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Nanoplastics. A Home System

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Detailed information on the Structured Planning process used for this project can be found in papers by Prof. Charles Owen on the Institute of Design web site: www.id.iit.edu

See also the Nanoplastics presentation:
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Preface

Nanoplastics was one of two projects conducted in the Institute of Design's 1992 Systems and Systematic Design course. It considered the ultra-small through the lens of a striking new technology just beginning to make its appearance, molecular nanotechnology. The other project, **Aerotecture**, took the opposite end of the scale for its domain and considered what might be possible if an ultra-large rigid airship could be developed. Both projects were entered in international competitions, and both achieved success.

For 1993, the giant Finnish plastics company, Neste Oy, had announced the theme for its third international Forma Finlandia Design Competition to be: the "future of plastics". From the information accompanying the announcement, the theme seemed almost to mandate a deep investigation of molecular nanotechnology, a subject already selected for study by one of the fall 1992 Institute of Design planning teams.

Nanotechnology is strongly associated with carbon as a construction material because of carbon's chemistry and physical properties. The plastics industry is heavily committed to carbon chemistry because all plastics are built around it. And the processes involved in plastics production are fluid processes, much as will be the assembly processes for the products of nanotechnology. The connection seemed obvious—and the future for plastics, as far as we could see, was the future of molecular nanotechnology. The question was how would this technology affect the way people live, and a good way to investigate that was to look at what the house of the nanotechnology future might look like.

When the results of the competition were released, **Nanoplastics. A Home System**, our project, was among 70 selected for a traveling show to tour eight European countries. The competition had drawn 736 entries from 33 countries.

Surprisingly, first prize went to a fish hook remover, cleverly designed to use plastics, but hardly the future of plastics. As sometimes happens, the criteria used for judging did not very well match the goals set forth in the call for entries. The traveling show, however, gave the European public an opportunity to think about the larger issues raised by the future of plastics, and the possibilities suggested by **Nanoplastics**, the term we coined for the new materials.

The results confirmed our convictions. We soon began receiving calls from the European media, and our story went out via the press. Media in eight countries carried a number of articles on Nanoplastics and PBS (Public Broadcasting System) in the U.S. devoted a segment of its Future Quest series to elements of the Nanoplastics home. Through 1998 at least 22 articles in the U.S. and abroad reported on the project, and the Voice of America broadcast its story to many more countries.

For the team, the project was special in another way. For most team members, it framed a new kind of question. Designers work within limits and, until now, material limits have been very emphatic. Molecular nanotechnology will change that. Where do you look for guidance when materials can do whatever you ask of them? Goals of stronger, tougher, brighter, cleaner, more efficient, etc. become less relevant because they are so much more easily attainable. The source for direction inevitably turns to human and environmental concerns.

In the end, the project was probably best viewed as an opening to a new era in design thinking. Nanotechnology will force us to clarify our values, goals and philosophy as the foundation for building and using design knowledge.

Charles L. Owen, 2004

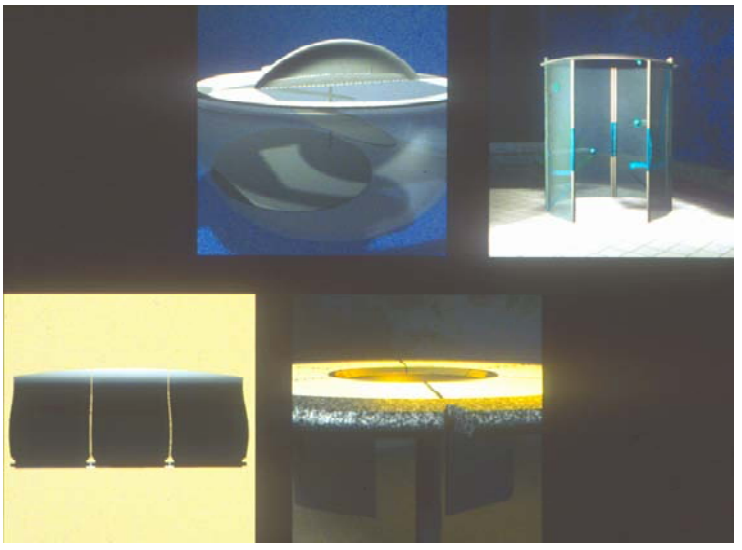

Figure 1 **Nanoplastics**
Nanotechnology, through processes of atom-by-atom construction, presents a promise of materials and intelligent products able to change form and behavior to respond to human and environmental needs.

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Introduction

As a product, the home boasts a history of 12,000 years. While the technology used to construct it has changed drastically, its functions remain basically unchanged. The modern home still meets basic needs as shelter, protection, a place to prepare food, a place to rest and a place to raise children. In recent years, it has also extended its roles as a center for entertainment, a workplace and a place for education. But, in essence, its many roles in support of human activities have not changed—over millennia. Technology has not replaced activities in the home; *technology has found ever more sophisticated ways to assist.*

The products used in the home today are current manifestations of the human capacity for tool making and communicating—processes evolved over two million years. The significance of tomorrow's products is that they will be qualitatively different. An exponential growth in technology over the last 200 years has brought us to a stage now where tools and communications need no longer be constructed as independent, monofunctional extensions of human action. A systems approach to the design of products, a radically new technology that actively implements systems' thinking, and unprecedented materials that can incorporate the new technology, will make possible products for tomorrow that are manifoldly more powerful and flexible through interconnection and interdependence. The home is the perfect environment to explore the new relationships to be expected among technology, materials, products and users.

Plastics are truly the materials of tomorrow. But in that tomorrow, what will plastics be? In leading research institutions across the developed world, a revolutionary new technology is under intense development: molecular nanotechnology. In nanotechnology, materials science, biology, chemistry, computer science and functional technologies meet at the nanometer scale, and products are literally built from individual atoms. This radical

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new technology dramatically changes the way materials and products will be produced. It also mandates sweeping rethinking of how products will be designed and used. The ability for materials and products to intelligently alter form, texture, color, and myriad other characteristics only hints at what nanotechnology portends.

Nanotechnology most certainly is the future of the plastics industry, and ***Nanoplastics*** present revolutionary possibilities for product design. This project explores a new conceptual landscape, one in which the home of tomorrow is a system of truly intelligent, adaptive, self-organizing products.

Molecular Nanotechnology

The new technology will be revolutionary in scope and effect. Nanoplastic materials and the products manufactured using them will have extraordinary properties: prodigious computational power, abilities to sense and react to surroundings, capacities for changing function, form and visual characteristics, and capabilities for virtually any other adaptation. The incredible compressions of function made possible by nanometer-scaled structures and machines open this new world of possibilities. At nanometer scale (one billionth of a meter), all the information in the world's libraries can be stored in a device the size of a credit card. One of today's super computers could be built in a cube no more than five microns on a side—a mote the size of a human blood cell, too small to see without a microscope. Nanoplastic materials (and products) will be literally infused with billions of molecular machines and computers like this, interconnected and capable of changing their surroundings according to the desire of the user within the intent of the designer.

From its inception, nanotechnology has meant a fundamental rethinking of how materials are structured. Richard Feynman, Nobel Laureate physicist, first suggested in 1959 that substances could be synthesized from the bottom up, atom by atom. In 1981 the first scientific paper on molecular nanotechnology was published by K. Eric Drexler. Soon after, work in the field was rapidly accelerated by the development of the scanning tunneling electron microscope (STM); it allowed researchers to see and move individual atoms for the first time. Since then, rapid developments have occurred in the field, principally in the U.S., but also in Japan and in Europe. In the U.S., the national Institute for Molecular Manufacturing has been created and a number of companies (such as I.B.M. and Xerox), research institutions and universities have established research programs. Japan's Ministry of International Trade and Industry (MITI) has identified control technologies for the precision arrangement of molecules as a basic industrial technology for the twenty-first century.

The goal of nanotechnology is the precision arrangement of atoms. Using atoms as building blocks, perfect mechanical structures can be created: struts, bearings, gears, shafts, motors and a host of other analogs to macro-world devices. The ideal element for the construction of these structures is carbon because of its atomic bond strength. Machines built from these nano-scaled parts will be fully functional, multi-component mechanisms. But these molecular-sized pieces of equipment are only part of the intended nanotechnology inventory. Very sophisticated machines and systems will be constructed to provide materials with amazing computing power and physical capabilities. Mechanical computers the size of a blood cell will have enormous processing power. Sensors and emitters will be constructed to absorb and transmit pressure, sound, and nearly the entire electromagnetic spectrum. These will provide materials with the ability to sense their surroundings, and to respond with physical change or the transmission of sound, light, heat or other emissions.

Nanomachines will likely be part mechanical, part sensory and part computational. Materials will be created by assembling masses of sophisticated nanomachines. One cubic centimeter of Nanoplastic completely filled with nanomachines 10 microns on a side would contain one billion nanomachines. The sensing and actuating capabilities of the nanomachines will allow them to communicate, permitting distributed computational power. The mechanical capabilities of the nanomachines will allow them to connect and hold on to each other, forming a lattice structure (and, therefore, a solid), or to move past each other with appropriate energies to behave like a liquid or even a gas. By varying their behavior among these paradigms, they will enable Nanoplastics to take on the properties of almost any known material.

Nanoplastics will be produced from basic nanomachine parts assembled by "nanoassemblers" operating under instruction from "nanocomputers". Just as factories operate hierarchically in the world at human scale, nanofactories will organize and automate production at the nanometer scale. Designs for basic elements of this production technology already exist, and research institutions are scrambling to build and test prototypes. *In the fall of 1992, ten years ahead of most predictions, the development of the first nano-scale logic gate was announced in the U.S. by researchers at Los Alamos Laboratories.*

Product Design

Mass production is headed the way of mass marketing and mass communication. Flexible manufacturing, niche marketing and narrowcasting (vs. broadcasting) exemplify the incontrovertible trend toward production to satisfy individual needs. Whether the targets are actually individuals or identifiable groups with similar needs, it is apparent that a real movement exists in a wide range of industries to create products that better suit specific users. Technology, at last, is making it possible for designers to design for the individual.

