# The Application of Automation and Robotics at BRE's Cardington Large Building Test Facility, UK.

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## ABSTRACT

This paper reports back on the BRE-IAARC sponsored workshop held in the UK in November 1995. It was unusual insofar as the principal theme sessions were focused on the exploitation of the unique Cardington Large Building Test Facility (LBTF). The LBTF comprises a programme of full-scale buildings constructed 'indoors' for the purposes of whole-building process and performance studies. This paper examines how Automation and Robotics in Construction (ARC) can exploit the LBTF by accelerating development towards the marketplace. The theme sessions addressed issues in 1)inspection, maintenance and repair; 2) integrated site measurement and 3) material handling. Feedback indicates a very positive response to the idea of establishing specialised 'forums' with further workshops in each of the theme areas in addition to establishing an internet 'home page' following consultation with both the British Association (BAARC) and IAARC.

## 1. BACKGROUND

The future competitiveness and success of the Construction Industry will be dependent upon the application of research findings, the introduction of innovative processes and products and their practical demonstration and marketing. Professor Hasagawa's[1,2] and Dr Garas's[3] observations on the importance of robotics in construction and problems facing the industry remind us that there is still a long way to go for Automation and Robotics in Construction (ARC) to achieve widespread acceptance. Haas[4] suggests there is a steady maturing of construction automation. However, the very limited number of photographs of commercial applications in ARC and their trend in recent ISARC proceedings could be taken as challenging this assertion.

BRE's interests in this field are primarily applications in the built environment with particular bias towards multi-storey forms of construction. It is well understood that the cycle of innovation is incomplete without prototyping and field demonstrations and yet it is the apparent lack of physical 'test beds' in this area that prevent good ideas realising their

market potential. For a vision of the future in this area one has to look little further than to study the Japanese Taisei Corporation's 'Automated Construction Concept'[5] in which they illustrate diverse robotised construction and maintenance activities being undertaken on a multi-storey building.

Research into the ARC state of the art[3,6] in the UK prompted BRE to explore the possibility of convening a focused international workshop at the LBTF. The workshop invited *active* participants, ie. not *observers*, to exchange information on their own interests and assess the potential for exploiting the LBTF. The workshop was held on 7 November 1995 and was jointly sponsored by BRE and IAARC and endorsed by the British Association - BAARC. It gave BRE particular pleasure to welcome the IAARC board members present who had convened a meeting the day before the workshop also at Cardington.

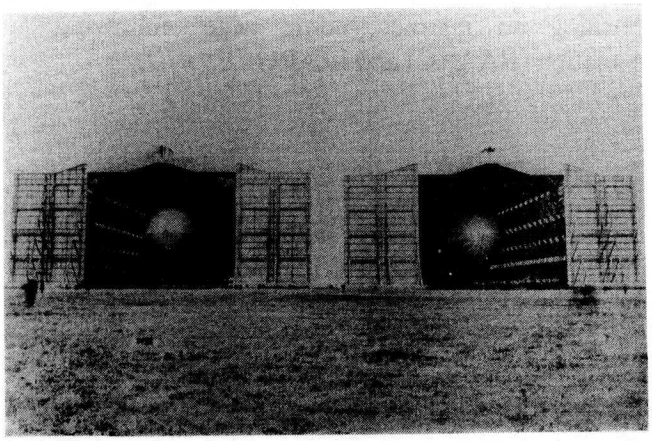
It is clear from Poppy's[7] 1993 paper that ARC does not yet play an important role in many European countries. Garas[8] considers actions needed to accelerate the integration of the design and construction process including the use of automated systems in site operations which include:

- *establishing a number of test beds where the integration process of IT, machines and human resources should be demonstrated.*

The above sentiments are taken up by Vos[9] who appeals to the professional institutions to pay more attention to the matter of implementation of new technologies. The difficulties Poppy experienced in securing meaningful answers back in 1993 were overcome in the UK to a large extent with the comprehensive City University Construction Robotics Unit's report for the DOE[6] titled: 'The Mechanisation of Construction Industry Processes'.

## 2. BRE'S CARDINGTON LARGE BUILDING TEST FACILITY (LBTF)

The LBTF is itself located inside one of the massive former airship hangars (250m long, 80m wide and 55m apex height) near Bedford, north of London, now known as the Cardington Laboratory. Data from the LBTF's full-scale physical testing will be used in reviews of both current UK and draft ENV Eurocodes in addition to calibrating and validating computer programmes, particularly in the areas of structural and fire engineering. The importance of this facility on sustainable development is reflected in the world-wide interest and demands being made for this emerging data.



