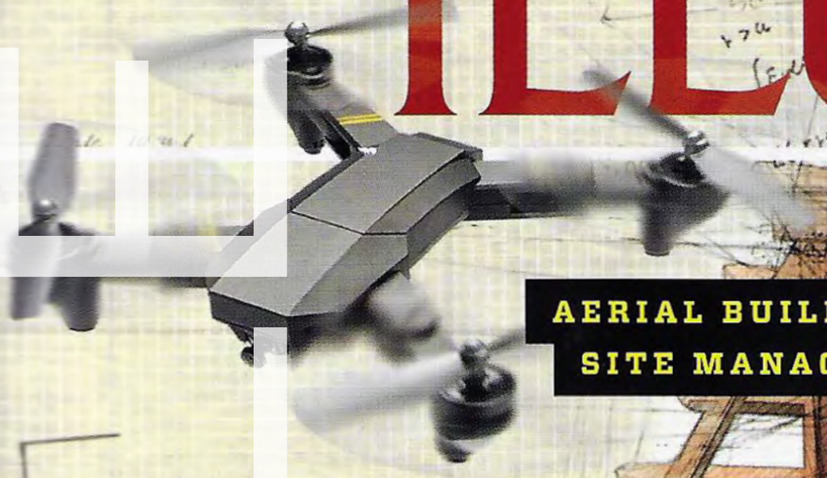
FROG FINDS ITS TEETH
after 225 million toothless years

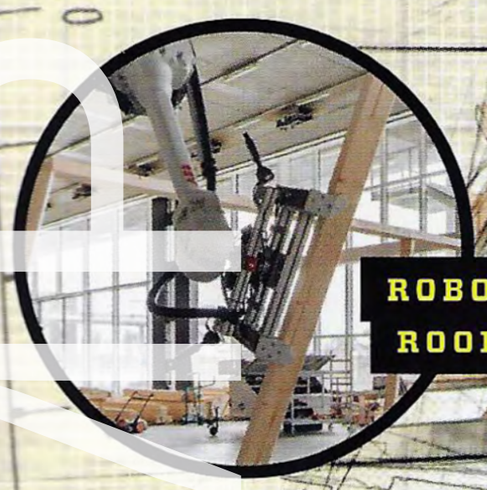
CHRISTMAS WISHES
What do scientists want from Santa?

AUSTRALIAN

SCIENCE ILLUSTRATED



AERIAL BUILDING SITE MANAGER



ROBOTIC ROOFER

COLOUR-CODING CARPENTER

AUSSIE-MADE BRICKLAYER

DRIVER-LESS EXCAVATOR

ROBOT TRADIES

BOTS THAT BUILD

Coming soon to an automated construction site near you

› Endangered species
BACK FROM THE BRINK

› The strange theory of
COSMIC WHITE HOLES

› Congratulations! You're living on
THE UNIVERSE'S LUCKIEST PLANET

The latest construction workers are computerised:

ROBOT TRADIES' CONSTRUCTION REVOLUTION

A driverless excavator does the digging, a robotic arm lays 1000 bricks per hour. With new accurate sensors and smart algorithms, robots have built entire houses. In a few years, these robot tradies may be a common sight.

CLAUS LUNAU & BUILT ROBOTICS INC. & FBR LTD & AIST & ROMAN KELLER/NCCR DIGITAL FABRICATION

Computers draw accurate 3D models of houses using algorithms that have been fed data about many previous construction projects. They have 'learnt' the rules of architecture.

TRUCK DRIVER

A driverless excavator excavates the foundations. It manoeuvres by a combination of GPS and sensors that measure the vehicle's inclination and acceleration.

By **Mikkel Meister**

BUILDING MANAGER

A drone monitors construction. It takes photos and analyses them via algorithms 'trained' by analysis of previous data to recognise materials and patterns.

BRICKLAYER

A robotic arm builds walls at a speed of 1000 bricks/hour. The arm grabs bricks, adds adhesive, rotates the bricks and lays them, all in one motion.

ROOFER

Robotic arms assemble a timber frame for the roof. Controlled by algorithms, the arms saw and connect posts into a structure that can carry a roof.

CARPENTER

A robot installs plasterboard. It navigates by emitting laser beams and measuring distances based on reflections from the surroundings.

hadrianx

It's another noisy construction site, with excavators, cement mixers, and power tools pounding out their noise. A roof is mounted on one house while foundations are excavated on an adjacent site. In a third house plasterboard is being installed onto timber framing. But there are no human beings here. All the tasks – from the casting of foundations to the installation of the last roof tiles – are being carried out by robots, while drones are flying about to check the progress.

This is how a construction site might soon be able to operate. Small computers, artificial intelligence and new sensors are enabling robots to build an entire house, from erecting the walls to installing the roof, within a single day.

Robots have already proved that they can build houses almost without human assistance, as in Switzerland, where the robot-constructed DFAB House opened in February 2019. Robots have also been selected, appropriately, to build a new robot museum in Seoul which opens in 2022. But beyond special cases, these developments will make houses easier to build, and that is becoming vital. According to the UN, by 2030 new homes will be required for some three billion people – 40% of the world's population.

Not only can the new robotic building crews handle physical construction tasks, they are also on their way to taking over the roles of architects and building managers by designing, planning and supervising the entire construction process.

30

minutes is the time in which drones can quickly map a 20,000m² work site.

