholm) and Associate Professor, University of Limerick (Ireland)

Marika Hedin, Ph.D., Museum Director, Museum Gustavianum (Uppsala), formerly Museum Director, Vasa Museum (Stockholm).

Gunnar von Heijne, Ph.D., Professor of Theoretical Chemistry, Stockholm University, former Chairman of the Nobel Committee for Chemistry

Karolina Keyzer, Architect, SAR/MSA, City Architect of Stockholm

Anders Nylander, M.Sc.Eng., former Managing Director of a listed real estate company

Inga Varg, Architect, SAR/MSA, Varg Arkitekter, member of the Council for Protection of the Beauty of Stockholm

Harriet Wallberg, Professor of Phsyiology, former Vice-Chancellor, Karolinska Institutet

Per Wästberg, Writer, Swedish Academy, Chairman of the Nobel Committee for Literature, former member of the Council for Protection of the Beauty of Stockholm, former Chairman of the Association S:t Erik

Rapporteur

Peter Ohrstedt, Architect, SAR/MSA, Project Director, Nobelhuset AB, former member of the Council for the Protection of the Beauty of Stockholm

Secretary

Elsa Thambert, Project Coordinator, Nobelhuset AB

The proposals assessed

In November 2013 the jury selected three proposals to be further refined during the second stage of the competition. The anonymity of the competition also ended at this point, and the members of the jury have thus subsequently had the opportunity to listen to the short-listed architects' own presentations and to directly communicate their own views.

The three proposals that were submitted on January 17, 2014 and that the jury has assessed during the second stage of the competition are:

- "Nobelhuset" by architects David Chipperfield and Christoph Felger, David Chipperfield Architects Berlin
- "The Nobel Snowflake" by architect Gert Wingårdh, Wingårdh Arkitektkontor
- "A Room and a Half" by architect Johan Celsing, Johan Celsing Arkitektkontor

The jury's assessment

Overall conclusions

In preparation for the refinement of the proposals in the second stage of the competition, the jury formulated general conclusions and specific instructions to the finalists. More in-depth knowledge of the potential for increasing the efficiency of spatial use, and experience from the first stage of the competition, also enabled Nobelhuset AB to reduce the programme area required in the brief by about 15 per cent.

The jury has noted that all three contestants succeeded in substantially decreasing the size of their competition proposals and changing them in varying degrees in the direction the jury requested. The jury has therefore been able to compare and evaluate three qualified proposals.

In preparation for its final assessment, the jury gathered opinions from the above-mentioned specialists and advisors.

The jury is of the opinion that the proposal it has selected as the winner and has recommended for additional refinement and implementation, meets the stringent programme requirements for the future Nobel Center. During the coming process of planning and pre-construction engineering, the winner may further refine and improve the building in a dialogue with the client and public authorities. The proposal as a whole will be easily capable of satisfying the requirements of the Center's activities, enhancing the quality of the urban public space that Blasieholmen represents and generally contribute to the city.

The urban setting

A Nobel Center will draw international attention as a symbol of the Nobel Prize, in particular if the Nobel Prize Award Ceremony is held there. It will thus significantly complement Stockholm's most prominent and important public buildings. Located on the Blasieholmen peninsula, it will have all the prerequisites to become one of Stockholm's most attractive destinations, with an international impact – giving both visiting tourists and Stockholm residents a place to return to. With its broad public activities, the Center will increase the value of its site in the

heart of Stockholm and will make it more accessible to the general public.

Because of its location, the Nobel Center must be a building, without a back, that connects to the various outdoor public spaces on the Blasieholmen peninsula. Right after the first stage of the competition, the jury came to the conclusion that the best location for the building is at the north-west corner of the current site, with a connection to the adjacent city fabric. This location makes it possible to create a well placed, attractive and sunny city park with a quay towards the south-east. At the same time, it gives opportunities for suitable traffic solutions and transport access.

All three finalist entries propose a widening of the Hovslagargatan street into an attractive urban space. This creates the potential for good entrance areas both for the Nobel Center and for surrounding properties. The positions of the "Nobelhuset" and "A Room and a Half" proposals, leave free most of the sight lines deemed especially important in the cultural history inventory. The back of the Nationalmuseum building also enjoys a freer location, making possible both a possible future extension of the museum and better use of the park.

