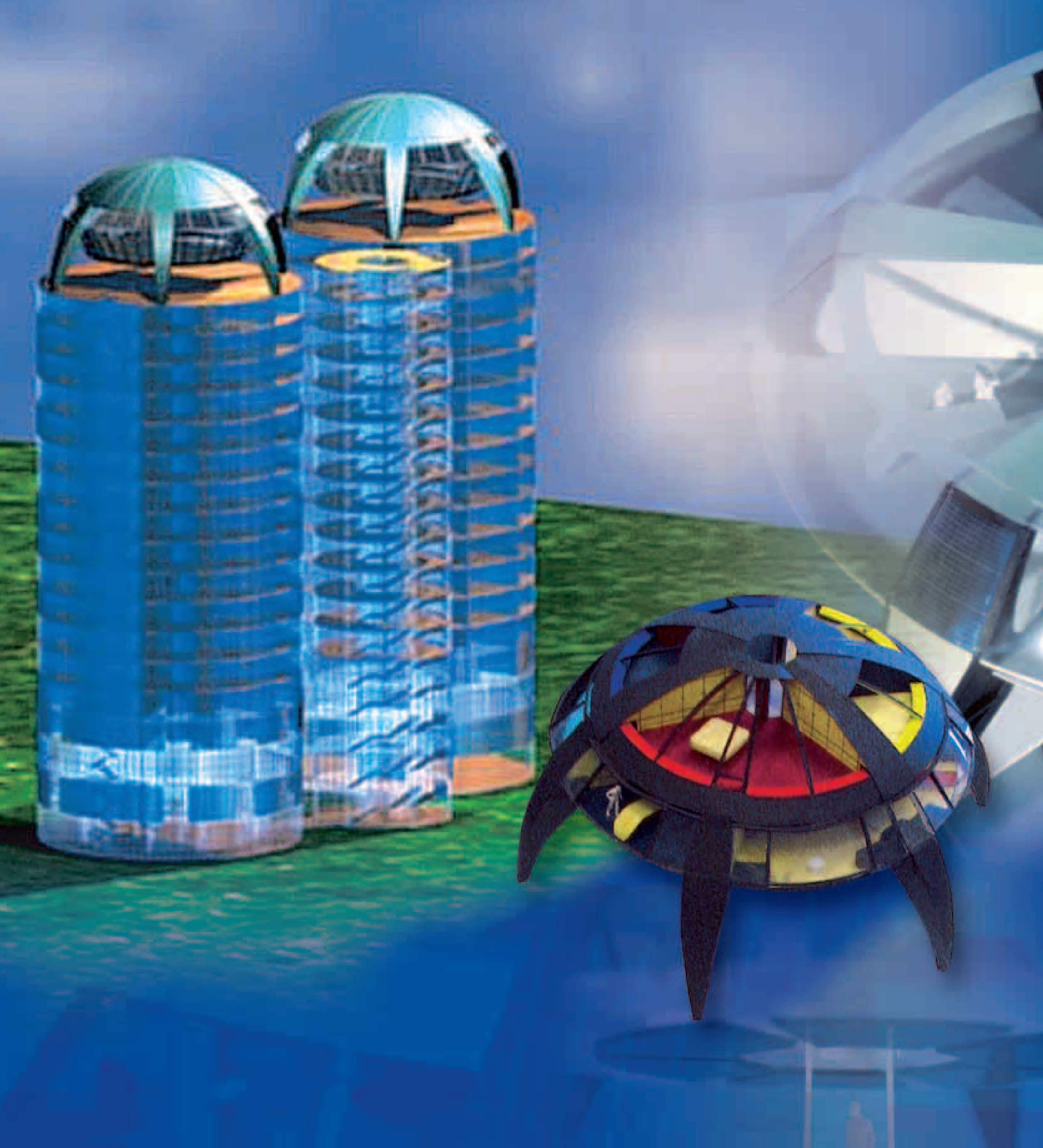

Space Technologies for the Building Sector

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One of the roles of the United Nations is to serve as a 'global conscience' and it has been inviting its Member States to give priority to addressing topics of global concern. One of the most debated and therefore best known initiatives is the 'Kyoto Agreement', dealing with the prevention of further man-induced global warming. Another similar UN initiative in recent years is designed to address the problems of the World's largest cities, or 'MegaCities', through a programme known as 'Habitat 21'. It is against this background that those involved in the ESA Technology Transfer Programme have been looking at how the Agency might be able to contribute to such initiatives by proposing space-derived and space-based technologies that can help to provide solutions. ESA's sponsorship of the publication in 2001 of the 'Megacities' book containing spectacular satellite remote-sensing imagery of the World's largest cities was seen as a first step in this direction.