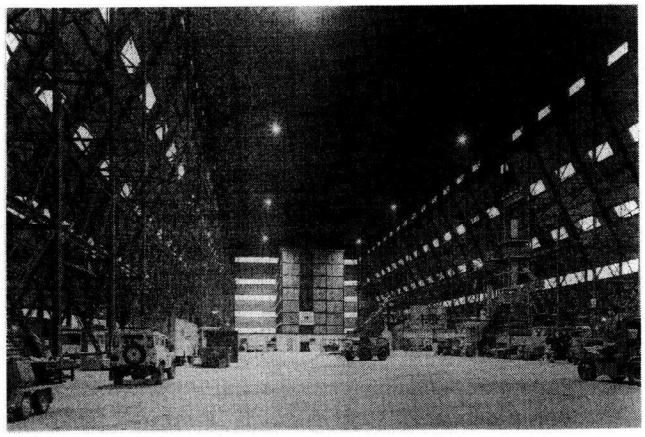
Cardington airships c1930. R101(left) and R100

For many decades building regulatory authorities had to rely on data from elemental or sub-assemblage testing but BRE's ambitious LBTF programme of research and demonstration projects on full-scale whole buildings will generate a quantum leap in the quality of data.

The first building at the LBTF is a conventional 8-storey steel-framed structure, 45m long

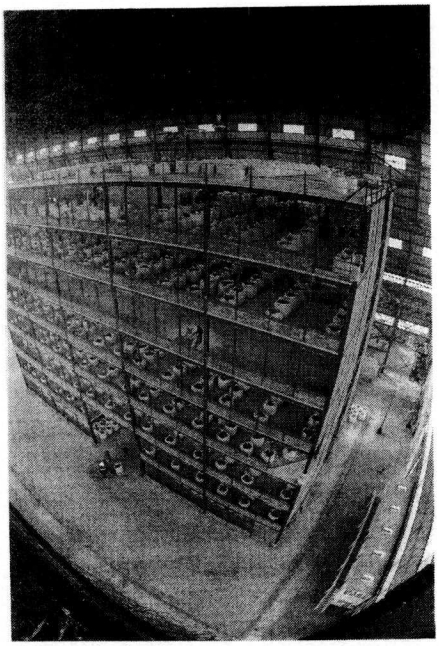
by 21m wide and 33.5m high, with 3 vertical access shafts and a 2-storey atrium at the building's entrance. Its main construction components comprise composite floors with steel decking and lightweight concrete with concrete blockwork cladding. Construction began in the summer of 1992 and following a number of research breaks was completed in February 1994. Additional multi-storey structures in concrete, timber and masonry are also planned over the next few years.

The core research and demonstration programme at the LBTF is sponsored by the UK's Construction Sponsorship Directorate which is part of the Department of the Environment (DOE). The major areas are: structural responses to static, dynamic and fire loadings. Each of these areas have a rolling programme of progressively more destructive tests on the building.



The Cardington Laboratory - 8-storey building at rear

A coordinated pan-European fire research and demonstration project is exploiting this first LBTF structure by staging fire tests on an unprecedented scale. These will provide compelling evidence which may lead to reductions in passive fire protection on steel-framed buildings. The commercial benefits for many years to come are likely to be hugely disproportionate to the R&D investment. Independent commentators[10] have gone further to observe that knowledge flooding out from the LBTF will, in 25 years time, have revolutionized the understanding of how real structures work. An ongoing programme to disseminate LBTF results and information includes LBTF quarterly newsletters and Cardington conferences.



The LBTF's first building

## 3. THE WORKSHOP

The title of the workshop was 'The Application of ARC at the LBTF' which reminds all that its objective was to focus on the applied end of the development continuum in ARC. Other technological sectors such as aeronautics, offshore, manufacturing, nuclear, defence and power were encouraged to be represented since all have achieved progress in AR that could benefit the construction industry.