The ideal product is one that possesses a range of capabilities that exceeds the needs of its user, but at any time is perfectly matched to the user's wishes. When the production, material and "intelligence" constraints of today's technology are lifted, products will be designed to learn their users' actions, habits and patterns of use. The ultimate product anticipates its user's purpose, adapting to conditions, needs and desires as they occur, and gracefully implementing its user's intentions.

In a world with this technological sophistication—the world Nanoplastics will shape—designers will no longer design one-of-a-kind products for mass replication. They will compose the rules under which classes of adaptive products will be created. A design will encompass a multitude of configurations, defining limits and variabilities and dealing with how a product can adapt in appearance, function and relationships with its human users and system mates. In any specific situation, the user will control the product, but always within the range of actions and adaptations established by the designer.

System Overview

Designing products as a system rather than as independent devices significantly increases the capabilities and flexibility of the products. The user reaps the benefits and is further empowered by the sophistication that the system possesses. The potential for interconnected products is especially great in the home, where the interaction between user and machine can be both personal and adaptive.

Nanoplastic products inherently possess "intelligence", enabling them to communicate with their users and with each other. The ability to adapt to user

and environmental needs creates an opportunity for products that "know" how to respond under varying conditions. This real plasticity leads to symbiotic associations among products, which can act as a true distributed network, further improving the system's responsiveness.

In the context of this potential, all activities in the home have been re-examined for opportunities where Nanoplastics can significantly improve the quality of life. The conclusion is clear: virtually all of home living will be affected positively by Nanoplastics. The Home System discussed here addresses a sample of the diverse range of activities that make up home living.

In this Home System, Nanoplastic products share features and work together to fulfill complex system functions. All devices are served by a common infrastructure that links them into a network, controlled along with individual products through a palette of interface options which include voice, graphic, video, holographic and gestural communications.

While complementing the operation of other products, each product also plays a specific role in the system. As an example, the Entrée Prep processors in the kitchen environment can be used as multi-functional, hand-held devices for food preparation. They also operate as part of the Chef's Assistant cooking system, taking on some of the food processing activities during meal preparation. Nanoplastic furniture takes on the form appropriate to the activity: a task chair in the Explore Room, a reading chair in the living room.

Nanoplastics make possible novel energy sources for the home. Beyond the improved efficiency Nanoplastics bring to solar energy production, Nanoplastic products can make use of other forms of energy, even sound and motion. The Companion, as an example, is partially powered by transforming the inertial energy created when it is carried. Extremely high efficiency is characteristic of all Nanoplastic products, benefiting the environment through dramatically reduced energy consumption and pollution.

The Home System products presented here display the range of possibilities that can be anticipated as nanotechnology changes forever the nature of man-made materials and their service to humankind and environment. The potential gain is truly awesome.

Maintenance

Nanoplastics have little need for maintenance as long as they have access to energy. The materials and devices of our world today require maintenance because they degrade. Materials react with their environment; dislocating crystal lattice structures in the case of metals; breaking down chemical compounds and polymer structures in the case of plastics. Mechanical parts wear from friction; electrical components lose conductive and insulative properties—all suffer because the materials they are made of degrade. Because of material degradation, it is necessary to specify expected lifetimes for products and to conduct periodic maintenance.

In the Nanoplastics Home System, materials do not require conventional maintenance for the wearing of moving parts. Moving parts in most cases are replaced or supplemented with more efficient machines at a micrometer scale. These small machines are composed of mechanical parts that are frictionless and many times stronger than steel.

Nanotechnology does, however, suffer from wear and failure: chemical transformation failure. Changes at the atomic level can result in failure of a nanomachine, analogous to a gear losing a tooth and halting a machine's movement. There are two remedies for this kind of degradation: redundancy and self diagnosis.

Because of the size of nanomachines (5 to 10 microns), redundancy of machines is inherent in all Nanoplastic materials. Products usable at human scale incorporate billions of nanomachines. Each of these machines has considerable computing power, and they are interconnected throughout the material. When any fail, there is measurable effect on the product's operation.

Self diagnosis occurs at two levels in a Nanoplastics system. At the product level, each product conducts its own diagnoses, checking for structural failures at the atomic scale and monitoring its own operations. Each product also reports to the System Custodian (a system element of the Nanoplastics home). If a problem has been detected, the product reports immediately, otherwise it stores a report on a routine basis for future review. The Custodian periodically conducts a survey of the operational status of all products in the Home System. This provides the system-wide diagnosis that the Custodian needs for both its own analyses and reports to its users. With this level of surveillance, the likelihood of product failure is extremely low. Maintenance can evolve from macro-scaled cleaning, lubrication, repairs and replacements to new kinds of nano-scaled tasks—reorganizing functions around deficient components to new units in the "network" of nanomachines, repairing nanomachines with "nanorepair" machines (much like cells will be repaired in the human body)—and updating.

Updating

Updating computer hardware and software—and even some more traditional products—is a serious problem today. The pace of new product releases and upgrades to old products is rapid and continues to quicken. Considerable effort must be put forward to understand the range of options available at any time in any product category. It is said that the only "expert" is someone who has just made a purchase.

The nature of nanotechnology suggests that much similarity will exist between development rates for Nanoplastic products and today's computer software and hardware. Computer periodicals now print monthly information about current releases of software to enable computer owners to keep abreast of rapid improvements. The consumer electronics industry is fast approaching the need for similar information dissemination. All efforts, however, require the purchaser to gather information widely and to begin anew periodically, whenever a purchase is being considered. This is a model from the past, neither desirable nor acceptable in the Nanoplastics home.

The problem of "repairing" and updating products in the Nanoplastics home requires a new method of sales and service: subscription. "Subscribing" attains new meaning in this context. As long as a subscription continues, a Nanoplastics product is upgraded automatically. Updates to information and control systems are provided on-line from the supplier through the home's connections to the world information network. Updates and replacements for materials (nanomachines) are provided through service calls instigated by demand of the Custodian or initiation of the supplier. The user buys the function or services of the product rather than the product itself, creating the climate for a long-term relationship based on product integrity and customer satisfaction.

Installation

When home products are purchased today, one of two courses of action is followed. For most products, such as a VCR, the customer simply places the product where it is appropriate, connects it to other products (a television set in this example), and begins using it. For other products, such as a dishwasher, installation is more complicated, requiring experienced help. Before the product can be used, an expert, typically a tradesman or company representative, must come to the home to complete the installation properly.

Nanotechnology makes it possible to incorporate installation procedures within the product itself. Most Nanoplastic products can establish their own connections with the home's utility and control infrastructure. Products that cannot are able to instruct the user and home control system as to how installation should be accomplished, interactively assisting, step by step through the process.

As part of installations that extend the home's infrastructure (for example, when an extension to the size of the home is involved), nanotechnology makes it possible for the homeowner to add to the utility and control system without the need for tools or professional assistance. Floors and walls are constructed from special Architiles (see Infrastructure) that adhere and seal to each other automatically. Within them, utility and control channels line up and join as the tiles are connected. Interactive graphic instructions on the surface of each tile instruct the user on connection procedures, then disappear when installation is complete.

Communication

Conveying messages between people or between people and their machines involves increasingly complex systems for retrieving, sorting, transforming, and sending massive amounts of information. In addition, the networks in which we convey messages—between two people in one home, between two or more homes, between home, workplace and space station—are becoming increasingly flexible and, therefore, more complicated. If we add to this the possibility that future communications will be composed not only of text, voice and image, but also of tactile information maps, olfactory and taste quanta, we can imagine an almost unbounded system of discourse.

Nanocomputers will be capable of processing these vast arrays of previously unimagined forms of information in a way which is both expedient and transparent to the user. Invisible to people in the home, the Nanoplastics communication system is composed of Gatekeepers, Butlers, Custodians and Advocates which contain the encoded rules by which a discourse may proceed. Users are free to customize their own system preferences as they choose, selecting to receive messages visually rather than verbally, for example, or using face-to-face contact as the primary mode of discourse.

Feeding into the communication system is every nanotechnology-based product as well as all communication interfaces—flexible screens, voice processors, notepads, touch surfaces and tiles of the infrastructure. In effect, the communication system acts as the home's central nervous system, coordinating messages between people, their machines, and the outside.

Storage

Storage—there's rarely enough of it; and when there is, we tend to lose track of things in it. We like to store items we use constantly as well as things we can't bear to throw away. Contemporary houses have no such low-priority space for long-term storage. When units are added to the home to supplement existing storage space, the cost is a reduced living environment.

A good system should provide space-efficient, easily accessed storage that is protective of its contents. The system should also be safe, dimensionally coordinated, and should recognize its contents. Four general concepts can accommodate these needs:

- flexible storage units that provide access to otherwise unusable space;
- conformability for matching patterns of access to individual users;
- computer control for maintaining inventory information and reducing retrieval time;

• environmental control for protecting stored items and preventing their deterioration.

Nanoplastic storage products offer revolutionary improvements in each of these areas because of their computing capabilities their ability to transform.

• Adaptive materials permit adjustable container volumes, using only the amount of space necessary for stowed items.

• Smart materials recognize both user identity and storage contents, controlling and aiding access to stored items in a timely fashion.

• An interface with the home's Information System allows users to quickly access needed items.

• An active system "files" contents in the most efficient scheme and retrieves or stows contents automatically.

• Flexible, active Nanoplastic materials control environmental conditions for food.