Designing the large conurbations of the future, as well as the individual buildings that will make them up, already presents a formidable challenge, and one where the latest space technologies can help to improve the daily lives of those who will live there. Within the ESA Technology Transfer Programme, therefore, we have also begun to examine the potential contribution that space technologies can make to the building sector. The target is to be able to propose a very different style of housing surpassing current 'eco-designs' as well as offering greater protection against natural disasters and environmental threats.

Space Technologies for the Home

High-efficiency rigid solar cells
As demonstrated by the two ESA-sponsored race-winning 'Nuna' solar-powered cars, 25% triple-junction GaAs solar cells would be a powerful energy source for household applications. As yet, for cost reasons they are only being used for very specific applications and test systems, but their use around the house in the not-too-distant future can already be anticipated.

High-efficiency flexible solar cells
ESA is already engaged in the development of truly flexible solar cells for space applications. Based on a low-temperature ion-deposition technique onto any plastic substrate, they promise about 15% efficiency at a substantially lower cost than with today's rigid-panel systems. They will be ideal for the SpaceHouse, being able to follow the curvatures of its outer contours. Being foldable or rollable, they can also be used as a portable energy source.

Large-scale application of Li-Ion battery cells
Where energy autonomy is required around the clock, lithium-ion batteries can be combined with solar cells using an energy-management system developed for satellites, known as a 'power point tracker'. This was one of the leading-edge technologies that helped take the 'Nuna' solar-powered cars to victory in the World Solar Challenge races in 2001 and 2003.

Carbon-Fibre-Reinforced Plastics
Although CFRPs are sometimes regarded as a typical 'technology of today', the building and construction sector so far has little knowledge of or experience with these materials. Understandably so, perhaps, when the drive in the public sector is for minimum-cost private housing, or for 'winning the competition with the lowest bid'. However, with the introduction of new safety requirements, there is growing interest among architects, building engineers, housing associations, and insurers, etc. in trying out CFRPs. The challenge will be how to transfer the high-end manufacturing technologies of space to the manufacturing processes in the building sector. One might have to offer additional incentives such a 'service free lifetime' for the primary structure.

Carbon-fibre screws
ESA is currently engaged in optimising a new type of carbon-fibre screw for space applications with very stringent requirements. These screws would be ideal for the assembly of the SpaceHouse's structure, as well as for other long-life applications with chemical-resistance and anti-oxidation requirements.

Natural-fibre composites
Alongside the development of carbon-fibre-type composites, work is also in progress on the use of 'natural-fibre composites'. Much of the initial scientific work has been conducted in the car industry, which is still something of a niche market. Their application in the SpaceHouse would be for walls and secondary structures, using calculations made with 'space tools.'

Fire-proof materials
To meet future fire-proofing requirements, there might be a need to change from the currently used epoxy-based to phenolic-based resins. Various aerospace laboratories are already performing application-oriented research and this know-how could be transferred to the housing market.

Flash-over protection
Not all European countries require that protection systems of this type be installed in buildings, but where they have to be applied they pose a formidable aesthetic challenge. As a result of space-technology transfer, so-called 'Polymet' metal-covered plastics are available which can be used non-obtrusively as a flash-over suppressant. In the SpaceHouse, for example, a very thin layer of this foil would be applied to the composite.

Water recycling
Highly efficient, space-technology-derived 'reverse-osmosis' concepts are being turned into commercial products in the form of two-water-loop systems. Current sanitation regulations in Europe preclude the use of this type of recycled water for drinking purposes, but it can be used for washing machines, toilets and gardens.

Air purification
It might sound far-fetched to think of using space technologies to 'clean' the air that we breath. However, there is an EU Directive on 'Particulate Matters' that calls for not more than 40 micrograms per cubic metre of particles smaller than 10 microns in that air in order to protect us from dangerous carcinogens. There is also growing concern about the rapid spread of global epidemics due to our greatly increased mobility. The relevant expert groups are therefore preparing even more stringent requirements to counter so-called 'background dust values' that they believe are reaching excessively high levels in some European regions.

On the International Space Station (ISS), there is already a highly efficient particle filter able to trap particles as small as 100 microns. With some additional development, this space technology could also be used here on Earth.