To promote this development in ARC and, without disrupting the programme, exclusive press coverage was arranged with a leading UK Sunday newspaper *The Sunday Times* and the satellite TV programme *European Business News* attended. Participants were shown demonstrations of *Nero, Robug II and Robug III* robots by

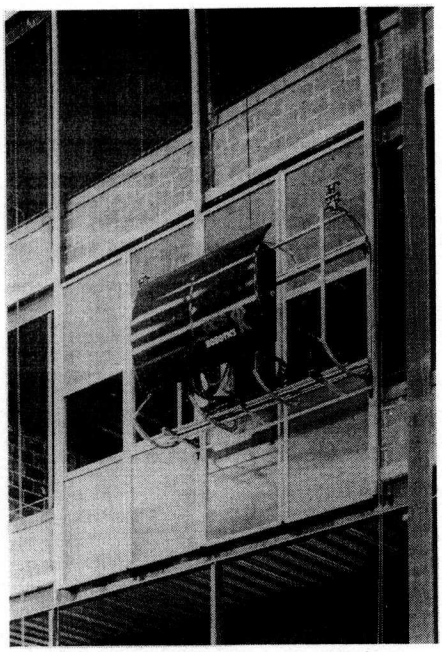
Professors Collie and Virk of Portech; DRA's Universal Gripper in action; and BRE's new 3-d laser. In addition there were several exhibits to view and a tour of the experimental set-ups and damage, scientifically inflicted, on the 8-storey steel-framed building made for a very full day at the workshop.

The DOE report[6] recommends national working groups are established in three field application areas for the purposes of achieving agreement on the main development parameters which will serve to guide research and development. These three areas are:

1. *Surface inspection and repair*
2. *Integrated site measurement*
3. *Material handling including assembly and masonry*

Thus the adoption of these themes for the workshop was a logical step forward.

***Session 1 - Inspection, maintenance & repair (chair: Mr Peter Johnson, OCS Group Ltd)***



ARCOW trials at Cardington

The workshop got off to an excellent start as Peter Johnson described his company's development of an automated window cleaner system[11] that carried out extensive commissioning and development trials at the LBTF during April/May 1994. The system, known as ARCOW (autonomous robotic cleaning of windows) ideally needs to be incorporated at the concept stages of the design process. Subsequent developments have moved the system into the marketplace in the UK.

Denis Chamberlain then drew upon his extensive experience in ARC to describe City University's Construction Robotics Unit's progress looking into how AR might solve some of the difficulties of maintenance on steel bridges. Reduction of hazards in both location and removed material ingestion were amongst the prime drivers in the quest to introduce AR into the bridge inspection process. Unlike manufacturing robots bridge inspection robots need to be flexible and capable of tackling a range of awkward tasks and positions in an environment prone to traffic and wind-induced vibrations. Finally Joe Michael took a leap well into the next century with his concept of shape changing robots and the maintenance operations he believes they could handle[12].

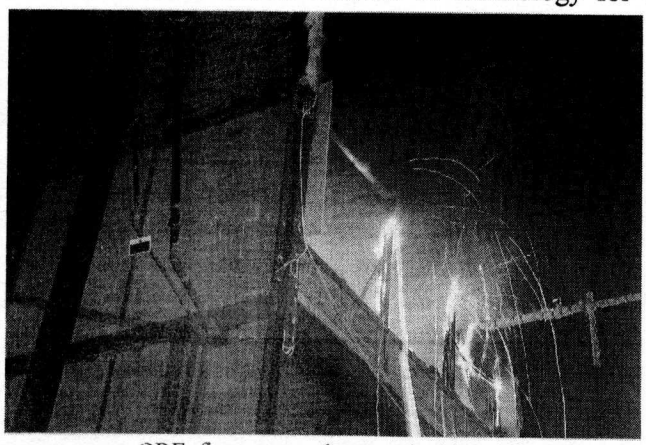
The discussion period that followed raised a number of issues such as attachment systems to buildings and the implications on health and safety legislation for inspection and maintenance systems. Maintenance systems for facades currently rely on roof-mounted cable systems and futuristic wall-climbing robot also need the security a roof-mounted safety line brings. Nishi[13] describes the limitations of walking machines which include speed and traversing obstructions and goes on to examine mechanisms for both propelled and flying external robots. The commercial application of such innovations will have to overcome considerable safety audit scrutiny. Availability of suitable test buildings and compliance

with Regulations[14] were cited as a limiting factors which tends to lend support to the LBTF for prototyping and commissioning. Whilst it is hard to argue against this holistic viewpoint many of the participants voiced their support for the leverage prototyping on full-scale buildings, such as at the LBTF, can bring to the development process. This recognises the special situation of the LBTF's programme of experimental buildings not being operational in the conventional commercial sense. This offers scope for discussions with the UK's Health and Safety Executive (HSE) for relaxations on regulatory issues to accommodate the research process.