Recycling

One the greatest barriers to wide-scale recycling is the complexity of material handling required of the individual in the home and of the industrial infrastructure outside the home. For the person at home, the problem of separating materials correctly is an unwanted burden. For industry, having to collect and transport uncompacted, whole containers is problematic. The importance of recycling, nevertheless, demands that we solve these problems.

In the nanotechnology age, recycling for the user is no more difficult than throwing away garbage. The recycling system of the home separates the garbage into material categories after examining each item for possible erroneous disposal. Having separated the waste, each segment is reduced to microgranules in a method appropriate to the material. Nanomachines do the work. Their ability to recognize material at the molecular and atomic scales makes them ideal for separating multi-material objects. When a Nanoplastic product is disposed of, the item is separated from all other materials. Disassemblers break down the object into its fundamental nanomachine parts, and distribute them into handling containers. Other materials are treated similarly. Dangerous substances are either disassembled to no-longer-dangerous elements or compounds or they are encapsulated in Nanoplastic containers that will render the material safe for handling (chemically or physically active elements). All handling containers are collected by an outside agency for industrial processing and reuse.

Infrastructure

The infrastructure (utility supply, transfer and control systems) in any house is highly instrumental in determining how people live. Living patterns are constrained by the capabilities of products. Products, in turn, rely on the home's infrastructure, and can only operate within the limits of what the infrastructure provides. The infrastructure, as a designed element of the Home System is, therefore, one of the most important products in the system. Infrastructural designs today are based on fixed installation concepts. Rarely are infrastructural systems flexible in terms of either structure or use. Great potential exists for a design that can change its configuration to meet changing needs of products and the patterns of their use.

Flexibility is created in a Nanoplastics infrastructure by eliminating the need for dedicated ports of access. A system that can be accessed at any location for any purpose allows its users to determine where and how products are to be located. Self rerouting then enables paths of the network to be reconfigured when products are moved or new products are added. Flexibility is further enhanced by improving the interdependence of products and infrastructure, in effect, creating a

symbiosis. In this case, a product is designed to take advantage of special functional capabilities of the infrastructure, and the infrastructure is given additional sensitivity to the needs of the product.

A difficult challenge to any system of infrastructure is retrofitting, combining elements of a new system with elements of an old system expected to continue in use. Because the Nanoplastics system of products is intended to be retrofitted into older homes as well as homes built anew with nanotechnology materials, it must accommodate different levels of implementation. A small retrofitted system might include and support only three kitchen products. An extensive system could create an entirely new system of infrastructure and products within the framework of a reconditioned house. To meet such a wide range of specification, the infrastructure must be capable of installation with minimal structural modification. Minimal user effort is also desirable.

Nanotechnology enables the Nanoplastics infrastructure to meet these challenges. A house can be considered to be a connected set of environments. Individual environments can be left intact, modified within their own bounds or allowed to participate partially or fully with other environments served by the new infrastructure. Bringing the infrastructure to any environment involves only the extension of its Architile system to portions of walls, floors or ceilings.

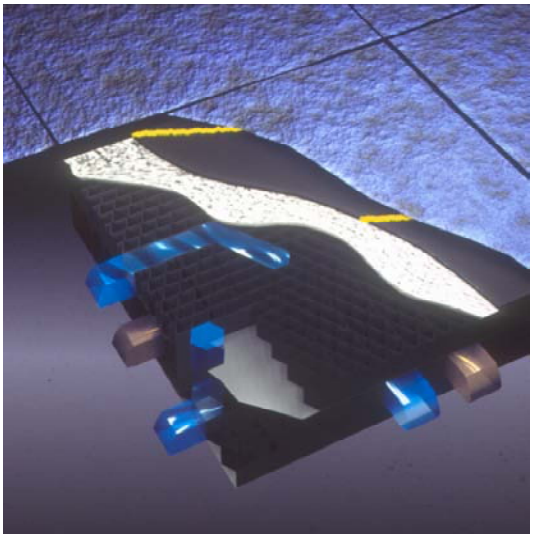

Figure 2 **Architile**
Architiles, at once surface elements and distribution channels for utilities, are fundamental components of the Home System infrastructure.

Architiles

A system of modular, interconnectable Architiles is central to the Home System's Nanoplastic infrastructure concept. Some Architiles distribute power, water and other utilities and maintain the networks of communication and control. Others serve specialized functions such as those needed for sensing, display, communication, sound control, environmental modification and water filtration. Acting together, they invisibly supply energy, information and material where it is needed among the system of products.

Architiles join together to create the physical paths of infrastructure in a Nanoplastics home. Attached to one another, they form floors, walls and ceilings that can serve dual roles as infrastructural and environmental elements. Within them travel the power, communications, fluids and materials necessary to operate the home. Each Architile contains a series of layers: a layer for power supply, a computer layer for communication and control, and a layered core of honeycomb structures that provides both thickness and pathways for the transfer of materials. A layer at the base of each tile acts as a leveling structure to fit the tile to uneven substrates. Covering the Architile on one or both sides is a "skin" face that varies in function with the tile's use. Architiles used in walls or ceilings connect their infrastructure with floor tiles when they are in fixed position; walls may be moved and may be deformed into curved patterns.

The innermost honeycomb core of all Architiles can be one of two types: transport or filtration. Transport Architiles are the primary form used throughout the home. These tiles have three layers of Nanoplastic honeycomb, each separated by a plane of Nanoplastic. Surfaces within the layers are frictionless, reducing to absolute minimums the head pressures required to move liquids. The layers can be adaptively reconstructed to form pipeways by designating the route to be taken on the surface of the tiles. The route is recognized by the

Architiles, and interfering honeycomb walls along the path are appropriately reintegrated into the Nanoplastic material to create a smooth pipeline from designated point to point. If, for example, water were to be piped from the kitchen to a table in the living room, the desired path might be drawn on Architiles in the floor. If another "pipeway" already crossed the path, the appropriate tile would detour the new pipeway below or above it. If the table were moved, a new route would be determined, and the pipeway would follow it.

Filtration Architiles pass water through active filters in their honeycomb structure. Filtered water is fed into adjacent Transport Architiles for return to use. Waste material is transported to the disposal system, also by Transport tiles. In this way, little water is consumed by the home, significantly increasing the efficiency of water use.

The "skin" facing on each Architile is specialized by function. The user determines the infrastructure's capabilities by specifying the skin types of its Architiles.

- Wall Skin. Creates wall colors and patterns.
- Floor Skin. Creates floor colors and patterns (with greater durability).
- Wall Modification Skin. Provides a control position for changing wall function, moving and deforming walls.
- System Interface and Communication Skins. Provide a general purpose system control interface and a communication site for internal communications and communications to the external world.
- Sensing Skin. Senses acoustic, thermal and visual information for the system.
- Sound Absorbing Skin. Adaptively adjusts to absorb extraneous ambient noise.

When a wall is assembled, the user chooses which facing skins will be used and how they will be arranged. Some general guidelines apply. In a wall comprised primarily of standard surface Architiles, one of the tiles should be a Wall Modification Tile to allow reshaping of the wall. A System Interface Tile should be included in the wall to provide access to the home control system. Sound Absorbing Tiles can be placed at various locations on the wall to selectively reduce noise levels. A Communication Tile placed in the wall will enable video communication inside the home and outside through the general communication network. Choices once made, however, are not irrevocable. Any Architile facing skin can be peeled off and switched with a face from any other tile.

Architiles are installed simply by placing them edge to edge. The user's job of connecting and arranging them is made easier by intelligent assistance from the tiles themselves through dynamic interactive surface graphics. Tiles remain free to move until they are locked in place by the user's action at the surface interface. Once locked, the Architiles' intermediate layers bond together at the edges, forming uninterrupted layers across the wall, ceiling or floor structure. Facing skins on each tile meld with faces of neighboring tiles, erasing seam lines and creating a continuous surface.

The most important feature of the Architiles is their accessibility. Any Nanoplastic product can obtain access to the intermediate layers of an Architile. When the product is placed in contact with the tile, the contacting surface of the product emits a signal detectable by the computer layer of the tile. The Architile's surface layer then opens to reveal the power layer; the power layer opens to reveal the communications layer, and so on until the layer requiring connection is reached and a joint between product and tile is grown.

Sensing. A house given the interactive qualities implicit in Nanoplastics needs extensive sensory capabilities—multiple means for users to interact actively with system elements, and multiple ways for the system to sense its users and environment.

Sensing, however, can be a very intrusive activity, especially in the assumed privacy of the home. The sensing system, therefore, must be designed keeping in mind the psychological influence its presence has on the inhabitants. Conflicting with this is the need for the system to constantly monitor the sights and sound of the home in order to be able to respond appropriately to any situation.

The solution to the dilemma takes two forms. First, the user is given ultimate control at all times. At the expense of losing many system functions, a user can turn off any of the sensing devices. Control extends also to the storage of information. Information that the system can associate with an individual is stored with the individual's identifying code, for external retrieval only by the individual.

A second solution involves the resolution of monitoring systems. Monitoring operates at two levels. In low resolution, the system can identify individuals, their locations, and their motions, but does not record this information and does not monitor conversation. In high resolution, the system expects a high degree of active interaction and is much more sensitive—seeking out with greater accuracy (and in greater detail) all the information monitored in low resolution mode and, in addition, information that might lead to requests to be answered. In this mode, the system also monitors conversation for verbal commands and motions for associated gestures. A "chameleon" graphic symbol on Sensing Tiles supplies a visual cue to the monitoring status: visible in high resolution, invisible (wall color) in low resolution.

Figure 3 **Living**
Nanoplastic products and system elements work together to support personal needs and interaction through adaptation to environmental conditions and social situations.

