DESIGN EXCELLENCE AWARDS 2016

BERGEN LIGHT RAIL STAGE 3

Association of Consulting Engineers of Ireland

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Mott MacDonald

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EXPERTISE BROUGHT TO THE PROJECT

Design works included all sub- and superstructure works such as ground works, drainage, bridges, tunnels, track, terminals, tram stops, power, road signal & telecommunications works, engineering and information systems. The commission also included handling noise reduction measures, the planning of the rerouting of traffic and all other substructure designs and technical requirements.

STADLER VARIOBAHN TRAM IN OPERATION IN BERGEN CITY CENTRE

Executive Summary

Bergen is a city on the west coast of Norway, in Hordaland County. *Bybanen* - the Bergen Light Rail System - comprises about 21 km of double track between Bergen city centre and Bergen Flesland airport.

The *Bybanen* project is part of the Bergen program for transportation, urban development and the environment, which is a collective effort to coordinate and prioritise public transport, environmental issues, road construction and pedestrian and cycle paths over the twenty year period 2005 to 2025.

The first two stages of *Bybanen* head south between Byparken, in the centre of Bergen, and Lagunen, a major retail hub. The route comprises approximately 14 km of double track. Stages 1 and 2 are complete and are in operation.

Stage 3 continues the double track from the existing Lagunen stop to a new underground stop at Bergen airport, and also provides a Depot, comprising a Workshop and Parking Hall, sized for 40 trams to allow for future stages of the light rail system. This Depot, on a 7 ha. site, will provide a facility for tram maintenance and a control centre for operation of the system.

Bybanen Utbygging (Light Rail Development) is the department in Hordaland fylkeskommune responsible for procuring the Bergen light rail system. While they used Norwegian consultants for Stages 1 and 2, Mott MacDonald Ireland (MMI) were asked to tender for Stage 3. In summary the Stage 3 Contract included:

- 7.8km of double track
- 6 tunnels, total length approximately 2800m
- 4 track bridges, total length approximately 340m, with the longest 110m
- 3 pedestrian bridges over track and roads
- 4 culverts for track, total length 680m
- 8 portals attached to tunnels
- 7 tramstops
- Workshop and Parking Hall for 40 Trams
- Office building for system control, drivers, maintenance staff, and administration

MMI was appointed at the end of 2011 to provide a complete engineering design service. This included full design and coordination of: track, trackform, civil, structural, traction power, building services, depot operations, environmental, geotechnical, architectural, noise and vibration, and equipment specification design elements.

DESIGN EXCELLENCE AWARDS

BERGEN LIGHT RAIL STAGE 3

MMI have led a design team from 10 different offices in 6 countries across the Mott MacDonald group. In addition, MMI have used Pascall + Watson in Ireland as architectural sub-consultants, the Railway Procurement Agency (RPA) as Depot Operations consultants, Ramboll Norway for local technical advice, Sweco Norway for Independent 3rd party control and ACK arkitekter as *ansvarlig soker* (responsible applicant).

The contract commenced with initial feasibility and optimisation work, and following detailed design and construction is now in the Systems Proving phase. MMIs role will be complete at the end of the construction defects responsibility period.

Construction commenced on site in July 2013 and is on programme for completion in early 2016 with passenger operations commencing in mid-2016. In parallel, Avinor, Norway's Aviation Authority, are developing a new Terminal 3 in Bergen airport, due for completion by 2017, which is being constructed over a new tram stop.

The overall construction budget is NOK 3.6bn (€ 450 million).

ADMINISTRATION AND OPERATION CONTROL CENTRE BUILDING. CONSTRUCTION NEARING COMPLETION ON THE DEPOT SITE. THIS BUILDING ALSO PROVIDES FACILITIES FOR DRIVERS, INCLUDING A GYMNASIUM.

32M STADLER VARIOBAHN TRAM. BYBANEN WILL EXTEND THEIR CURRENT FLEET OF 20 TRAMS TO 42M IN THE NEW STAGE 3 DEPOT

We continued to support the project throughout the construction phase, providing a full range of technical support services to the client, across all construction activities.