Medical support for the elderly
With the ever-growing percentage of elderly people in European society, the medical experience acquired from, and the equipment developed for, human spaceflight is becoming more and more interesting for ground-based exploitation.

System-engineering methodologies
Last but not least, it seems appropriate to look not just at individual space technologies that can be transferred to the building and construction sector, but also at space methodologies. Space endeavours have spawned many novel system-engineering approaches that could benefit the building sector, and the construction/building engineer's role would be enhanced accordingly.

The Building Sector

Today, more than at any time before, buildings and other structures are incorporating a multitude of new technologies, materials and processes. There are several reasons for this, including:

– environmental and ecological issues
– safety aspects in view of increasing natural hazards
– attractiveness in terms of a building being a corporate ‘icon’, and
– growing pride of home owners in their properties.

There are currently about 380 million people living within the European Union (E-15), about 42% of whom are currently in work. The building and construction sector is one of the largest employers in the Union, providing some 28% of Europe’s industrial jobs (11.5 million people). Its turnover amounts to some 870 billion Euros, representing nearly 10% of GDP. By comparison, the European aerospace industry has a turnover of some 80 billion Euros, and employs approximately 450 000 people. On the other hand, it could be said that the building sector is not yet one of the most technologically ‘innovative’ sectors, although in recent times some spectacular buildings have been put up or are currently on the drawing board. The fact that ‘space habitats’ have to support life in hostile environments by relying on leading-edge technologies means that the latter can also be a valuable source of innovation for the building sector back here on Earth.

Building Design and Concepts

Architects, designers, builders, environmentalists and – last but not least – consumers have already begun to embrace new technologies in areas that promise lower energy consumption and hence lower running costs. But photovoltaic, solar-thermal or geothermal energy sources are still only rarely seen in office buildings or private houses. In terms of structures, progress has been more conspicuous, with very fashionable, modern-looking designs using steel, plastics and glass extensively to provide more natural light and more efficient heating and insulation.

With the EU having now started a serious drive towards the proposed 15% reduction in carbon-dioxide emissions, ‘green thinking’ is no longer the domain solely of the dreamer and the enthusiast. The deregulation of Europe’s energy market could also offer new opportunities to design office buildings and even individual houses in such a way that they are self-sufficient in energy or even net contributors to the energy grid.

Aside from the purely economy-related targets, there are already a number of established ‘political targets’ at European and global level:

(a) WHO Health Targets for Europe

– “By the year 2015, people in the region should live in a safer physical environment, with exposures to contaminants hazardous to health at levels not exceeding international agreed standards”. *(European Health 21, Target 10)*
– “By the year 2015, people in the region should have a greater opportunity to live in healthy physical environments at home, at school, at the workplace and in the local community”. *(European Health 21, Target 13)*

(b) Kyoto Protocol Target

– “To reduce the demand for energy by 18% by the year 2010, to contribute to meeting the EU’s commitment to combat climate change, and to improve the security of energy supply”.

(c) European Housing Ministers

– “The Ministers agree that the existing stock conditions (social housing) still require a considerable effort in order to meet sustainable quality norms, to be defined by each country...”*(Paragraph 4 of the Final Communique, Genval, Belgium, 2002).*

Space Technologies and Methodologies

When transferring space technologies to applications here on Earth, a careful look at their true innovative potential is needed to avoid the trap of ‘wishful thinking’ and to establish their true market and economic value.

Space technologies are by their very nature developed to work in extreme environments, relying on unusual combinations of materials, and to have a long intervention-free operating life. The principal design requirements for space vehicles are:

– very lightweight but nevertheless robust designs
– maintenance-free operation throughout their lifetimes, particularly as far as thermo-mechanical properties are concerned
– high degree of automation during the operational mode
– energy autonomy based, with few exceptions, on solar power only.