Living

The shared living spaces in a home each have multiple roles that place different requirements on the space and the products it contains. Living environments act as social interaction spaces for the family. They provide an area for entertaining guests. They are often a center for entertainment, especially media entertainment. Living spaces are also used by individuals who want to do their own thing, but in the company of others. Each of these activities carries with it a set of needs for how the environment should be formed and used, ranging from open seating spaces to semi-private activity areas. The needs for products for each activity are also very different. Social interaction has little concern for products other than those that enhance interaction. Passive relaxation may rely heavily on media products, and other activities require their own special products.

Nanoplastics offer a chance to create living spaces that can be transformed for new uses by the user or by the system. The Architile system allows inhabitants to change their space by moving or reshaping walls and reinstalling products wherever they should be most appropriately placed. Products can be temporarily relocated into the living spaces from other environments, creating an opportunity for people to share more activities.

Scenario

To set the mood for your exquisitely prepared Japanese dinner, you request the Window to offer an expansive view of the Japanese countryside in springtime when the cherry trees are in blossom. The Window adds to the view a gentle breeze which conveys a delicate fragrance from the trees. During the final stages of your meal preparation, the Dining Table begins to lower and adapt itself for Japanese-style seating. You touch a Wall Modification Tile and, when its graphic commands appear, use them to move one of the wall partitions to partially encircle the Table, affording you and your guest a cozy eating area by the Window. During the meal, the Dining Table keeps each dish at its proper temperature, allowing you to eat at your own pace while the food maintains its just-out-of-the-kitchen condition.

Windows

Windows constructed of glass are selective barriers, blocking the passage of physical material, while allowing light to pass. Nanoplastic Windows, powered by the absorption of light and sound, change the selectivity of the barrier by allowing air as well as light to pass through freely, while stopping liquids and solids. Breezes can be permitted to flow unrestrictedly into the home, or the Windows can block air flow entirely when the weather is too hot, cold or inclement. Air passing through pores in the Nanoplastic material of the Window is monitored by Airsensors located on the outdoor edges of the pores. When an unwanted particle is detected, the pore is closed at the indoor surface, trapping the particle until it can be transported back to the outdoor surface and released.

The nanomachines in the Window can also selectively reflect, absorb and transmit light, a useful capability on a hot summer day. Derived from this is a unique feature: Windows can act as one-way, privacy-ensuring screens. By absorbing light on both indoor and outdoor surfaces, but emitting only the outdoor light on the inside, the Window appears transparent to anyone in the home, but opaque to an observer on the outside. The effect of viewing a distant landscape can be achieved in a similar way by emitting from the inside a transmitted image from a remote camera. This is used in the large "window" in the AquaRoom—a private space with a very open feeling.

Sensors

One of the kinds of facing skins that cover Architiles is the Sensing Skin. This skin creates a Sensing Tile, able to supply the system with a wide range of sensory inputs. Sensors in the skin are of two types:

- Biosensors. These sensors emulate biological processes, using nanocomputing capabilities to "feel" radiant heat, detect motion, recognize gestures, identify people and learn visual patterns.
- Wavesensors. Sensors of this kind incorporate detectors that use physical principles to monitor ambient sound, light and other electromagnetic radiation.

PressurePoints

PressurePoints are sensory areas that can be incorporated in any Nanoplastic product. These areas contain networks of nanomachines that communicate their relative displacement in order to determine when pressure has been applied. Because of the size of the individual nanomachines, the level of detail in the pressure map that a PressurePoint sensory area can record is very fine. From this map, fingerprints can easily be identified (they look like cities to nano-scale sensors). The amount of pressure applied is also registered. Changes in pressure can be interpreted as control information, allowing a Nanoplastic surface to be deformed progressively under the touch control of a user.

AirSensors

AirSensors are sensing areas incorporated in the filters of the air transfer system. These embedded sensors detect particles in the air ranging in size from individual gas atoms to pollen, smoke and dust. AirSensors communicate the quality of the air to the system, which controls air purification processes in both filters and windows.

LuminAir

LuminAir is a modular room lighting system that creates multiple direct and indirect lighting sources. System elements are comprised of a tubular housing containing a light generator, a primary morphing reflector, and the large secondary reflector, both constructed of Nanoplastic sheet material. Light from the shielded generator is reflected to the room from the primary reflector, which can shape its form to redirect the light as direct or indirect lighting. The secondary reflector adjusts the character of the light, adding color and diffusion as desired. Its ability to change form is limited to a series of curved surfaces that are also visually graceful, requiring the majority of the light modification occur in the less obtrusive, smaller, primary reflector.

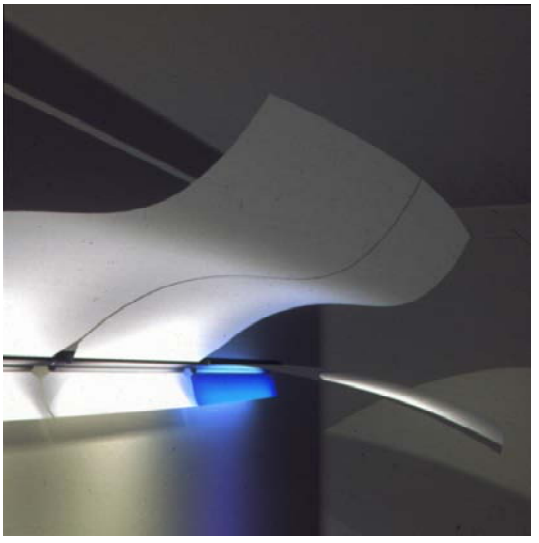

Figure 4 **LuminAir Light Fixture**
LuminAir lighting elements adjust the quality of light and put it where it is needed in form, color and intensity.

LuminAir modules can be placed side by side in an installation, and are linked to solar collectors and the power layer of the infrastructural tiles. Lighting is controlled through the system interface by voice, Companion, Tablet or hand gestures.

The system has unique interactive features, among them the ability to track an object, such as a book in the hands of a reader. Using thermal mapping information from the sensing system, the lights can also compensate for locally low temperatures by heating affected areas with low frequency light waves in the infra-red range. For aesthetic variation, the system can simulate sunlight filtered through trees, clouds passing overhead, or the quality of the current light outside the home.

Figure 5 **Dining Table**
The Dining Table adjusts its height, form and visual characteristics to suit diners and the dining occasion. Heating, cooling, power and water supply are available on its surface where they are needed.

Dining Table

The design of the traditional dining table only nominally respects the complexity of dining. Both procedural and social aspects deserve more attention to improve the dining experience.

Exploiting the capabilities of Nanoplastics, the home's Dining Table supports both. By verbal command, the Table's surface can be raised and lowered to simplify table setting and seating the diners. The Table can be expanded in size, increasing or decreasing seating capacity or accommodating meals with more elaborate table settings. When serving containers are placed on the Table, the surface can heat or cool a container as necessary to maintain temperature. Heating and cooling occur only under containers, because Nanoplastics can control heat conduction. When a Foodware Container is placed on the Table's surface, the Table supplies power for the bowl. The Table is connected to the floor's Architiles, enabling it also to provide water or other beverages directly from a dispenser placed on the Table and connected through it to the tile supply source.

Chairs

Improving the functionality and comfort of seating is an ideal application for Nanoplastics. Taking advantage of the ability of Nanoplastics to change flexibility and elasticity, many kinds of seating surfaces can be created using very thin "sheet" surfaces to conform to different chair archetypes. Varieties of pattern and/or texture can also be created as decoration, allowing an owner to select from a palette of style alternatives created by the Chair's designer. Chair form as well as style can be altered freely within this range.

For those who need it, a Chair can assist in the processes of sitting or standing. Because thermal comfort levels differ significantly for many, particularly the young and the old, a Chair can also warm or cool as desired. Chairs remember the preferences of the home's inhabitants through the mediation of their Advocates.

Single Chairs can serve multiple purposes because of their ability to change form. Major changes in form cannot be quickly performed, however, because of limitations in the rate at which Nanoplastics can reform large amounts of material. If a reclining Chair is to become a task Chair, the change may take some time. Variability at this scale can only be used to satisfy changes in seating foreseen well enough in advance of their need to allow for the time required to change.

Figure 6 **Chair**
Chairs adapt in size and shape to fit users and uses. Forms can vary dramatically from working applications to social settings.

Advocate Band

The Advocate Band is a small information storage device that contains personally chosen user data. It is sized to be discreetly worn on clothing, but it can also change form to become another piece of jewelry, for example, a bracelet, pin or ring—or even a clip that can be worn on a watch strap. The Advocate provides a means for users to carry with them personal information as well as information for preferences, choices and initialization values for nanotechnology products (chairs, for instance). This allows products in environments other than the home to be able to configure themselves to the user.

The information contained in the Advocate is accessible audibly (for editing) through a voice-recognition interface, or indirectly through other products. For instance, by attaching the Advocate to the surface of a Tablet, its information can be transferred and displayed in a variety of visual formats.

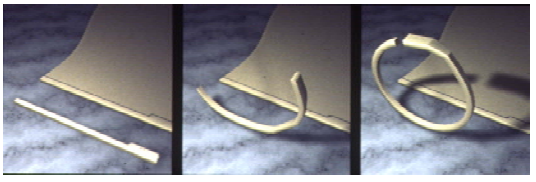

Figure 7 **Advocate Band**
The Advocate Band is a wearable personal identification source and portable memory supplement able to take a form appropriate to its owner's dress.

Because of the information compression possible with nanotechnology, the storage capacity of the Advocate is very large, even though it is itself quite small. Since its size is conditioned more by human scale considerations than the need for memory capacity, its considerable extra capacity is available as a portable storage medium for images, sound, text and other data. The Advocate derives its energy from environmentally absorbed light, sound and heat.