1 DESIGN CHALLENGES AND PROCEDURES

CONSTRUCTION OF TRAMSTOP AND TRACKFORM AT SANDSLIMARKA AT THE ENTRANCE TO THE DYRHOFF TUNNEL. THIS TUNNEL PROVIDES A TRAMWAY AND A ROUTE FOR CYCLISTS AND PEDESTRIANS

For MMI one of the key challenges in undertaking a major infrastructural project in Norway was ensuring the application of sound engineering principles and practices to the design and deliverables, in what was a new territory for the organisation.

Central to this was the application of relevant design codes, primarily the Eurocodes, with the correct use, and understanding of, local annexes. MMI also undertook a significant exercise in sourcing and understanding all relevant local codes and standards. Where relevant specific internationally recognised codes were used, (e.g. VDV and Bostrab codes for Depot planning).

An awareness of construction issues in Norway, and a detailed understanding of local building practice, was an important element in delivering a commercially competitive design that Norwegian contractors could work with. For example the Norwegian approach to dealing with rock is very different to that in Ireland. Rock is typically blasted, and managing large quantities is not unusual. However, mass balance throughout the construction period is important as excess rock is not a benefit, (as it is typically in Ireland), excess rock must be disposed of in landfill at a significant cost.

One fundamental engineering principle applied throughout the project was the use of detailed optioneering studies for solutions to engineering problems. Design challenges, large and small,

Design challenges, large and small, from overall track alignment to reinforcement detailing, were evaluated with optioneering studies and decision papers.

TUNNEL PORTAL AT STEINSVIKBROEN OCS (OVERHEAD CONDUCTOR SYSTEM) IN PLACE.

from overall track alignment to reinforcement detailing, were evaluated, where necessary, with optioneering studies and decision papers. Options were assessed both internally, and externally with the client, by various designers and cost management specialists as required. This ensured a considered and properly evaluated engineering solution was delivered.

MMI were keen that environmental and sustainable engineering principles should be an integral part of the overall design process. To this end, MMI devised a set of overarching environmental principles which have been used throughout the design and construction phase of the project, to guide the development of the project, and to assess the environmental performance of the project.

In order to ensure that the environmental principles for the project were meaningful, it was critical that they were based on a full understanding of the local receiving environment, on the local and national environmental legislative and permitting requirements, and on the environmental conditions laid out as part of the planning approvals process. To ensure an in-depth understanding of these requirements a detailed review was undertaken of the *reguleringsplan* (zoning plan) for the project, of the environmental legislation pertaining to the project, and of the licensing and permitting requirements required by the City, Regional and National authorities. Furthermore site visits were undertaken to identify all environment constraints within the study area and consultation was undertaken with relevant staff in *Bergen kommune* (Bergen City Council), *Hordland fylkeskommune* (county council) and *Hordland fylkesmannen* (County Governors Office – regional authority).

The delivery of the contract in Norway required that MMI produce all contract documents in English and Norwegian. Along with normal MMI Quality Assurance design checking procedures it was critical that all documents in Norwegian communicate the exact design requirements. To ensure this a rigorous checking process for all Norwegian documents was established utilising an accredited profession translation company, our Norwegian sub-consultants Ramboll, and some native Norwegian speaking engineers hired specifically for the project.

QUALITY ASSURANCE

Along with normal MMI Quality Assurance design checking procedures, it was critical that all documents in Norwegian communicate the exact design requirements. Translation of technical documents was key.

BI-DIRECTIONAL BALLAST TRACK AT YTREBYGDSVEGEN

RETAINING STRUCTURE AT BREIHOLTEN. STEEL TUBULAR PILES, DRILLED INTO ROCK, CONCRETE FILLED, AND ANCHORED.