During the discussion it was mentioned by the author that the HSE had indicated their willingness to be active in assisting the application of ARC in any of the three theme areas. Neale, in his paper[15] reminds all that the application of ARC will, like traditional construction practices, require the logical identification of risks, their minimisation and then the controlling of remaining residual risk elements.

***Session 2 - Integrated site measurement (chair: Professor Arthur Collie, Portech)***

Emerging areas such as laser-guided earthworks machines and piling rigs are cutting labour costs, saving setting out time and increasing efficiencies. This area has particularly benefited from inward transfer of technology for example the joining of forces of US's Trimble Navigation and UK's Stent Piling to offer their GPS-based Stent Automatic Pile Positioning and Recording system (SAPPAR).



BRE fire test panel scanned with 3-d laser

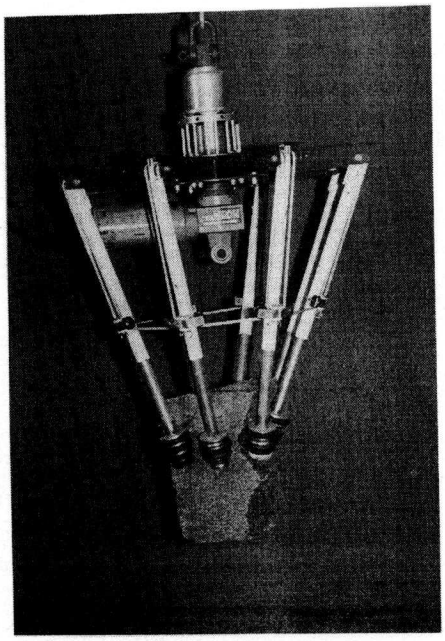
The development of the LBTF has demanded new ways of recording extensive nodal point spatial displacement on a real-time basis to contribute to their advancement of understanding whole building behaviour. André Bougard from BRE's Structural Performance Division described an innovative system developed specifically for the LBTF that can be used in a remote manner where it is difficult to place traditional instrumentation such as displacement transducers. The system is still in its development infancy but can achieve accuracies of 1mm over a 30m range under certain conditions. The software currently constrains the number of targets to 128. The system is based on a modulated beam of laser light which is aimed at a target, and the detection of a change in the phase of the reflected laser light, knowing angular positions, giving a change in range to the target from which every target's spatial location can be determined. Mr Bougard described its first major application in October 1995 when it recorded the displacements of 31 targets located on a masonry panel bordering a major fire test on the 8-storey building.

David Martin, Spectra-Physics Laserplane then described his company's laser products following which a lively debate on the accuracy and reliability of GPS unfolded. Whilst this was inconclusive on the day there was considerable interest in the BRE 3-d laser from those present in the nuclear and offshore industries.

The continuing distortions arising from the LBTF's progressively destructive research and demonstration programme on the first building is providing excellent commissioning opportunities for the evaluation of laser systems. In particular an assessment of the building's integrity can be carried out following major 'events' such as fire and explosion tests. This has implications for the rapid evaluation of damaged buildings - particularly if 'benchmark' data on the dynamic attributes has been previously recorded. The Japanese Taisei Corporation[16] have demonstrated the contribution laser-controlled erection management systems can make in the construction of high rise buildings and it would seem that, given further development, the BRE 3-d laser could be central to similar applications.

BRE's new 3-d Laser System

***Session 3: Materials handling, including assembly & masonry***
***(chair: Dr Robert Wing, Imperial College and BAARC)***



DRA's Universal Gripper

Dr Wing outlined the activities and membership of the British Association (BAARC) and his own university's interests including work investigating the potential of jointing for new fixing systems in the cladding industry. Dr Kurz, University of Stuttgart, Germany, then described the advanced masonry building robot - BRONCO - whose development has been endorsed by EUREKA. Working priorities in this project have been the mechanical design, kinematic structure as well as control and sensor strategies for the bricklaying process. Mr Nishigaki, Hazama Corporation, Japan, followed providing an fascinating insight into the 'Innovative Intelligent Field Factory' (IIFF) concept that addresses three work packages: 1) study on new assembling methods; 2) material handling systems for 1 and 3) autonomous agents for decision making. Mr Nishigaki's own work[17] on 'hiyari-hat' (serious accident near-misses) has shown that 'humanware' failure is often the cause and thus the integrated application of the IIFF with ARC should create safer construction working environments.