Companion

The role of the Companion is one of assistance. It is a powerful personal computing and communications device that is also used for information collection and retrieval. On its face is a display screen and a sound sensor. The user can interact with the Companion audibly or through the screen, which accepts hand-written input. On the back of the Companion is a sampling surface that can record sound as well as two-dimensional and three-dimensional images. Storage capacity is enormous by current standards. Nanotechnology makes possible information storage in a space the size of the Companion that exceeds the contents of all libraries in the world. Without half trying, hundreds of thousands of hours of video can be stored—or millions of hours of stereo sound—or billions of still images.

Companions are given to children at the age when they are beginning to explore their surroundings and are developing a sense of ownership. Through neural network processing, a Companion develops with a child, expanding its knowledge and capabilities in parallel with the child's growth and understanding.

Tablet

When the physical size constraints of the Companion limit its usefulness (too small), the user can switch to a Tablet. The Tablet improves functional capability over the Companion through additional tools and increased surface dimensions. It is designed for expanded uses. Whereas the Companion is a personal device, the Tablet extends its user's capabilities to group interaction, even supporting multiple members of the group. For example, in a situation in which all group members do not have a Tablet, layers can be "peeled" off the face of a single Tablet. Because of the distributed processing characteristics of Nanoplastics, each peeled layer becomes a functioning Tablet. Within the reasonable limit of a small group, the Tablet can be repeatedly subdivided without significant loss of function.

Figure 8 **Companion and Tablet**
A Companion is a high-powered personalized computer and communication device. The Tablet extends its powers to larger surfaces and group interaction.

Along with the graphic and video communications received and transmitted electronically by the Tablet, the communication possibilities among users and Tablets include voice and handwriting. Because of the increase in surface area of the Tablet over the Companion, handwriting can be used more effectively as an input medium. This capability, accordingly, is significantly more exploited in the Tablet's use, especially in group work applications. A stylus adheres to the edge of the Tablet, removable only when touched. When folded, (as it is for storage) the Tablet's folded edge also acts as a scanning surface.

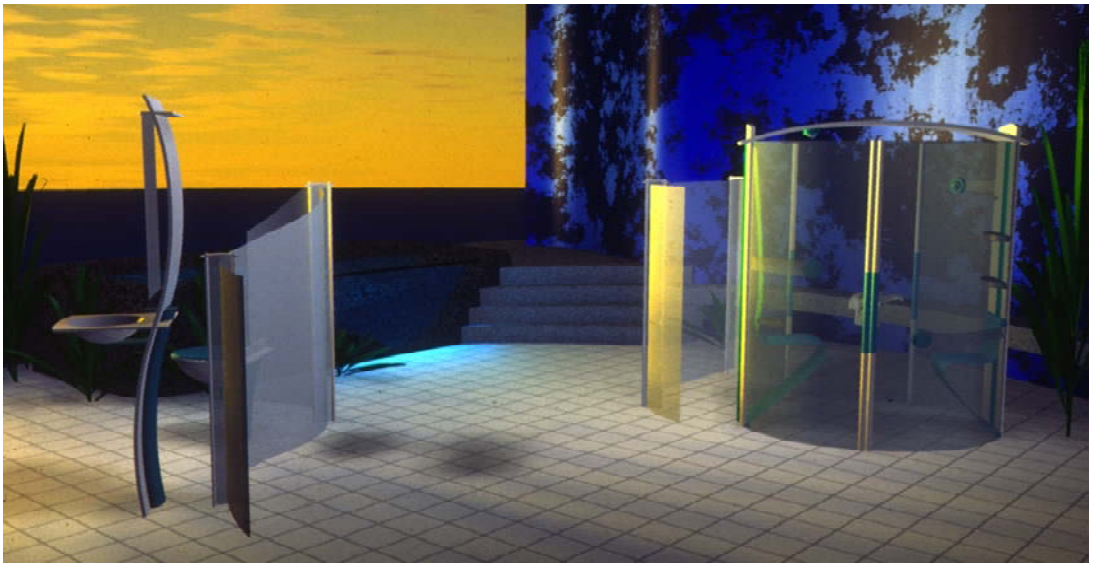

Figure 9 **AquaRoom**
An AquaRoom evolves the experience water use in the home. Extending beyond the conception of bathroom as a place for hygienic cleansing and body care, it promotes pleasure and the use of water for physical and mental rejuvenation.

Regeneration

Western culture has gotten away from a love affair with water it once enjoyed. In the Home System, the affair is resumed. The AquaRoom is more than a conventional bathroom. It is an environment combining the elements needed for bathing and hygiene with water-based components for relaxed regeneration.

AquaRoom

In the AquaRoom, fundamental components—showers, sinks and toilets—are arranged with work surfaces in zones that can be defined and redefined with a system of adaptive SpacePlanes. All can themselves be readily moved and reinstalled should the circumstance of houseguests make special plans desirable.

Supplementing the shower and extending water therapy to more languorous contemplation is the AquaFrame, able to use water with seeming extravagance because of the recycling made possible by nanotechnology filtration. The Nanoplastic sides of the AquaFrame sense bathers' orientations and adapt to support weary bodies and direct currents and eddies of soothing water.

Scenario

You've had a long, hard day at the office, and you need a back massage—right away. You step into the AquaRoom where the Shower has been "informed" by your personal Advocate to create a cool mist environment from one of its DiscJet shower heads. A second DiscJet creates a massaging and pulsating stream of hot water at shoulder height. You are about to step into the shower, when... the water shuts off. It knows that you have forgotten to remove your socks! After fully undressing, you decide you would rather relax in a hot bath. At your voiced suggestion, the Aqua Frame begins to fill itself with water at your favorite thermal and whirlpool settings. You step in and sit back as the Aqua Frame surface conforms to your body while supporting and massaging your tired muscles.

Water Recycling

Nanotechnology makes highly efficient water filtration possible, allowing the home to be relatively self-sufficient in water use. Localized water filters at the toilet, sink and shower, as well in the central waste control unit, allow water to

be cleansed and recycled continuously with imperceptible effect on the water supply, even during periods of high demand. Small amounts of make-up supply water are drawn from the public utility system from time to time to replace the routine small losses expected from a system that is not completely closed. Beyond its value as an environmental investment, the recycling process allows water to be used in ways that previously would have been considered wasteful.

SpacePlanes

SpacePlanes in the AquaRoom define functional zones and modulate privacy. Users can relocate SpacePlanes by lifting and moving their support columns, and can adjust their curvature by rotating these columns. SpacePlane screens are given soft, elastic properties by their Nanoplastic materials. Changing the opacity of the Nanoplastic varies the degree of privacy and separation between zones.

Figure 10 **SpacePlanes**
SpacePlanes are movable space dividers, variable in size and opacity, with the ability to dispense water when used for showers.

Shower

Stepping into the Shower is like being wrapped in a warm, cleansing robe. The Shower's variable opacity screens are drawn out from two main support panels, accommodating one or more users at a time. Directional DiscJets, spraying in combination from anywhere on the screens, provide mists, powerful streams or pulsating massage. Water drawn up from infrastructural Architiles through the support panels, is heated to the desired temperature, distributed radially into the screens and then out through the DiscJets. On contact with the floor, water drains directly into the Architiles, which transform their surfaces when wet into porous, non-slip skins.

Shower screens, once positioned, become rigid. As they do, built-in dispensers, small storage units and shelves for toiletries, protected during movement by sealed covers, open to the user. Two wet seats, created by a Nanoplastic fabric plane extruded from horizontal tubes on the support panels, provide relaxing support for users. Special support needs of the elderly and health-impaired are met by adjustment capabilities incorporated into the Nanoplastic seats. Shape, height and position adjustments are stored in the user's Advocate so that a personal configuration can be created automatically whenever the Shower is used.

Figure 11 **Shower**
Created with specialized SpacePlanes, a Shower has storage and seating configurable adaptively for any user built into its surfaces.

Sink

A Sink can be positioned anywhere on the floor. Wherever it is placed, its Nanoplastic base forms a sturdy weld-like joint with the infrastructural Architiles. Fresh water, drawn up through the support plane, is heated or cooled and fed out through the faucet console. Waste water is drained from the basin and channeled back into the Architiles via the support plane.

By touching different zones on the console surface, users can adjust flow rate and temperature, and change the width of the water plane from a wide sheet to a concentrated jet. To accommodate difference in user heights, the basin and the special mirror above the sink, can be easily raised or lowered.

The sink's mirror adjusts its magnification by changing its spherical radius and can "reflect" true, non-reversed as well as ordinary reversed images because it projects a nanocomputer-processed picture of what it sees.

Figure 12 **Sink**
Sinks can be relocated easily anywhere on Architiles. Washstand and mirror move vertically at the command of a user's Advocate Band.

Figure 13 **Toilet**
Toilets change height and form to meet the ergonomic needs of individual users. Flushing water and waste are processed through the Architiles.

Toilet

Like the Sink, the Toilet is light enough to be moved by a single person, yet can forge a sturdy bond to the floor Architiles wherever it is positioned. The bowl is filled with filtered water drawn through its support plane from the infrastructural Architiles; waste is flushed down to Filtration Tiles through a separate channel.

Changing both height and shape, the Toilet conforms to a range of user differences spanning the needs of toddlers in training to the elderly. Responding to information broadcast from a user's Advocate, it begins its adaptation when a user enters the AquaRoom. Final adjustment of the seat form takes place as the pressure of a user's bony ischial tuberosities is sensed.

Figure 14 **The Food Preparation Space**
Nanotechnology for food preparation uses "smart" Nanoplastic materials to consolidate food preparation functions flexibly in time and space.

Food Preparation

The hours spent in housework are distributed mainly between various cleaning tasks and tasks related to eating. For an average sized family, the evening meal can easily require one-and-one-half hours for preparation and forty-five minutes for clean-up; for special occasions, this may double. When the other meals are considered, a significant part of the day is concerned with food preparation as well as with eating and related tasks. Because many people enjoy cooking, and considerable socializing may take place around meal preparation, the degree of time and effort spent preparing food must be thought of as a matter of choice. Any system meant to replace human labor in this activity should also support an alternative process for accomplishing these tasks by hand.