2 ORIGINALITY, INGENUITY AND INNOVATION

HOW WE'RE ADDING VALUE

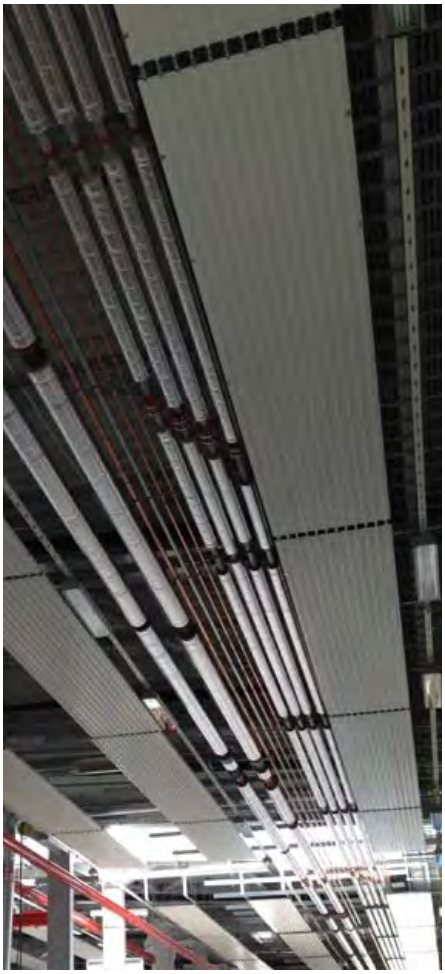
BIM – B**uilding Information Modelling** – is a co-ordinated set of processes, supported by technology, that add value by creating, managing and sharing the properties of an asset throughout its lifecycle. BIM incorporates data – physical, commercial, environmental, and operational – on every element of a development's design.

MMI have demonstrated originality and innovation in several design aspects, but perhaps the area where MMIs innovation is most obvious is in the use of BIM (Building Information Modelling) for all design elements of the Bybanen Stage 3 Project.

Bybanen Utbygging made it a contractual requirement that all design work was carried out in 3D from foundation infrastructure up. The client had a clear understanding and vision of the advantages that would be offered from planning, designing and constructing from a fully coordinated BIM design.

The design team, led by MMI, comprises staff from Mott MacDonald's offices in Dublin, Cork, Belfast, Manchester, Croydon, Prague, Budapest, Bristol, Poland, South Africa and sub-consultant offices in Dublin and Oslo. One of the greatest benefits in all design work being developed and completed using BIM, is that it has enabled Mott MacDonald's most appropriate experts, in a range of different countries, to work on the project. This enabled a level of collaboration, led by our Dublin office, but working together in multiple locations, cultures and languages, which was not possible a few years ago.

A number of different software packages were used to develop the design, and MMI utilised Bentley's ProjectWise to control and manage the project data and facilitate sharing between the



3D MODELLING DELIVERED A CO-ORDINATED SOLUTION TO THE HEAVILY SERVICED WORKSHOP BUILDING

THE DELTA AREA AT THE DEPOT ENTRANCE WITH TRACTION SUBSTATION TO THE RIGHT. OPERATIONS MODELLING HELPED UNDERSTAND MULTIPLE TRAM RUNNING MOVEMENTS AND ACCESS / EGRESS SCENARIOS.

parties. Staff working on the various design elements all have access to the same live information. This allowed the team to deliver a fully coordinated BIM and engineering deliverable – the 3D model and associated 2D drawings – which provided confidence and assurance in the functionality of the design, it's constructability and future asset management & maintenance.

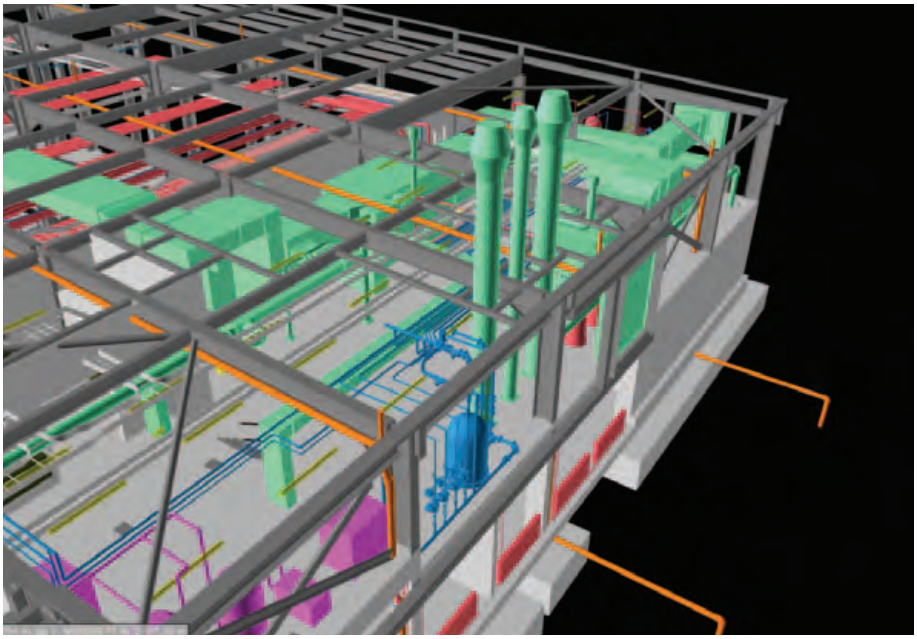
There were language barriers to contend with both internally within MMI's design team, and externally with the Client, the Contractors (Norwegian and international), local sub-consultants and project stakeholders. BIM broke down language barriers, and design concepts were easily explained and understood by all parties.