Two of the proposals are lower than the adjacent buildings on Hovslagargatan. The third proposal, "Nobelhuset", rises moderately above this level, but is in return vertically divided; with a horizontal façade line that reflects existing cornice heights.

The proposals show possible entrances facing Hovslagargatan, the walkway from Blasieholmsgatan, the quay and southeast towards the park. Together with the new park, the building will create an attractive urban space that adds substantial qualities to the overall urban setting. The site will be accessible both to Nobel Center and Nationalmuseum visitors as well as to those who are strolling towards the isle of Skeppsholmen.

These outdoor spaces and the opportunities they offer for future development of both urban life and the cultural environment of Blasieholmen are of great importance to Stockholm.

The three proposed buildings receive visitors and link their ground floor to the site in different ways. While "Nobelhuset" has a welcoming winter garden and two clear entrances, "The Nobel Snowflake" offers small protruding roofs as protection for the visitor. In "A Room and a Half", the ground floor offers inviting benches for sitting both outdoors and indoors.

During the first stage of the competition, the jury noted that none of the proposals that were submitted were able to describe how a new Nobel Center could be combined in a satisfactory way with the preservation of the existing Customs House. However, new public activities on the site will instead provide major opportunities to breathe life into the harbour environment in a better way than today. All three proposals enable visitors to the Nobel Center and to the new park to arrive by boat and also make it possible to continue mooring larger vessels, thereby helping to preserve and perhaps even enhance the maritime character of the site.

The jury would welcome the creation of a roof terrace on the new Center to enable visitors to go upstairs and enjoy the magnificent view of the isle of Djurgården and the inlets and other waterways of Stockholm's inner harbour area. This is one way of enhancing the enjoyment of central Stockholm, which has been designated as a district of national historical interest.

Traffic and transport access

Given its central location, combined with the nearby Kungsträdgården metro station – located on a line that the authorities now plan to extend to the suburb of Nacka – there is good

potential for most Nobel Center visitors to arrive by public transport or on foot. This is highly compatible with the City of Stockholm's explicit accessibility strategy.

It is also desirable that many Nobel Center visitors can arrive by boat. This applies both to cruise tourists who will need to travel directly from their ships and visitors from other parts of the city. Stockholm Public Transport (SL) is currently studying extensions of public boat services. If such routes are established, bus traffic to central Stockholm can be significantly reduced.

It should also be possible for the Nobel Center to receive visitors who arrive in their own boats, as well as for large archipelago boats to moor directly on the quay in front of the building. All three proposals offer good potential for arranging berths for boats within short walking distance from the quay to the Nobel Center. The proposals also make it possible for other visiting vessels to moor along the quays near the Nobel Center.

All the proposals present realistic solutions for transport access as well as short-term loading and unloading of buses and cars. The three proposals have also located the programme-specified parking spaces for cars on an underground level. However, the proposed transverse ramps inside the building presented by "A Room and a Half" will be difficult to implement, according to the jury's experts, since they would involve too steep an incline.

Matters related to goods supply, refuse handling, vertical clearances and connections to the street network as well as the overall traffic solution for Blasieholmen are of great importance to the project and are therefore now being studied together with the City of Stockholm. In the opinion of the jury, it would be advantageous for both the environment and road safety on Blasieholmen if an underground driveway can be extended and also supply the adjacent Nationalmuseum building.

Traffic issues were not decisive to the jury's overall assessment.

Design and symbolic value

Because of the international significance of the Nobel Prize and the global attention it attracts, one of the most important and hardest-to-define requirements for the design of the building has to do with its function as a symbol of the Nobel Prize and related activities. At the same time as the building should exude quality, dignity and timelessness, it must be perceived as inviting, open and vibrant.

The planned activities at the Nobel Center will range from lectures by world-renowned Nobel Laureates to programmes for school children of all ages from the Stockholm area. The Nobel Center must provide adequate facilities for large-scale scientific conference activities, while exhibitions based on state-of-the-art interactive technology should display the significance of the Nobel Prizes to mankind. Temporary exhibitions and the opportunity to have a cup of coffee and enjoy the surroundings should attract people to make return visits.

According to the jury, the "Nobelhuset" proposal has these qualities: an attractive and timeless design – and at the same time inviting and easily accessible. The classic dignity and openness that characterises "Nobelhuset" is easy to associate with Nobel-related activities. Although "Nobelhuset" has an independent appearance and an identity of its own, it interacts nicely with the surrounding urban setting and buildings.