Nanotechnology has the potential to vastly improve virtually all tasks related to eating, from food storage to food preparation to clean-up. The Nanotechnology Kitchen employs transformable, "smart" Nanoplastic materials whose innate malleability maximizes space efficiency by consolidating myriad food preparation functions. Reconfigurable work surfaces make space and materials more flexible and more automated, while smart sensors relay feedback to the system, ensuring proper preparation.

Food freshness is ensured by self-regulating storage cells which monitor contents and environmental conditions, making necessary adjustments within each compartment. Linkage with the Home Information System provides users with information about food inventory and meal preparation. Cleanup is greatly simplified by liquid Nanoplastics, which transfer and clean dishes without water or detergent.

Tasks which are not normally enjoyed (such as clean-up) should be almost routinely performed, except where special care might be required. It should be possible, however, for members of the family to do any or all of the job they might desire. The system should support the social activity that so much surrounds dining in all cultures—by minimizing distraction and contributing to the service of the meal.

Scenario

You have arrived home from work a couple of hours early—the boss was in a good mood today. As you put away your coat, the Home System inquires whether you would like your dinner prepared earlier than usual. No, you would rather take a hot shower and prepare your own dinner for a change. While toweling off, thoughts of ethnic menus begin stirring in your mind—Chicken Tandoori, Yebeg Alitcha, Ethiopian Zizel Tibs. You walk over to a convenient Communication Tile on an infrastructure wall and request a display of menu options, preparation and cooking times. When you have selected a menu, the food preparation system begins laying out the ingredients for you. In the kitchen, the holographic Chef's Assistant walks you through every stage of preparation—from when to put butter into the pan to how to smooth lumps out of your hollandaise sauce. You prefer to make the sauces yourself, but let the system's food processors wash, peel and cut the vegetables. You're cleaning some pans under the WashPlane when the phone rings. It's your roommate from college days, and you lose track of time. The system notices your preoccupation, takes over to finish preparation of your meal, and suggests a simple dessert for you to make later for yourself.

Kitchen

For many families, the kitchen is the hub of activity in the home. It is often the point of entrance, and acts as a message center and workspace. Yet, the primary task of the kitchen, cooking, is seldom thoroughly considered in terms of kitchen layout, flexibility, product location and storage accessibility. Present-day kitchens do not reflect the fact that cooking as an activity varies in magnitude and complexity from meal to meal. Compounding the problem, people have different levels of enthusiasm when it comes to cooking. For some it is a chore; for others it is a form of highly enjoyable relaxation.

In the Home System, the cook is given priority. The cooking system can totally automate cooking, but is primarily tailored for cooking assistance. The interactive Chef's Assistant is a holographic projection of "your favorite chef", a personal guide to meal preparation. In the processing area, the user can participate in the meal preparation while turning over some of the processing to the system. The back quarter of the countertop is the automation zone. The storage tower, which resides both above and below the countertop, is placed against the wall. From it, food is transported through food processors, to the stove area and the oven. The oven can be divided into separate environments for different cooking requirements. Its door acts as an interface screen, providing a view of the food, but also a thermal map of the oven contents. The preparation area, adjacent to the environmentally controlled storage tower, looks out over the kitchen table in the garden corner, giving the cook a pleasant view and the ability to converse with people at the table. A Wet Island contains the cleaning devices and the primary sink.

Chef's Assistant

Whether preparing a child's glass of chocolate milk or an elaborate holiday feast, users of all ages and culinary capabilities may be assisted by the interactive, personal Chef's Assistant. The Chef's Assistant is software personalized by a portable, electronic imaging and communication device that projects a holographic phased-array image of a chef—chosen by the user from a palette of

personalities. The Chef's Assistant offers detailed, step-by-step instructions for preparing simple or elaborate meals. Favorite menus, recipes, and cookbook contents can be stored and retrieved at any communication port in the home, allowing users to browse the system for great menu ideas.

The Chef's Assistant communicates with other kitchen appliances, such as the Entrée Prep food processor, readying them for use at the appropriate time, or when a specific menu selection is made. In action, the visible persona of the Chef's Assistant leads users through all facets of their food preparations, offering advice on how best to prepare foods in conjunction with the new Nanoplastics kitchen appliances. At the same time, the Chef's Assistant is linked to the food inventory so that menu choices can be determined by available ingredients and future grocery lists can be updated.

Figure 15 **Entrée Prep**
Food preparation tasks are performed simultaneously in the Entrée Prep with tools adapting as needed to respond to the ingredient and process.

Entrée Prep Food Processor

The Entrée Prep food processor not only quickens preparation tasks, it allows multiple processing methods to proceed simultaneously. Coconut pieces, for example, may be dropped through the Entrée Prep's food chute to be shaved by the mechanism's uppermost blades, while blades lower down gently whisk the shavings into a heated sauce. Nanoplastic blades adjust their shapes and actions to the process and nature of the food, changing from whisk to spatula, for example, to ensure that all ingredients are completely blended.

Expandable to accommodate various bowl dimensions, the Entrée Preps hood secures itself to the top of a bowl before its control console becomes active. The user may operate the processor remotely through the interface of the Chef's Assistant or may select operations and their sequence by touching zones on the console's surface. Certain buttons are emphasized visually—one slides the food chute cover open; another allows the user to stop processing at any time.

Figure 16 **Cutting Palette**
Food is sliced readily to any width by microscopic nanomachine saws passing in a stream along the wire "blades" of the Cutting Palette.

Cutting Palette

In one motion, the Cutting Palette cuts food uniformly to any thickness—shaved turkey breast or a heartily sliced roast leg of lamb. As the two handles are pulled apart, thin but very stiff Nanoplastic wires are reeled out over food to be cut. These wires work by sending a stream of nanomachines along their length, cutting through food like tiny chainsaws. To avoid accidents, the Cutting Palette detects the difference between users' live flesh and the food being prepared. The Cutting Palette may operate at default settings for the different foods it automatically distinguishes, or specific cutting options may be selected remotely through the interface of the Chef's Assistant.

Foodware

Cooking almost always involves multiple containers. Recipes prepared in one container are moved into another for cooking, and yet another for serving. Leftovers are placed in a fourth

container for storage. A container that can adapt itself to all of these roles would significantly reduce effort, cleaning and storage, and would enhance system cooking efficiency.

Figure 17 **Foodware**
Foodware containers adaptable to cooking, serving and storage needs are created as needed from discs of nanoplastic material in the countertop.

The Foodware container fills this role. Foodware containers are stored as flat discs in the surface of the countertop. When a container is first needed for food preparation, the food is placed in the Foodware container zone, and the countertop creates a disc 0.5 cm thick under the food. As it is forced upward, the disc separates from the surface to form a bowl around the food.

As a preparation bowl, a Foodware container can stir its contents and monitor their physical characteristics. When preparation is complete, the Foodware container can be moved to the heating zone where it morphs again, adding an interface for heating and environmental control. A cover can be requested, also dispensed from the countertop. The Foodware container now fills the role of a stovetop, simmering, boiling, frying or grilling its contents. Alternatively, it may be placed in the oven, where heat is supplied from the oven rather than from the container. When cooking is complete, the Foodware container becomes a serving container. The interface disappears, and the form becomes an attractive addition to the table service.

When the meal is complete, any leftover food in Foodware containers can be stored. Foodware containers are returned to the kitchen where their interfaces return. As the user sets a container's control to "storage"; handles disappear, a cover is returned, and the unit is ready for placement in the general storage system. The Foodware container now chills its contents appropriately, drawing power from the surface of the shelf. Its internal environment is maintained continuously, eliminating the need for external refrigeration.

Wet Island
The Wet Island is a collection of products: a sink, a dishwasher and a cleaning device for small quantities of items. The set of products creates an "island" in the kitchen that can be used there or freely moved through the home, assisted by self-propelling surfaces on its base. For example, the Wet Island can be brought to the dining room for convenient work at tableside; while there, its water and power systems are connected to dining room Architiles. When the unit returns to the kitchen, the base reconnects water and power systems to the kitchen's Architiles, and dishwashing commences.

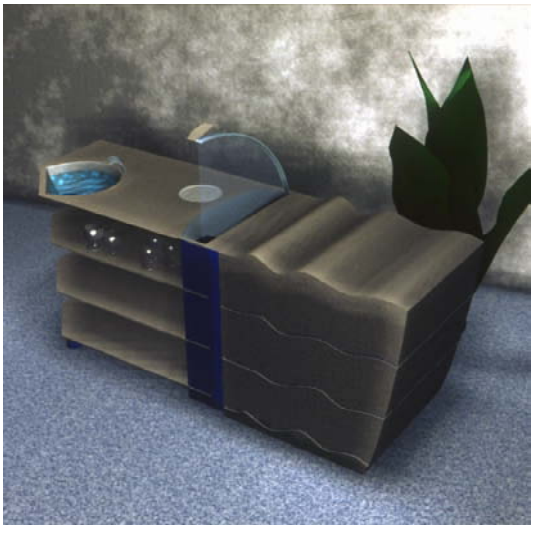

Figure 18 **Wet Island**
The Wet Island combines the functions of a sink, a dishwasher and a quick cleaning device in a movable island able to be used where best needed.

Dishwasher
The Dishwasher is a very simple device, thanks to nanotechnology. Dishes are loaded by sinking them one by one on edge through the Dishwasher's surface until they are stopped by one of two inner support trays. When a tray is loaded, the washer is activated. The plates descend into the Dishwasher, entering as they sink, a container filled with cleansing nanomachine "soup". The nanomachines forming this liquid actively separate waste from the dishes and transport it to the disposal port. Dishes reemerge on the surface when the cleaning is complete.