The contractors used the models to determine the construction sequence and efficient, safe construction processes, while also facilitating manufacture from design, maximising off site prefabrication and minimising waste.

Not only has the project been understood and planned utilising BIM, but the contractors also constructed directly from the models. The BIM models were developed with all the required information to enable the contractor use the data directly in their equipment. Surfaces contained within the model were loaded directly into excavators and grading machines, which were used for earthworks including tunnel blasting, rock and earthmoving, and laying the finished pavement surfaces. All trenches, utilities and pipelines were also set out and laid directly from the models. The traditional use of 2D drawings alone has passed for this project, and while they are useful to understand and interrogate each design and associated details, the primary source for construction information is the model. Through the linking of intelligence to the model, such as attribute data for facility management, BIM is a powerful project management tool and a lifetime asset for the scheme. Its benefits can be seen at all project stages, from preliminary design through to construction, operation and maintenance and in future decommissioning.

NEW 42M TRAM DELIVERED TO DEPOT WORKSHOP IN OCTOBER 2015.

The project was designed and modelled using BIM, and was worked on in design and project offices thousands of miles apart, led and managed by Mott MacDonald Ireland.



BIM SNAPSHOT: PLANT ROOM IN THE WORKSHOP BUILDING, DESIGNED TO SERVE ALL BUILDINGS ON THE DEPOT SITE. MODELLING ENSURED CO-ORDINATION AND EFFICIENT CONSTRUCTION ON SITE

3 BUDGET, QUALITY AND PROGRAMME

YTREBYGDSVEGEN OVERBRIDGE, WITH DRY STONE WALLS, PROVIDING RESIDENTIAL ACCESS.

The Bergen community expects Stage 3 of their light rail to be operational by mid-2016....in Norway adherence to programme is a cultural norm.

ROCK BLASTING AND TUNNELLING WORK AT SOLHEI TUNNEL, SANDSLIVEGEN

For the *Bybanen* Stage 3 project, programme was a primary driver. The Bergen community expects Stage 3 of their light rail to be operational by mid-2016 in line with the ongoing public announcements – in Norway adherence to programme is a cultural norm. MMI were initially appointed at the very end of 2012, with a programme of Depot complete by September 2015 and the line carrying passengers by mid-2016. All key elements are now complete, the first tram was delivered to the Depot in October 2016, and system testing and proving is ongoing. The Rail Safety Case is due for approval this quarter (Q1 2016).

To deal with a tight programme it has been necessary for the design and construction stages to overlap, and for the construction to be spilt into various elements and sections, leading to approximately 16 separate significant construction contracts with a total value of NOK 3.6bn (€450m), with some contracts – for example track installation – extending across the whole project area. This complexity of contacts has required very detailed and careful planning of the overall construction programme and contract interfaces, with a carefully balanced series of penalty milestones to ensure the required interface handovers are achieved.

Our design programme, with 12 month duration, was also very tight, with significant penalty milestones for delivery of different elements. To achieve this, MMI developed a detailed design programme at the start of the project, and used resources from 10 different offices in 6 different countries, with teams dedicated to different areas. MMI have recorded more than 200,000 man-hours up the completion of the design deliverables, with 60% of this recorded by the lead offices in Ireland. A further 100,000 man-hours were spent by MMD supporting the contractors during the construction stage, again with similar proportion recorded in Dublin.