In the opinion of the jury, "A Room and a Half" is a proposal with an appealing modesty. The proposed materials also signal high quality. But according to the jury, its appearance is too

anonymous and restrained for a building that will house Nobel-related activities.

Because of its round shape and concave glass surfaces, the "Nobel Snowflake" proposal has a divergent appearance all its own. The building is open to the world and awakens curiosity. According to the jury, this may be relevant to the Center's activities for the general public but is more difficult to perceive as a well-balanced symbol of Nobel-related activities as a whole.

Interior environment and spatial organisation

It is important that the building can both be given an interior architecture that exudes solidity, quality and good functionality, while in some contexts the spaces should be capable of more refined elegance. Its interiors should reflect the same values and appearances as those presented under point "Design and symbolic value" above.

According to the jury, the "Nobelhuset" proposal meets the programme's quality requirements in terms of appearance, materials and design of the interior environment. It has a well-organised structure, with clear spaces that are adaptable but still have architectural character. Exhibition and conference rooms are located and designed so that visitors can move through them in a simple, logical way. The general nature of the building is an asset, since the needs of different activities will constantly be changing. Entrances and connecting systems are well-balanced, and the ease of visitor orientation is good.

"A Room and a Half" is a proposal that features carefully crafted solutions to most programme requirements, with attractive rooms that are often vertically connected in more than one storey. The proposal has devoted extensive effort to giving the different parts of the Center's activities clear spaces, and museum activities in particular have been accommodated in an elegant way. The layout is more rigid, however, and certain solutions that were chosen might make future changes more difficult.

"The Nobel Snowflake" provides creative solutions for multi-purpose utilisation of some areas and is characterised by transparency to the visitor. It is an open building for broad cultural activities. At the same time, difficulties arise in accommodating the programme-specified activities on its round floors. Many activities that would benefit from daylight will be forced to use indirect light, even though they are located near façades. A large proportion of public connections are forced out towards the building's exterior walls, where it is difficult to achieve any large coherent spaces.

The Nobel Auditorium

According to the jury, the large meeting room or auditorium specified in the programme represents an essential function of the building. It should be possible to use this auditorium for large special events with up to 1400 attendees, such as the annual Nobel Prize Award Ceremony. At the same time, it should be flexible enough to be divided and adapted to many different functions in connection with lectures, scientific symposia, meetings, receptions, banquets and other kinds of stage programmes.

If the Nobel Prize Award Ceremony is moved from the Stockholm Concert Hall to the Nobel Center, the interiors of the Nobel Auditorium and the exterior design of the building will be perceived as important symbols of all the Nobel Prize activities. It is thus important that the auditorium has a clear, well designed architecture that provides an attractive setting for ceremonial occasions.

The "Nobelhuset" proposal has the most distinctive auditorium, which fulfils most of the wishes specified in the programme. It shows a uniqueness of design that the jury finds suitable for planned events. The proposal presents options for adapting the auditorium for different situations and numbers of people, but no options for dividing it among any concurrently occurring events.

"A Room and a Half" proposes a traditional half circle-shaped lecture hall that can be divided up radially. The auditorium is flexible and will work well for conferences, lectures and similar events.

The proposal for a Nobel Auditorium in "The Nobel Snowflake" has a general design that can be divided up. It can be utilised for different types of scientific and/or cultural events.

Environmental assessment, sustainability

The competition brief emphasised that the building should be designed using solid materials and good construction engineering solutions that make it possible to preserve and maintain the building for a long time.

The building shall incorporate environmental engineering characteristics enabling it to achieve one of the highest ratings under the BREEAM international energy and environmental assessment system.

The solutions presented in all three proposals do not appear to pose any problems in achieving a high BREEAM classification and have thus not been decisive in the jury's assessment.

Another important aspect of long-term sustainability is that the building should be designed in such a general way that it tolerates future changes without large, resource-intensive renovations. It should also be possible to make the building and its surrounding environment available, accessible and safe for everyone. The jury has paid great attention to this in its assessment task.

Technology and finances

One of the three main evaluation criteria is feasibility, that is, a proposal's prospects for actually being implemented within the limits established for the project. This is related to such variables as technical qualities, buildability, construction costs and operating costs.