New Building Requirements

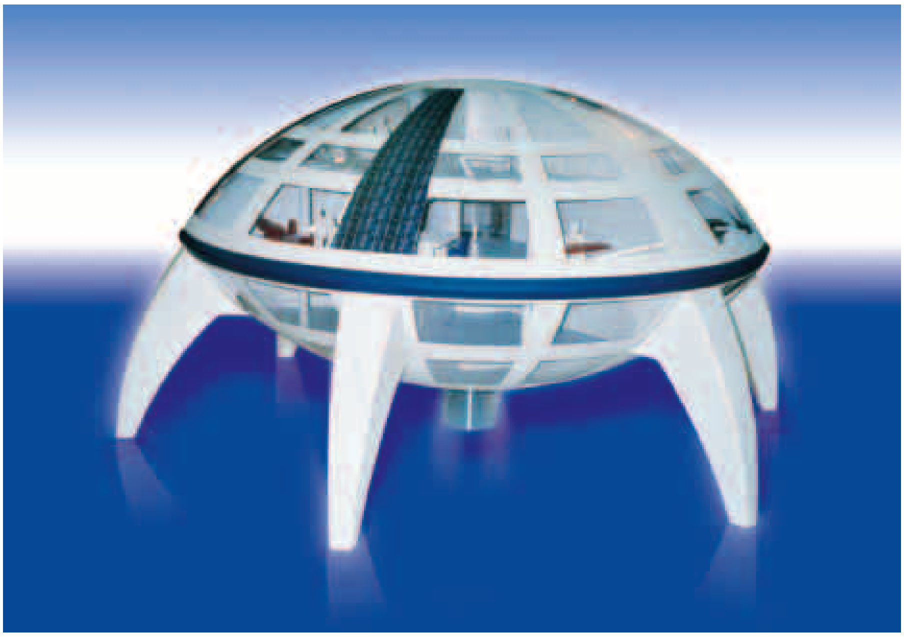
Discussions with the insurance and re-insurance sector show that they have ever greater concerns about the statistical increase in ‘extreme weather’ in recent years, coupled with the fact that more and more dwellings are being built in earthquake- and flood-prone zones. It is therefore proposed to adapt European building standards to these trends and to enable structures to cope with:

– wind speeds of up to 220 km/h (10-second gusts)
– flooding to depths of up to 3 m
– earthquakes of up to 7.5 on the Richter scale
– subsidence of 1.5 m during the lifetime of the building
– severe hail and exceptionally heavy rain, and
– for some areas of southern Europe, bush-fire resistance.

Europe stretches over 3500 km from north to south and 4000 km from east to west, and therefore experiences a high degree of climate variability, in terms of sunshine, winds, day/night duration, etc., even under normal weather conditions.

Can Space Technologies Help?

Discussions with city officials indicate that there is an urgent need to upgrade many inner-city areas to make them more attractive places in which to live and work. In addition, some city authorities would like to see new buildings constructed in such a



An early ESA SpaceHouse concept (Courtesy of HTS, D)

way that they do not 'seal the ground', and thereby avoid any further lowering of ground-water tables. A combination of today's space materials and lightweight composites would be well-suited for such applications, and would also allow striking new structural shapes. The accompanying evolution in building techniques would be comparable to the materials revolution that has overtaken the yacht and boat industry in recent years. Faster and more up-to-date city-planning methods supported by satellite remote-sensing technologies can be an indispensable aid in this respect.

Discussions with the most progressive energy providers show that they are keener than ever to use the buildings themselves as a source of energy generation. The challenge lies in deciding how to produce the storable and transportable energy and in balancing the financial and environmental returns against the start-up costs. In addition to high-efficiency, flexible and low-cost solar panels, space technologies offer a plentiful supply of design options for the exteriors and interiors of such buildings.

Discussions with demographers indicate that the current rapid increase in the number of elderly people in European society will have an enormous impact on housing needs in terms of interior design, communication requirements, and health/sanitation provisions. Here again, space-derived technologies based on the wealth of astronaut experience accumulated in these fields, with space-derived medical monitoring methods and sensors, could be made available within the building.

Discussions with water suppliers indicate that a more optimised two-quality water standard and piping system might be economically feasible in the near future. This would alleviate the stress on natural water resources to a certain extent. Water purification systems based on the return-osmosis concept developed for space application are now at the point where they can be applied in any domestic household. In such extreme and environmentally sensitive habitats as the French/Italian 'Concordia' station in Antarctica, new international environmental laws already dictate the application of such technologies.

Discussions with the health sector show not only that air conditioning might be needed on a greater scale in the future, but also that the provision of 'more healthy air' might also be a growing necessity, particularly in inner-city areas. Today such services are only provided in hospitals to cope with allergies, infections, etc. However, here again the novel space technologies developed for cleaning the air in Europe's Spacelab and subsequently on the Intenational Space Station, have a role to play.