WashPlane
The WashPlane is a cleaning "screen" used for small cleaning duties, such as cleaning a few plates. When the unit is activated from its

countertop location, a circular ring forms, encircling a plane of Nanoplastic detergent that extends between it and the food trap bowl. Plates are cleaned by passing them through the plane. The rate of cleaning is controlled by the Nanoplastic, which resists the motion, thus slowing the penetration. The feeling the user has of this process is that of passing a warm knife through butter.

Reissued July, 2004

Figure 19 **ExploreRoom**
The Explore Room functions as an interactive, multi-sensory exploratory environment for education, exercise, entertainment or general work.

Improvement

Beyond the necessities of basic living, the Home System contributes extensively to the kinds of activities that help people to maintain their physiological well-being and to grow intellectually and emotionally.

Scenario
Homework for tomorrow calls for a presentation on reptiles. It's time to do some serious research. You call your team of classmates to come over after dinner and then head for the Explore Room. Requesting a Brazilian rainforest, you face the wrap-around PADScreens and are "transported" thousands of miles away into the heart of a tropical forest. The sound system recreates the hush of an atmosphere laden with falling dew; frogs croak in the underbrush, and a family of parrots squawks faintly somewhere in the upper canopy. When your classmates arrive, you gather around the Stage, drawn toward a holographic image of an eight-meter anaconda. You request from the Sculptor a tactile map of the anaconda's skin. A short while later, the Sculptor's "Nanoclay" has formed itself into a physically accurate three-dimensional shell of your subject, which you then pick up and hold in your hands. The skin is not at all what you thought—it is neither slimy nor unpleasant to touch. You record these observations, discuss your findings with the group and request additional tactile maps—this time from desert reptiles in the Middle East. In what ways are they similar? The PADScreens transport you and your group to this new setting!

Explore Room
The Explore Room is an interactive, multi-sensory exploratory mediaroom. Used primarily as an educational environment, it can also function as an exercise area, entertainment room or general workspace. Six basic components outfit the Explore Room: an ExerSuit, a GeoPlane, PADScreens, a Sculptor, a Task Table, and a Dynamic Group Table. They find use, often overlapping, in three general kinds of activities: health and fitness, leisure and education.

Health and Fitness
Health and fitness often require more attention than the individual can manage alone. Maintaining proper health requires that the user's health be regularly monitored and proper recommendations be made that address medical history as well as current physical condition. A good exercise program combined with proper nutrition is the key to good heath.

Nanotechnology will make the maintenance of good health convenient and efficient. The user's health status can be monitored by nano-scale biosensors that relay the health data to the home health system. Each user's health data is then compiled into a medical profile which is used to modify exercise programs as well as diet and nutritional intake. This same medical profile will aid health care professionals during regular check-ups or in case of emergency.

Nanotechnology will make exercise not only more efficient but also more enjoyable. The GeoPlane, a platform for simulating outdoor environment; the ExerSuit, an isometric resistance replacement for free weights and exercise machines; and PADScreens, large-scale, high-resolution images; create a highly variable interactive exercise environment. Users can simulate a variety of experiences from downhill skiing in Switzerland to the New York marathon, or even mountain biking on the moon.

When exercise is fun and an enjoyable activity regulated by a powerful information system that knows your personal medical history, maintaining good health and fitness becomes a more manageable and appealing task.

ExerSuit

The ExerSuit replaces cumbersome weight sets and exercise machines. Used in conjunction with PADScreens, it creates a virtual exercise environment. A user in Finland can virtually exercise on the beach in Hawaii with his favorite computerized personal trainer.

Essentially a body-outfit augmented with patches of VariFlex Nanoplastic material, the ExerSuit can be selectively very flexible or very rigid and can change its rigidity during the progress of an exercise. VariFlex patches are located at all joints as well as at the body's major regions of flexure. By varying flexibility at these points, the ExerSuit provides isometric resistance to a user's movements, allowing the user to build muscle strength and endurance as well as cardiovascular capacity. Using nanotechnology biomonitors to sense heart rate, blood pressure and respiratory rate, and tiny transmitters to send the data, the ExerSuit relays these vital statistics to the Home System's health database. There the information is processed and compared with the user's physical profile, i.e., general physical condition, possible health problems, previous workouts and record of improvement. The result is good advice, improved safety, more efficient exercise and more enjoyment in the process.

Figure 20 **GeoPlane**
For simulating three-dimensional environment, the GeoPlane reproduces earth surfaces in dynamic form from snowy planes to vertical rock formations.

GeoPlane

With the GeoPlane come the means to attain new levels of excitement in exercise and recreation. The GeoPlane dynamically simulates moving earth surfaces such as rock, soil and snow; it can be used for rock climbing, skiing, running and many other activities. One of the features of the Explore Room, it is installed facing the phased array PADScreens to recreate an outdoor environment within the home. Depending on its use, it rises out of the floor at different angles to simulate terrain appropriate to an exercise. Completing the simulation is its movable surface made up of two layers: a bottom layer that generates macro-scale changes to surface land forms (0 cm to 100 cm), and a top layer that creates surface texture characteristics (-20 cm to 20 cm). The bottom layer houses Nanoplastic expandable struts which can rapidly vary their lengths from 15 cm to 100 cm, and houses the infrastructural interface for power and water. The top layer is made of rapid-change Nanoplastic that can change color and emulate textures.

When used for climbing, the GeoPlane is vertical. As the user climbs, the wall scrolls in the direction opposite to the climb. For example, if the user reaches to the upper right, grabs a rock projection, and moves toward it, the GeoPlane will scroll its surface to the lower left, maintaining the climber's position relative

to the room. When skiing, the GeoPlane is inclined downward toward the PADScreens. With its pistons and scrolling action, the GeoPlane can create moguls or smooth terrain. Surface texture changes can mimic conditions from ice to packed powder snow.

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Figure 21 **Task Table**
Highly adaptable, the Task Table is a study space for the individual and the interface through which users control other Explore Room components.

Leisure

Electronic home entertainment products have contributed to a decline in the quality and amount of social interaction in the home. While passive forms of entertainment may help us to relax under certain circumstances, entertainment should also stimulate and challenge people in the home, helping them to engage in social activities.

With the immense computing capability afforded by nanotechnology, users will have access to an unbelievable variety of communication media and information from around the world. The Dynamic Group Table, a transformable station for group interaction, and the Explore Room itself, a multi-function workspace designed for hobbies and creative expression, are the foundations for entertainment in the home.

Task Table

At the edge of the Explore Room stands the Task Table, a study space for the individual and the interface palette through which users control other Explore Room components. It can be adjusted to accommodate the requirements and dynamics of a variety of activities. Its size, shape and orientation are flexible, providing users with alternative states of conveyability, adjustability and reformability.

A transformable shelf with storage space for often-used items is mounted above the principal work surface of the Task Table. The work surface supports a small version of the PADScreen affixed to a holographic Stage projection platform. Used individually or in combination, the PADScreen here is primarily

for flat, two-dimensional, transparent, text and graphics, while the Stage is used for projecting three-dimensional objects behind it. A user studying the destruction of Amazon rain forests, for instance, would look through the screen's graphic window to view an animated three-dimensional image of deforestation in progress, while superimposed text editorials detailed causes and effects of large-scale environmental damage.

Figure 22 **PADScreens**
PADScreens are presentation screens with multimedia sound, imaging and sensory processes capable of representing real and imagined landscapes.

Dynamic Group Table

The Dynamic Group Table can be configured for many functions, from facilitation of group discussions, to computer-assisted role playing geared toward social interaction. It allows users to communicate and interact with others from around the home to around the planet. The Explore Room supports hobbies, crafts and other forms of creative expression. It also allows user groups to explore fascinating and unusual experiences by simulating various environments—anything from the inside of a human cell to the surface of Venus.

Bringing information into the home as an active form of entertainment, rather than passive display, enhances the quality of leisure and extends the social dimensions of the home.

PADScreens

PADScreens are at once the most and least prominent components of the Explore Room. In operation, they are presentation screens with full multimedia sound, imaging and sensory processes, capable of transporting the user's imagination at will across real and imagined landscapes.

They can be used as flat panel displays or curved to surround viewers. Forming the base of each PADScreen is a small-diameter, deformable tube which can be bowed into curves when the screen is retracted. The stiff, paper-thin screen is extruded upward in the shape of the base, expanding to full wall height for normal presentations, or just to notebook height for desktop use. It is retracted into the base for easy storage, transport and reconfiguration.

Through the use of phased array display technology, PADScreens can produce windows onto three-dimensional scenes. In this mode, objects appear to the eye as though they are located in space behind the screen. In front-projection mode, by generating converging spherical waves that transfer the image of a point source to a spot in front of the display, PADScreens create objects with a solid appearance in front of the screen's surface, much like a solid hologram. Each PADScreen can be used as an individual display. Joined side by side, several of them create a large seamless display area that can be configured as a flat wall or wrapped around the user to create a cyclorama-like virtual surrounding.

Figure 23 **Sculptor**
The Sculptor enables users to create physical objects, manipulating Nanoclay by hand or with computer-assisted tools.

Sculptor

A Sculptor utilizes nanoassemblers to construct physical objects out of Nanoclay. Users create objects by manipulating the Nanoclay by hand,

using a tool that extends a user's ability to control form, or by requesting forms to be constructed automatically under guidance of the home computer system.