For the local authority and statutory permitting for the project, the stages are not dissimilar to those used in Ireland. However, from good co-operation with the local Bergen kommune, it was possible to break the necessary approvals process into smaller elements as the design and construction proceeded.
The project is funded by the local Hordaland fylkskommune, with a significant amount of the funding sourced from local road tolls. Budgets were determined before our involvement in the detailed design. However, our designs are generally stayed within the available budget.

MMI emphasised value engineering within all our design work. In addition, the splitting of the overall

SANDSLIVEGEN TRAMSTOP AT WEST PORTAL OF SOLHEI TUNNEL (DRILL AND BLAST) WITH 100M POST TENTIONED SANDSLI BRIDGE FURTHER WEST, TO THE AIRPORT FROM BERGEN CITY.

construction into a 16 separate contracts probably reduced the overall price as smaller work scopes opened tendering to a wider number of contractors. In Norway's busy construction industry, to tender a large project such as ours would have probably attracted very high tender prices from a small number of large contractors.

In terms of quality, the approach in design is 'current industry best practice'. For design, we had significant ongoing interrogation of the developing design by the client's own specialists. At design stage we had a careful and detailed quality control process – standard for MMI using bespoke software and procedures. The client also had an independent third party control process on key elements of the design, to comply with Norwegian statutory requirements.

For the construction stage, it was necessary – and a regulatory requirement in Norway - to use contractors with appropriate skill and experience levels. In addition the client has used a third party control system to ensure that the contractors are maintaining and properly using their stated quality control regimes.

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PLANTASJEN TRAMWAY AND OVERBRIDGEWITH ELEVATED CYCLEWAY AND PEDESTRIAN PATHWAY CONSTRUCTED USING DRY STONE WALLS. THE OVERBRIDGE SERVES A CRITIAL ROADWAY AND TRAFFIC PLANNING WAS CRITICAL.

CONTRIBUTION OF THE PROJECT TO THE ECONOMY

4

With a construction value of NOK 3.6 billion (€450 million) the spend by Hordaland *fylkeskommune* on the *Bybaben* Stage 3 project is having a significant positive impact on the local economy – this is more than 2% of the Norwegian annual construction value.

The project itself is directly creating jobs for hundreds of construction workers. While the construction companies undertaking the work are for the most part multi-national, it is local arms of these companies, and local contractors, who are carrying out the work, and benefiting most.

IN A CONTRACTING IRISH MARKET MOTT MACDONALD LOOKED OUTSIDE TO INTERNATIONAL OPPORTUNITIES

The initial project spend is indirectly generating wider economic benefits, including jobs, through the impact of the project on the supply chain, for example manufacturing, consultancy services, real estate, transport, accommodation, etc. Typically each NOK spent generates a multiplier of approximately three in overall economic activity.

The economic benefits of *Bybanen* to the city Bergen will be borne out over the coming decades; a sustainable and efficient transport system encourages both business and tourism.

The project also had very important economic effects closer to home, for Mott MacDonald Ireland Limited

Bergen is expanding, with growth strongly related to the oil and gas industry, the city is slowly replacing Stavanger as the 'oil capital'. This expansion is supported by the overall light rail project as it makes Bergen a move convenient location to travel to and from.

Tourism is also growing in Bergen, and the city is a start off location for sea cruise traffic in the nearby fjords, the tourism business will be substantially enhanced by the delivery of *Bybanen* light rail, a safe user friendly mode of transport for visitors. *Bybanen* Stage 3, serving the Airport at Flesland, is particularly important in this regard, providing a direct route from the proposed terminal to the city centre.

The project also had very important economic effects closer to home, for MMI. In 2011, like the rest of the consulting engineering industry in Ireland, MMI were facing an ever tightening market with diminished or negative margins. Although a portion of our workload has always been overseas, MMI was still contracting with a shortened forward order book. Thus the winning of the Bergen commission was critical to us – the total fee was equivalent to almost twice our then annual turnover. While our work on this project has been very challenging for the past 3 years, it has been a significant factor in our ability to survive the recent crisis in our industry.

For MMI winning this project has provided full-time employment for more than 40 Irish engineers for the duration of the project.