The UK's Defence Research Agency's (DRA) Nick Warner then described their 'Universal Gripper' that offers a mechanism capable of handling any shape or weight using

extending telescopic fingers that evenly distributes contact forces. This project was shortlisted by the DOE report[6] as being worthy of future funding support. Applications could vary from a personal lifting assistant to fully-automated work in hazardous environments.

The discussion period following acknowledged the significant progress being made in this area. In particular the harnessing of the inherent manipulative flexibility built-in to the BRONCO design and its potential for transferring to other ARC tasks was encouraged. Much work in this area has been carried out by Rosenfeld[18] with further development into the painting, tiling and plastering of walls and ceilings. However, realistic full-scale trials are needed to reduce the current amount of human intervention needed in these processes. The incorporation of isolated material handling tasks into construction 'workcell' modules presents a further development[19] which increases efficiencies of manipulator usage and thus productivity. The LBTF's future building programme provides opportunities for material handling and assembly techniques with masonry infilled panels most certainly being required. Other countries not represented at the workshop are of course active in this area for example, at a recent meeting with UNIDO details of a Russian proposal, later rejected for funding, on multi-arm robotic manipulators with multipurpose control system were exchanged.

***Funding Session***

A final session aimed to increase participant awareness of UK, EC and wider funding mechanisms that are already or could be receptive to proposals in the ARC arena. Most of these are 'shared cost' actions which means that the public sector support will match the industry input which can be valued in 'kind' as well as cash. UK University funding is administered by the Engineering and Physical Sciences Research Council (EPSRC), in particular their 'Built Environment', 'Innovative Manufacturing Initiative' (which supported the Stent GPS-based pile positioning system) and Link-IDAC (Integrated Design and Construction) programmes. The DOE also administers R&D through BRE's own programme and its 'Partners in Technology' programme which also matches industry's contribution. Smaller schemes exist such as the Institution of Civil Engineers R&D fund. The Department of Trade and Industry also runs a programme called 'Carriers in Technology' which aims to assist in the transfer of technologies between industrial sectors which, for example, could arise from the 'peace dividend' through diversification of military technology.

European research programmes are embodied in 'frameworks' and the current 'Fourth Framework' typically calls for at least two participating organisations from different countries which should include an 'end user' and needs a well-defined 'Exploitation Plan'. Assistance in the promotion of the workshop was kindly provided by the TELEMAN robotics programme office. A non-EC programme - EUREKA focuses on the near-market end of the development spectrum, quite appropriate for the workshop theme and the bricklaying robot mentioned above has benefited along with other AR projects, particularly in the offshore and manufacturing industries. The EC's own 'Industrial Materials and Technologies' (Brite-Euram III) views construction as a manufacturing process and would look favourably on proposals involving the inward transfer of technology to construction from other areas. Hazardous situations also attract special funding through the EC's 'Environment and Climate' programme. Mobility of researchers is offered through a range of 'Accompanying

Measures' to the main programmes and as such, in the application of ARC a thematic network could be established to finance the travel and subsistence costs for this activity. The LBTF is currently looking to secure support from the 'Training and Mobility of Researchers' programme for the setting up of 'Euroconferences' whereby the EC supports conference expenses and the costs for scientists, particularly if they are young (under 35!), female and from 'less-favoured' regions in Europe.

Funding that brings together scientists engaged in ARC that goes beyond Europe is less clear. However, NATO funding can assist its member countries to develop ideas through awarding mobility grants and the British Council may fund 'first' visits to academic institutions almost anywhere. It should be noted that in May 1995 the UK's EPSRC and Japan's Ministry of Education, Science and Culture (Monbusho) signed an Implementation Agreement for co-operation in basic research and physical sciences and the extent to which ARC developments might be supported should be investigated. This Implementation Agreement, which supports exchange of researchers, information and co-operative research is reviewed triannually and thus there may be scope for advancing discussions in the field of ARC.