Nanoclay is Nanoplastic material worked in thin-walled shell form to enable it to undergo rapid form change. As the Sculptor's tool is passed near Nanoclay, it changes the material's characteristics, depending on how the tool's controls have been set. Changes may be as simple as sharpening or softening edges, or they may be complex: changing opacity, blending colors, creating textures, enforcing constraining relationships or replicating component features. When an object is formed under computer guidance, the Nanoclay's internal assemblers and nanocomputers take over the morphing tasks. Highly detailed replicas can be constructed of animate and inanimate forms, allowing, for example, an Indonesian song bird to be modeled—to the tiniest feathers—as part of an educational exploration of Southeast Asian wildlife.

As an object is formed, its three-dimensional representation is captured through the Sculptor and displayed on the Stage, a holographic display platform. With its form stored in memory as a history of changes, it can be reconstituted in image or physical form as it was at any phase for reference, renewed work or communication.

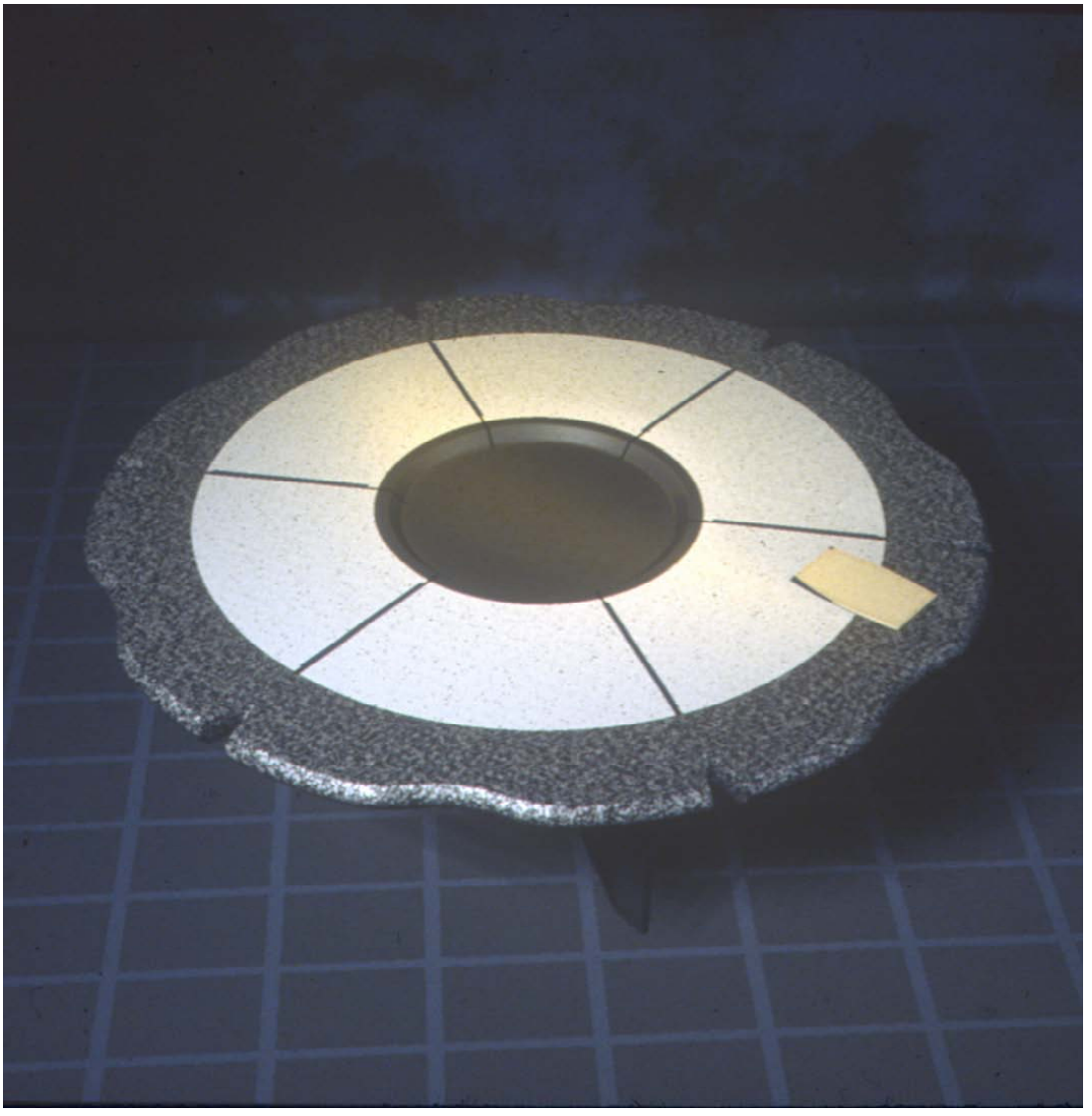

Figure 24 **Dynamic Group Table**
The Dynamic Group Table is a close-contact work surface designed to optimize interactive work and discussion for groups of two to twelve people.

Education

While schools of thought differ on the best methods for education, most agree that learning is an interactive process—a period of discovery for people working individually or with others, and using the tools of learning to understand and shape their world in new ways. Facilitating the means by which people interact and extending the range of available sensory experiences are two of the most important components of any educational method. By supporting these two processes, virtually any activity in the home can become a learning experience.

In a home filled with Nanoplastic products, vast amounts of information are readily accessible through tiny and ubiquitous nanocomputing machines, globally networked databases and decentralized workstations. And even more powerful means of diminishing the limitations of time, space, and human creativity are possible: nanosculpting tools that can recreate three-dimensional mock-ups of historical or imagined artifacts; seamless wrap-around display panels that can reconstruct the landscape of distant planets or remote regions of our own earth; modular, flexible workspaces that swiftly adapt to the needs of individual or group study and communication sessions. The Home System needs such tools

even more than tools to meet physical needs. Nanoplastics will make possible a system of products whose role is to facilitate the creativity in all of us by challenging and extending the limits of our own imagination.

Dynamic Group Table

Group meetings are frequently conducted around tables because of the obvious benefits of face-to-face contact, a work surface and comfortable interpersonal distances. In the meetings there is usually information that must be viewed by all members, but individuals must have access to their personal information as well. The problem is the information that must be viewed by all. An object or information displayed in the center of a table is viewed in a different orientation by each person at the table. The Dynamic Group Table is an interaction facilitation device designed to address this issue for groups of two to twelve people.

At the center of the Dynamic Group Table's work surface is a large holographic projector that floats a manipulable image over the table. The region around the projector is divided into individual seating zones, each supplied with a personal projector and an interaction area. The personal projector creates a smaller version of the central image. The interaction area can be used to view documents and for keying or hand-writing input. Seating around the Dynamic Group Table can be increased or decreased following a predetermined pattern for optimal seating arrangement. Seating zones can also be removed from the Dynamic Group Table for laptop use in an informal setting.

Summary and Conclusions

Nanoplastics explores a radically new future for plastics, perhaps only a few decades away. The technology that will bring sweeping change is *molecular nanotechnology,* a topic of concentrated attention in major research institutions in Japan, Europe and the U.S. Focused at the scale of the atom—one billionth of a meter—this new technology brings materials science, chemistry, mechanical engineering and computer science together in a most fundamental task: the design and production—directly from atoms—of specialized machines (nanomachines), dynamic material structures and production systems for them. Progress has been unexpectedly fast, and it is now clearly time to project the impact on design of what many expect to be a technological revolution that will dwarf the industrial revolution. The invisible machines embedded in materials (including supercomputers too small to see without a microscope) will operate in vast networks to change the properties of materials and products on demand.

The plastics industry stands most likely to reap the substantial rewards of production, because it is based in carbon chemistry (also the base of nanotechnology), and because it already possesses relevant industrial processing expertise. The new materials, then, may appropriately be called "Nanoplastics".

The problem for design is a problem of first principles. New rules must be found for designing in a world of materials virtually without limits. Guidelines are no longer usefully grounded in the limits of material and technology, but in human values. The project described here takes on the challenge of this tomorrow—in the home, an appropriate test ground for the kind of design that must be practiced soon.

Because they are literally landscapes of interconnected machines, Nanoplastics have the potential to vary their properties in kind and degree beyond anything previously known. Some of these properties are:

• Super strength and hardness—carbon structures using diamond configuration can be constructed without imperfections by nanomachines.

• Frictionless surfaces—nanomachines at a surface interface can eliminate resistance by preventing attractive contacts between stationary structures and the moving molecules of contacting materials.

• Variable permeability—pore structures in thin sheets of material can be monitored by nanomachines to allow selected molecules of liquid or gas to pass while others are blocked.

• Light control—light reaching an opaque wall can be detected by a nanometer-scaled cellular surface, channeled to the inside surface, and re-emitted with the effect that the opaque wall appears transparent from the inside.

• Changeable form—under guidance of nanocomputers with "topographical construction maps", surface material can flow to positions appropriate to recreate textures and specific physical features, such as rock forms for a climbing machine or a control panel for a viewing screen.

Of all technology under development today, nanotechnology has probably the greatest potential for improving human relations with the environment. Because nanomachines are the size of molecules, they are able to act directly upon molecules. This ability can be translated in many ways directly to problems of restoring environment already degraded—but it also brings a host of indirect means to more benevolent associations between humankind and nature.

1. Materials can be made without imperfections, extending the lives of products almost indefinitely by preventing localized material failures.

2. Energy can be obtained from many local, otherwise-untapped sources, among them: sound, motion, vibration, heat and light.

3. Waste products can be broken down cleanly to element and compound levels for recycling.

4. Deterioration of materials can be almost eliminated by using nanomachines to repair and clean material surfaces.

5. Energy consumption, mechanical and electrical, can be reduced drastically by eliminating or reducing the friction caused by molecular and atomic interferences.

Unprecedented properties are the norm when nanotechnology is the subject. Applications for such properties were the subject of this design project. The intent was and is to anticipate potential applications at the best time to have impact on their development—*before research is complete and the applications are upon us.*

Design *unfettered by material limitations* is as new an idea as nanotechnology itself. Designers, too, need time to find the way.