STEINSVIKBROEN POST TENSIONED CONCRETE BRIDGE BETWEEN STEINSVIK TUNNEL TO THE EAST (RHS) AND SOLHEI TUNNEL TO THE WEST (LHS) . AN ACCESS AND SAFE REFUGE AREA WAS DESIGNED IN THIS AREA BETWEEN TWO TUNNELS.

SANDSLIMARKA CURVED 2-SPAN PEDESTRIAN BRIDGETRAVERSING THE TRAMWAY PROVIDING A ROUTE BETWEEN OFFICE BLOCKS FOR STATOIL STAFF.

5 SOCIETY - QUALITY OF LIFE

BRYGGEN, BERGEN. UNESCO WORLD CULTURAL HERITAGE SITE.

Bergen is ideal for public transit, given its mountainous topography the population is concentrated in valleys which are typically less than 2 kilometres wide and radiate from the city centre.

To the west, the area is dominated by the industrial/commercial areas of Kokstad, Sandslimarka and Flesland Airport, to the east lie the residential neighbourhoods of Rastolen and Steinsvik. This general layout of business and residential has resulted in very significant traffic congestion in this area of Bergen during the morning and evening rush-hour. The development of Bybanen Stage 3 links these industrial and residential areas, offering a viable alternative to car transport for commuters. Along the Bybanen line tram stops are integrated with the local transport facilities for pedestrians and bicycles, some tram stops will link with bus services, and many stops will also include parking spaces for commuters.

The development of the *Bybanen* scheme is providing a reliable, safe, comfortable, and frequent alternative to car transport for commuters. This is leading to a significant model shift to a more sustainable transport system in Bergen, resulting in less traffic congestion and improved environmental

UPTAKE OF BYBANEN BY THE BERGEN PUBLIC HAS BEEN STRONG.

THE DEVELOPMENT OF THE BYBANEN SCHEME IS PROVIDING AN ALTERNATIVE TO THE CAR.

conditions for all. The quality of life benefits for the City of Bergen are clear to see.

Bybanen Utbygging estimate, that when complete, as part of the 2005 to 2025 Bergen program for transportation, *Bybanen* will be within walking distance of 50% of houses and 80% of work places in the Bergen area.

These benefits of the scheme are appreciated by the local population with strong passenger uptake on Stage 1 and Stage 2. In 2011 approximately 7 million passengers used the service, this increased to 8 million in 2012, with a further 1.1 million passengers using *Bybanen* in 2013, with the opening of Stage 2. It is projected that between 40,000 and 50,000 passengers on a normal weekday are expected to use the system when Stage 3 is completed to the airport.

Integral to the design of the project, and to the benefits of the project in terms of quality of life improvements for the people of Bergen, was consideration of any specific environmental impacts, both during construction, and during operation.

MMI undertook an assessment of the environmental conditions and sensitivities of the potential area of impact surrounding the Bybanen Stage 3 scheme, under the following heading: watercourses, flora, fauna, air quality, contaminated land, waste management, cultural heritage and community and social impact.

Due to the nature of the study area (residential, industrial and commercial land uses), and the type of work to be carried out, (tunnelling, rock blasting, excavation and general construction work) noise and vibration impacts were of particular importance. MMI set out construction noise and vibration mitigation measures ensuring contractors adopted a rock blasting strategy that would reduce vibration levels.

Operational phase noise and vibration impacts arising from the Stage 3 are limited to a small number of locations. Based on the identification of over 30 individual properties where noise limits would be exceeded during the operational phase, MMI proposed and designed noise mitigation measures to reduce noise impacts at these properties.

QUALITY OF LIFE

The development of the Bybanen scheme is providing a reliable, safe, comfortable, and frequent alternative to car transport for the Bergen public.

VIEW OF BERGEN CITY CENTRE FROM MT. FLØYEN

6 A BENCHMARK IN IRISH ENGINEERING

'GATEWAY TO BERGEN' THE FEATURE BRIDGE ON THE 'FLYPASSVEGEN' THE MAIN ROUTE BETWEEN THE CITY AND THE AIRPORT.