## 4. FEEDBACK

The workshop included a comprehensive questionnaire for participants to complete in order to help identify ways forward beyond the workshop. Around 140 responses to the workshop fliers were received which included about 40 who could not attend but wished to be kept informed of progress. Thus a useful database has been created that represents an excellent starting point from which to explore proposals in specific applications of ARC at the LBTF.

About 75% of the 60 participants (a further 20 did not turn up on the day) completed questionnaires. The approximate representation by sector was academic (25%), industry (45%), research organisations (20%) and 'other' (10%). 78% were from the UK, 7% from mainland Europe and 15% from elsewhere including North America and Japan. Highlights from the feedback were:

- Over 90% made personal contacts that they considered will help advance their own ARC interests
- Over 95% wanted BRE to contact them following the workshop to explore ways for future collaboration
- Over 80% considered that this type of workshop should become an annual event
- Over 30% asked for membership details of either BAARC or IAARC
- Over 85% considered that internet WWW pages should be established to provide a focus in the theme areas

The above represents encouraging feedback concerning the merits of calling the workshop. A number of organisations have outlined proposals with potential for involving the LBTF and it is hoped to report back on progress on these at future ISARCs.

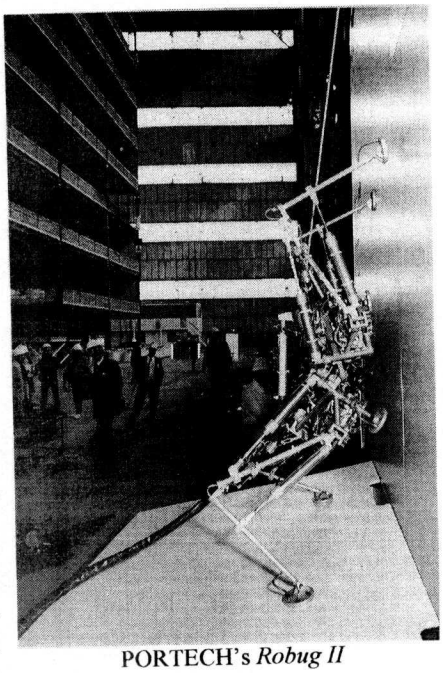
## 5. THE WAY FORWARD...

The above highlights suggest further actions should be taken and this will be done, and where appropriate, in consultation with both IAARC and BAARC. It is hoped to report back on progress in these areas at the 13th ISARC in Tokyo. The results of the questionnaires

provide the clearest indication of the strength of the active interest in the theme session areas and, implicitly, the need for UK and EC public sector funders to collaborate on an 'umbrella' ARC strategy that can be administered through university, government departments and collaborative research and demonstration schemes.

BRE will be contacting those 95% of questionnaire respondents who wished to discuss the application of ARC at the LBTF, particularly with respect to constructing proposals that would comply with European funding workprogrammes. Of these about 20 organisations offer the possibility for a UK or European collaborative research project. In addition the questionnaire feedback results will be passed to, at least in the UK, funding organisations to help construct a compelling argument for increasing funding in future projects in the application of ARC.

The issue of safety pervades every stage in the concept, design, construction, maintenance and demolition part of a building's life cycle. Discussions with the HSE will be reported on at the Tokyo ISARC and hopefully tangible project areas can be identified and prioritised and partners sought to progress collaboration. Demolition of the LBTF's first building is currently scheduled for Spring 1998 and thus there exists considerable scope for the application of manipulator and material handling technologies to be tried out for the 'deconstruction' and 'demolition' processes.



PORTECH's *Robug II*

Most respondents indicated their willingness to attend a more specialised workshop on each of the three theme areas with perhaps one day devoted to the subject but to include scope for exhibitions and working displays. The demonstration of early prototypes, even scaled down working models, was considered to be central to showing the *real* 'state of the art' despite practical difficulties still to be overcome. The LBTF, with its facilities and space, was considered by most to be an ideal venue, albeit at a warmer month in the year! to convene these suggested forums. The establishment of an EC 'thematic network' will be considered along with an EC programme of 'Euroconferences' in this area.

Realising potential requires looking at ways of exploiting existing resources in different ways - seeking economies of scope. BRE believe that the LBTF can make an important contribution towards the acceleration of ARC development towards the marketplace and would hope to report on solid and tangible progress at future ISARCs. Finally, in seeking to assist in the application of ARC in an evolutionary, not revolutionary, manner the LBTF is on a journey that began by implementing the words of Milton Berle: 'If the opportunity doesn't knock - build a door'.

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