Discussions with the tourism industry indicate that fully autonomous and re-locatable chalet-type buildings might be needed to conform with future norms in terms of sustainable development and the seasonal use of ecologically sensitive recreation areas. Space technologies of the sorts already mentioned above could be 'bundled' for this particular purpose.

Current Technology-Transfer Activities

On the basis of the various discussions outlined above, and a review of recent and expected future research and technology development activities in the space sector, efforts within the ESA Technology Transfer Programme (TTP) have been focused on three major areas of application for the available space technologies:

– safe houses/buildings with respect to the natural and human-induced environment
– healthy houses/buildings with respect to medical and mental well-being
– ecological houses/buildings with respect to sustainable energy supply, natural-resource consumption and manufacturing processes.

The 'SpaceHouse'

In the wake of the devastating earthquake in Turkey in 1999, the idea of attempting to design an 'absolutely earthquake-safe building' was born. The initial objective was to apply CFRP (Carbon-Fibre-Reinforced Plastic) composites to design a self-supporting, lightweight, shell-like structure able to withstand the forces of a Richter 8.5 earthquake. This approach would be in sharp contrast to other contemporary design solutions, which use ever more steel and concrete to withstand the induced forces.

The results of the initial feasibility studies indicated that it was a technically viable concept, but that a careful eye was needed on the cost of such a building. A 1:50 scale-model of the SpaceHouse was then built by architects from the University of Munich. It was exhibited for the first time at the

Hanover Industrial Fair in 2000, together with the flexible solar cells of Swiss origin that could provide the house's power.

The 'TranSphere'

This first engagement with the real world of the architect was based on a mutual interest in learning from each other and looking at new futuristic, but still realistic shapes. Carbon-fibre-reinforced structures gave the final concept a very 'transparent' appearance, far removed from that of any 'normal' house.

The 'Swiss Space Vitrine'

Halfway through the TranSphere activity, a new opportunity arose in the Swiss town of Yverdon-les-Bains. A large steel structure had been erected in Lake Neuenberg for the Swiss Expo 2002 fair, not far from the lake shore and in an ecologically sensitive area. This structure, known as 'The Cloud', was offered after the fair as the home for a future 'Swiss Space Vitrine', of which the existing collection of 'Maison d'Ailleurs', a world-renowned science-fiction museum in the town, would form a part. The exciting challenge was that original structure would only allow a lightweight construction to be added on top. CFRP was thus the ideal material for the 2000 square metre addition. Unfortunately, the project failed to gain sufficient public support in a local referendum.

The 'Ecospace'®

The Ecospace® initiative of TNO-Bouw (Delft, NL) is striving to 're-innovate' the building sector, as proposed within EU's 6th Framework Programme. They are exploiting the SpaceHouse approach in their attempt to foster a visible forward leap for the construction and building industry. The challenge will be to adapt the SpaceHouse concept to meet the constraints of, for example, social housing, necessitating the use of novel manufacturing methods for the composites and a cost breakthrough in terms of exploiting solar-energy sources.

The 'Innospace' initiative

The authorities in the Basque country (Departement des Landes, La Region Acquitaine) would like to establish a highly visible 'communications platform' for the region by exploiting the SpaceHouse concept. The region would like to present itself as a centre for 'high-tech' located within an environment of great natural beauty, a region in tune with the future where sustainable development can be combined with economic growth.

Requirements for human-friendly and safe enclosed spaces (Courtesy of TNO/Ecospace, NL)

The New German Antarctic Station 'Neumayer-3'

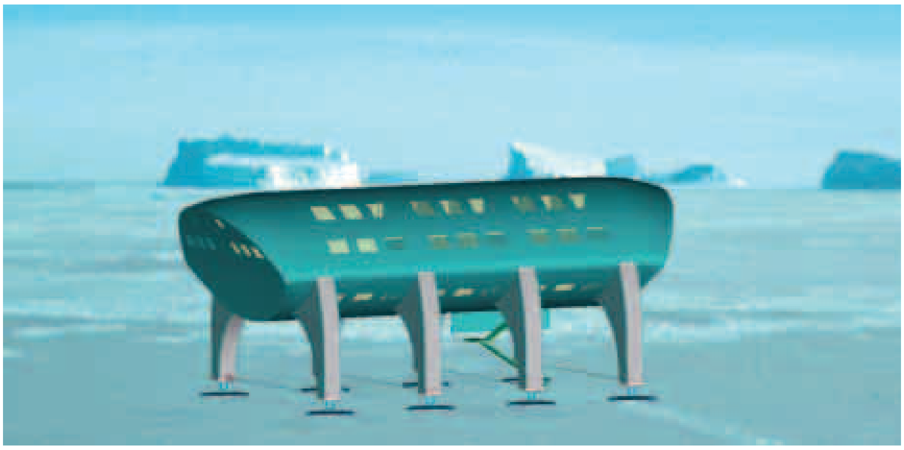
Contacts made at the Hanover Fair in 2001 have led to the ESA TTP supporting the Alfred Wegener Institute (AWI) in Bremerhaven, Germany, in the development of new station concepts. Given the more stringent environmental rules now applying to the Earth's polar regions, and the possibility of an accelerated build-up phase, AWI is assessing the merits of the SpaceHouse technologies for its future Neumayer-3 station concept.