Winning the project, gaining a foothold in Norway and pioneering "desk to digger" model transfer are notable benchmarks for an Irish Consulting Engineerng firm.... this expertise can also be brought back to Ireland, for large infrastructure projects

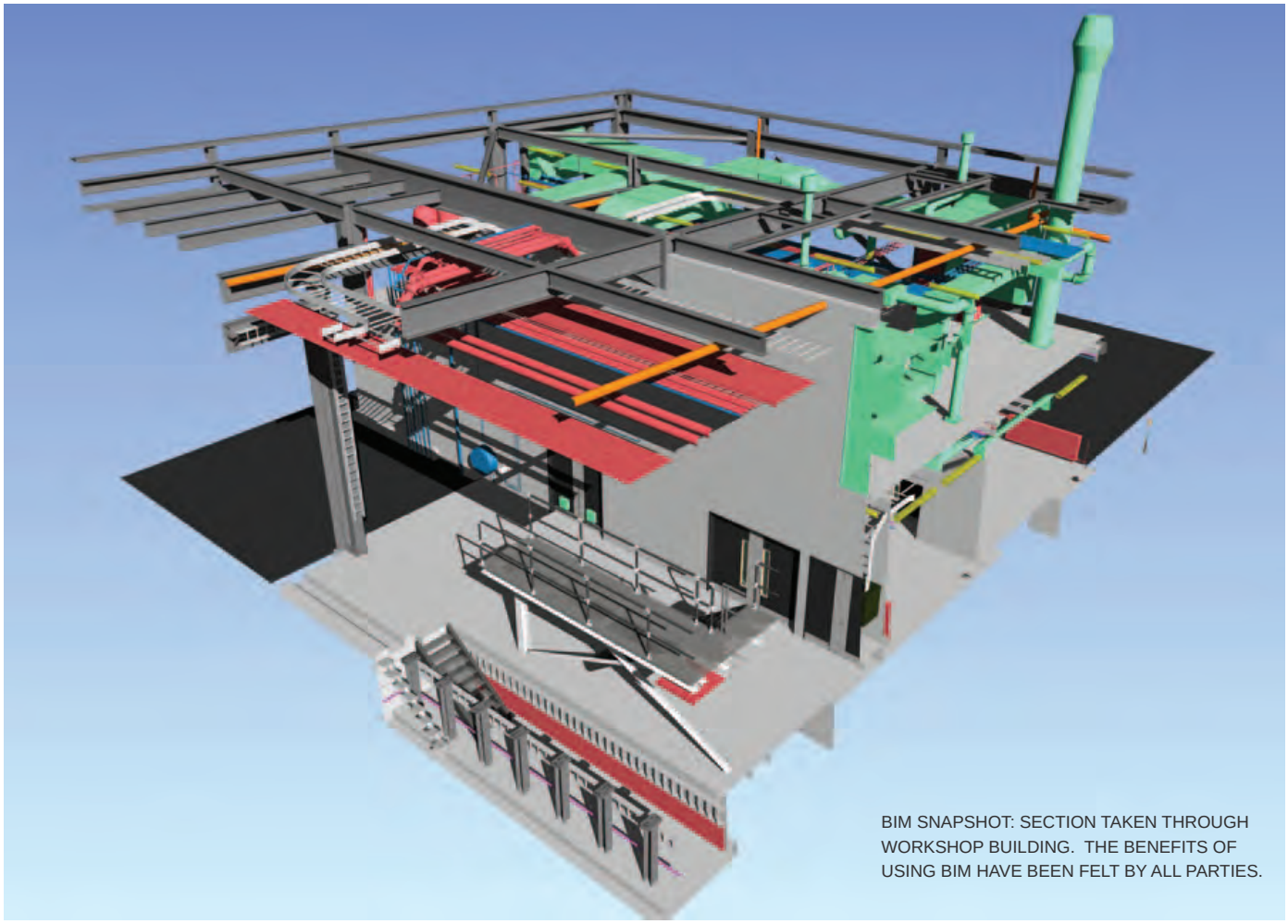
When *Bybanen Utbygging* commissioned MMI to undertake the detailed design for the Stage 3 of *Bybanen* in Bergen, it was a bold move on their part and a significant challenge for MMI's Dublin based light rail design and management team.