After comparative technical assessments and cost estimates, the "Nobelhuset" and "A Room and a Half" proposals appear capable of being constructed within the proposed cost limit, while "The Nobel Snowflake" is somewhat above the specified level.

Neither technical nor cost aspects have been decisive to the jury's overall assessment.

Future expansion

None of the three proposals presents any clear, convincing solution for the possible future expansion requested in the competition brief. This issue is still topical and must be resolved no later than during the further refinement of the winning proposal into a proposal for planning consultations during the autumn of 2014.

In the jury's assessment, all three proposals have equal prerequisites for allowing an

expansion possible if this is deemed desirable. Correspondingly, their prerequisites for a reduction of the building are similar.

The potential for expansion has not been decisive to the jury's overall assessment. Instead, general structures that allow alternative uses can to some extent replace an additional expansion.

The jury's recommendation

The jury has been impressed by the quality of the finalist proposals. The "Nobelhuset" and "A Room and a Half" proposals demonstrate carefully crafted, attractive solutions to the issues raised by the competition brief. The "Nobel Snowflake" proposal presents a new and different solution to the requirements in the brief, although some further refinements are needed.

In an overall assessment of the three finalist proposals, the "Nobelhuset" proposal appears to be the best. It meets most of the requirements specified by the competition brief in a convincing way. The proposal has an elegant, timeless and attractive external appearance, which according to the jury can symbolise Nobel-related activities in a persuasive way. At the same time, it has a lightness and openness that are appealing. The building also features a good, clear floor structure that can allow future changes and a beautiful Nobel Auditorium. The slim shape and moderate footprint of the building create good opportunities for pleasant outdoor settings on all sides of the building. This will please not only visitors to the Nobel Center, but also those who find their way to Blasieholmen to visit the Nationalmuseum or to stroll through this attractive urban space.

The jury is of the opinion that after additional refinement, the proposal can lead to a dignified, exciting and inviting Nobel Center building while helping create a better, more engaging and beautiful urban setting on the Blasieholmen peninsula.

The jury therefore selects the "Nobelhuset" proposal as the winner and proposes to the competition organisers, Nobelhuset AB and the Nobel Foundation, that they take this proposal as the starting point for further refinement and implementation.

Stockholm, March 24, 2014

Lars Heikensten

Olov Amelin Lars Drangel

Elizabeth Hatz Marika Hedin

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Anders Nylander Inga Varg

Harriet Wallberg Per Wästberg

Individual reviews

Nobelhuset

David Chipperfield & Christoph Felger, David Chipperfield Architects Berlin



The Nobel Center is intended to be a prominent, public and openly accessible building with a content that is important to many people. In the opinion of the jury, a Nobel Center could thus be allowed to have a slightly higher profile than other buildings. The elegant, slim external design of "Nobelhuset" has a clear identity of its own that enables it to be experienced as a free-standing building, at the same time as it alludes to the nearby masonry buildings. With its three-part structure – consisting of a base, middle and a top section – the building alludes to the traditional design of Stockholm's masonry buildings.

The jury appreciates the open, inviting nature of the building, both with regard to its location in an area that can be developed into an attractive public space and in light of the Nobel Foundation's explicit ambition to seek contact with and open up the Center to the general public.

The jury appreciates the appearance of the building, with the Nobel Auditorium placed like a crown at the top. It will provide an impressive view of the city from the foyers adjacent to the auditorium, while making it possible for people moving through the city to visually follow the ongoing events. If the auditorium is used for the Nobel Prize Award Ceremony on December 10 each year, the light from the Award Ceremony will shine above the city.



The revised façade design, with its shimmering vertical brass elements and glass, has a lofty elegance and quality that can be associated with the position of the Nobel Prize. This kind of architecture requires great precision and quality during construction, which must be ensured during the subsequent pre-construction engineering process.



The open ground floor, with entrances in three directions, provides an open appearance that may also attract casual visitors. It is important that this part of the façade helps create a pleasant setting in the immediate vicinity of the building. The entry hall comprises an indoor square in which all visitors to the building arrive. The connection to the park towards the south-east through the long garden loggia feels pleasant and inviting.

A visitor's walk through the various floors of the building can be turned into an exciting experience. The general structure, with a nave and two parallel aisles, allows good lighting and enables the use of the floors to easily change over time. There are good conditions for creating well-functioning conference rooms and shifting their use between conference and exhibitions. Perhaps the proportions of the really long exhibition rooms must be reviewed, since the room heights in the revised proposal appear somewhat low in relation to the room length. The jury assumes that these proportions will be further studied during future work.