A City Attraction: the Greifswald 'Muon Space-Weather Telescope'

Following the initial proposal for a Muon Space-Weather Telescope (MTG), financed by ESA's TTP and TRP programmes and to be developed together with the University of Greifswald, Germany, the city authorities have expressed interest in taking the next step. Concepts are therefore being developed for using the Telescope as a highly visible element in Griefswald's drive to present itself as a 'science city'. Hence, the MTG would ideally be presented in its own SpaceHouse-like habitat, alongside other science-oriented tourist attractions.

Dresden Aerospace Centre of Excellence

The Technical University of Dresden in Germany has engaged in an effort to draw its faculties together in commissioning a SpaceHouse-type building that would serve as focal point for the University and the aerospace industry of Saxony. A



Artist's impression of the Neumayer-3 Antarctic station (Courtesy of HTS, D)

working group has been formed to consolidate the various requirements and assess the suitability of several possible sites owned by the University.

The 'Safe-Eco-Space' Private Initiatives

Various expressions of interest have been received and private initiatives proposed for building one of the SpaceHouse derivatives. Currently, alternative manufacturing processes are under consideration that will on the one hand retain the novelty and flexibility in the space-technology/methodology based concept, and on the other keep costs within the financial bounds of the potential customers.

The 'Euro-District Platform'

In the context of celebrating the 40th Anniversary of the Franco-German 'Elysee Treaty' signed in 1962, the Foreign Ministers of the two countries decided to establish common innovative projects that would serve as a communication, cultural and scientific platform for the youth. Various interested partners and authorities in the Strasbourg area have put forward the SpaceHouse as one element. The site proposed is a small island in the middle of the Rhine, forming part of the community of Neuried, and it would meet the objectives admirably.

Lessons Learnt

Based on all of the above experiences and discussions, now seems an appropriate moment to begin the pioneering activity of building the first real SpaceHouse, in which to live and work and demonstrate its wider market potential. Several space-technology suppliers have indicated their willingness to provide support in terms of knowhow and hardware, and to look at the 'advanced building sector' as a potential complement to their core businesses. Europe's boat and yacht builders already have installed capacities for the economic manufacture of industrial-standard CFRP structures of the sizes that would be needed for the house's modular elements. Some of them are also prepared to enter this new niche market for an initial, limited-investment trial period.

The reaction on the part of Europe's architects has been mixed so far. Some of them feel that they would have to redefine their role in view of using new materials with characteristics with which they are not yet familiar, while others are very enthusiastic and eager to incorporate the new materials and manufacturing methods into their repertoires. The banking sector's reaction has been neutral as regards the financing of a private SpaceHouse, as long as sufficient security is provided. Last but not least, there is the reaction of the SpaceHouse enthusiast's family to be considered, who also have to be happy to live in such a dream-home. Gauging from the public's reactions at the various exhibitions, the appreciation and the vision needed to enjoy living in such a house is equally divided between the sexes.

Artist's impression of a future space colony (Courtesy of Tim White)

Outlook

Through its Technology Transfer Programme, the Agency has so far invested the resources needed to develop the initial SpaceHouse concept, prepare the technology base, provide the promotional platform, and foster contacts with potential investors. The TTP has recently added another tool to help make the SpaceHouse a reality, by exploiting the facilities of the European Space Incubator to develop the missing links needed to move towards a truly commercial undertaking.

ESA might also eventually build its own SpaceHouse, or rather 'SpaceOffice', on the ESTEC site, incorporating the latest space-derived technologies to make that office building as self-sufficient as possible. It would give the thousands of visitors to the ESTEC site each year the opportunity to witness first hand the advantages of 'bringing space technologies down to Earth'.