Coming at a time when Irish fortunes were low, the opportunity to export our Light Rail skills, honed in working with, and for, the RPA on the Luas for over 14 years, could not be missed. Competition was fierce, and Scandinavian. Our international competitors included the two established Norwegian consultants who had separately completed design and supervision of the first two sections of the route.

Our success in winning the commission to design the Stage 3 route extension and Depot, was, we believe, the first major venture into the Norwegian market by an Irish engineering consultancy. In a benchmark for the Irish engineering industry, MMI was able, against strong competition familiar with the local market, to demonstrate a clear appreciation of the technical requirements, a resolve to deliver an integrated design and the ability to deliver in a three dimensional BIM environment.

It is this last point that is now reaping rewards for client and contractors alike. Three dimensionally space proving every aspect of the design, from rock tunnels and bridges, through to hand rails and paving slabs, prior

MMI ARE TRANSFERRING SKILLS AND EXPERTISE FROM OVER 14 YEARS WORK ON THE LUAS IN DUBLIN TO BYBANEN IN BERGEN, NORWAY.

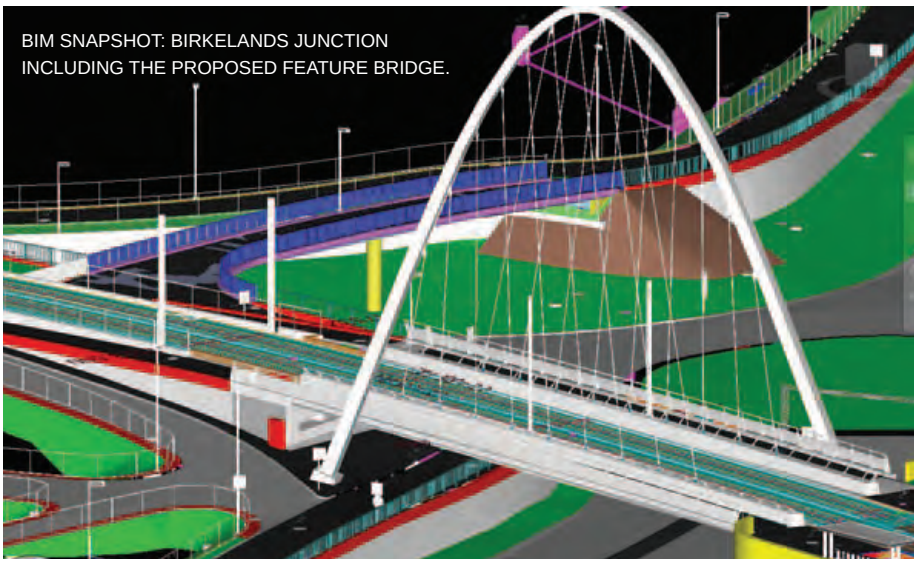


BIM SNAPSHOT: SECTION TAKEN THROUGH WORKSHOP BUILDING. THE BENEFITS OF USING BIM HAVE BEEN FELT BY ALL PARTIES.

to putting a spade in the ground ensured to very few site queries, and virtually eliminated down time and re-work on site. On a transportation project of this size, this is unheard of. However, probably the most significant impact the design approach has had is in the direct transfer of modelling information from desk to digger. Working with Norwegian survey software developers, rock blasting and ground profiling models are exported directly over wifi from the computer to GPS enabled plant. This eliminated the need for traditional setting out, increased accuracy and improved site safety. Norwegian contractors believe that this desk to digger expertise will now become the norm in Norwegian infrastructure construction for the next 10 years. MMI consider that this expertise can also be brought back to Ireland, ideally for large infrastructure projects.

MMI has now gained a firm foothold in Norway, establishing an active office comprising expatriate staff and local expertise. The MMI brand is now well recognised in western Norway both with our competitors and our potential markets. Working on a large multidisciplinary transportation project brings us into direct contact at a technical level not just with our immediate client but the highway authorities (local and national), utilities companies, planning and regulatory authorities and most departments within the local and county authorities.

Jim Sherry, Shane Knox, January 2016



BIM SNAPSHOT: BIRKELANDS JUNCTION INCLUDING THE PROPOSED FEATURE BRIDGE.