The jury suggests that transport systems be studied thoroughly in any future refinement of the proposal to ensure that transport of incoming and departing visitors will become a well-functioning system.

The main auditorium has an unexpected and exciting shape, which can serve nicely both as a setting for ceremonial events and for other large gatherings, but the jury is not convinced about the materials and colours presented for the interiors. During further



refinement, this and the possibility of dividing the auditorium should be studied further. As mentioned earlier, the question of a possible roof terrace up on the building should be studied during future refinement of the proposal.

A Room and a Half

Johan Celsing, Johan Celsing Arkitektkontor



This building has a deliberately restrained and precise appearance. The architect's intention is to create a neutral façade as an external framework for the Center's many and varied activities. During the second stage of the competition, the façade has gained an even more generic appearance. The jury is sympathetic to the building's unassuming look but fears that it may be rather anonymous. Its compact structure and low-key exterior represent a risk that the Nobel Center will have a weak, unclear identity. A Nobel Center is not only a matter for Stockholm and Sweden, but for the world. The appearance and image of the building should also be seen in light of this.

However, the jury is convinced that the building's detailing and material treatment are equivalent to the quality and thoroughness that can be associated with Nobel-related activities. The jury was especially pleased with the care that went into the design of the building's base, which forms spaces featuring benches that would be pleasant to occupy.

The large entrance hall appears likely to work nicely, with its varied gallery spaces and good connections. Its double height is a helpful spatial quality that would make it possible to exhibit tall objects in the publicly accessible exhibition area. The large downward opening towards the lower level helps to make the latter easy to see and to tie the exhibition areas together visually. The lighting is carefully thought-out and convincing throughout the building, and views between levels can make the interior rich, nuanced and exciting. The exhibition areas are consistently well-designed and varied.

The semi-circular shape of the main auditorium is a tried and tested concept with excellent options for divided spaces. But the jury is of the opinion that the auditorium that is presented should be given a more unique, dignified appearance in order to function well in case of a Nobel Prize Award Ceremony or other large event.

The proposal has been skilfully devised, with great insight into the nature and spatial needs of the various activities. Since a building of this kind must allow substantial changes over time, great spatial generality may be an advantage. In this case, empathetic spatial solutions may pose some limitations.

The Nobel Snowflake

Gert Wingårdh, Wingårdh Arkitektkontor



The proposed round building is a concept that is distinctly different from the one presented in the first stage of the competition. A round building is naturally directionless and, due to its divergent shape, difficult to relate to nearby structures. The major advantage of this proposal is instead the greatly diminished footprint and the management of the site that this allows. It would be possible to create a large, generous outdoor area for visitors. The design of this area is one of the finest qualities in the proposal, but it partially falls outside the scope of the project. The rounded shape may also lead to a lack of orientation and protected spaces next to the building. This is partly offset by elements that curve inward and roofs that project outward.

The jury was hesitant about the identity and design of the building, which according to the architect's description is to be perceived as a general cultural centre. Although the building will house broad, open activities for the general public, the selected shape functions less satisfactorily for a Nobel Center, which will also be a symbol of the Nobel Prize and related activities. A building with glass façades naturally provides many opportunities to look inside, but sometimes at the expense of clear identity. The glass surfaces may also cause reflections, making the façade less transparent than intended.

Because of the consistently requested rectangular room shapes, many intermediate spaces arise that may be difficult to utilise. Connecting paths are forced out towards the periphery, making it difficult to create coherent, clear spaces and large areas. Many rooms that would benefit from contact with direct daylight will only receive indirect light, which is less than satisfactory from both an energy and aesthetic standpoint. The small footprint has also resulted in large underground areas without access to daylight.

The entrance level may feel exciting and active, with its large atrium for vertical communication. The escalators would have a powerful sculptural shape that may be appealing. As a consequence, however, there is no room for necessary functions where there is the greatest need for visibility, light and open space. The generosity found in the entrance level of the first proposal is lost because of the large atrium, and the jury is not convinced that this is the best way to fulfil the gathering function that is intended.

The large curved glass elements that make up the façade of the building are both a technical challenge and relatively costly.