Automatic arms paint cars

Robots have been used in factories for decades, of course. In the car industry, robotic arms have welded and painted car bodies since the 1970s. Unlike people, robotic arms can repeat the same motions and tasks around the clock, maintaining accuracy without getting tired or injured. Robots can carry out monotonous jobs that include many repetitive tasks, and can do so more efficiently than humans.

But a factory is a predictable place. There is a standard process, from individual parts entering the system until the completed product appears at the other end. In such a setting it is relatively simple to design a robot to pick things up from a belt conveyor and put them in a box over and over again.

A construction site is a far more complex environment: machines and building materials can end

TRUCK DRIVER

Driverless excavator excavates the foundations

The worker in the cabin has been replaced by a box of computers and sensors. Based on a 3D model of the building, the robot independently excavates the foundations highly accurately.

ARM FOLLOWS INSTRUCTIONS

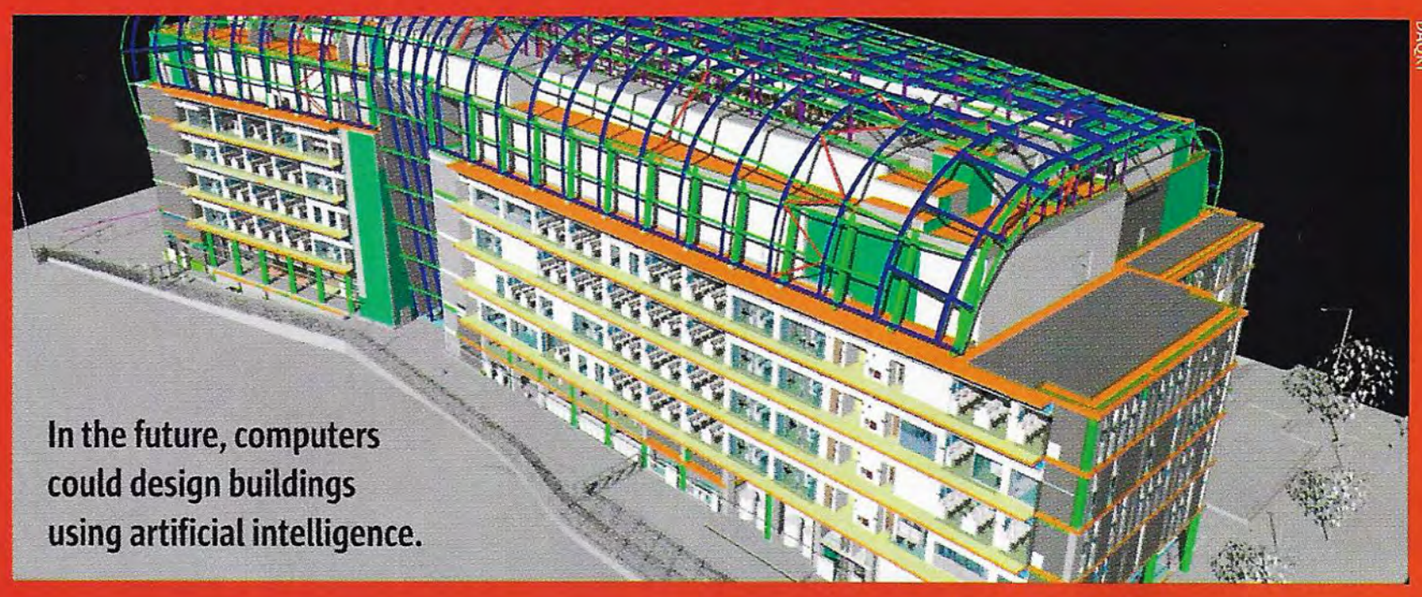
A computer calculates how the arm should move by means of meters that measure the excavator's inclination and acceleration. The data is registered in the computer and converted from data code into mechanical energy, so the arm's motions can be fine-tuned constantly.

BUILT ROBOTICS INC.

up in unexpected places; construction schedules can change; delays or weather conditions can require that workers switch to jobs other than those planned. Flexibility in cooperation and the value of traditional skills are among the reasons that the construction business is still dominated by human workers.

Lasers for 'eyes'

In recent years, new technologies have made robots much more flexible and increasingly autonomous. One crucial technology is the increasing power of small embedded computers, those which are integrated in a machine and customised to carry out specific jobs, unlike an ordinary computer which functions independently, not embedded. Embedded computers are used widely, examples being those in traffic lights and the navigation equipment of planes. Today, these computers are powerful enough to solve calculation-intense tasks such as ongoing image analysis that ▶



DAQRI

In the future, computers could design buildings using artificial intelligence.

Algorithm architects

Before long, a computer could take over the role of the architect. Given the general idea of a building, the computer could decide what to do by having learned from data covering thousands of other construction projects. Its algorithms are fine-tuned according to all this 'experience' to calculate the ideal materials for a specific type of building, the location of water pipes and cables, and the thickness of the roof for optimum insulation. The robo-architect then sends a 3D model via Wi-Fi to the robots which stand ready to construct the building.

ROOF BOX NAVIGATES

On top of the excavator there is a box with the computer which controls the caterpillar treads. The computer analyses the images from the excavator's cameras to avoid obstacles. The excavator automatically deactivates the caterpillars if a human being suddenly walks into its planned driving path.

DRIVER-LESS EXCAVATOR

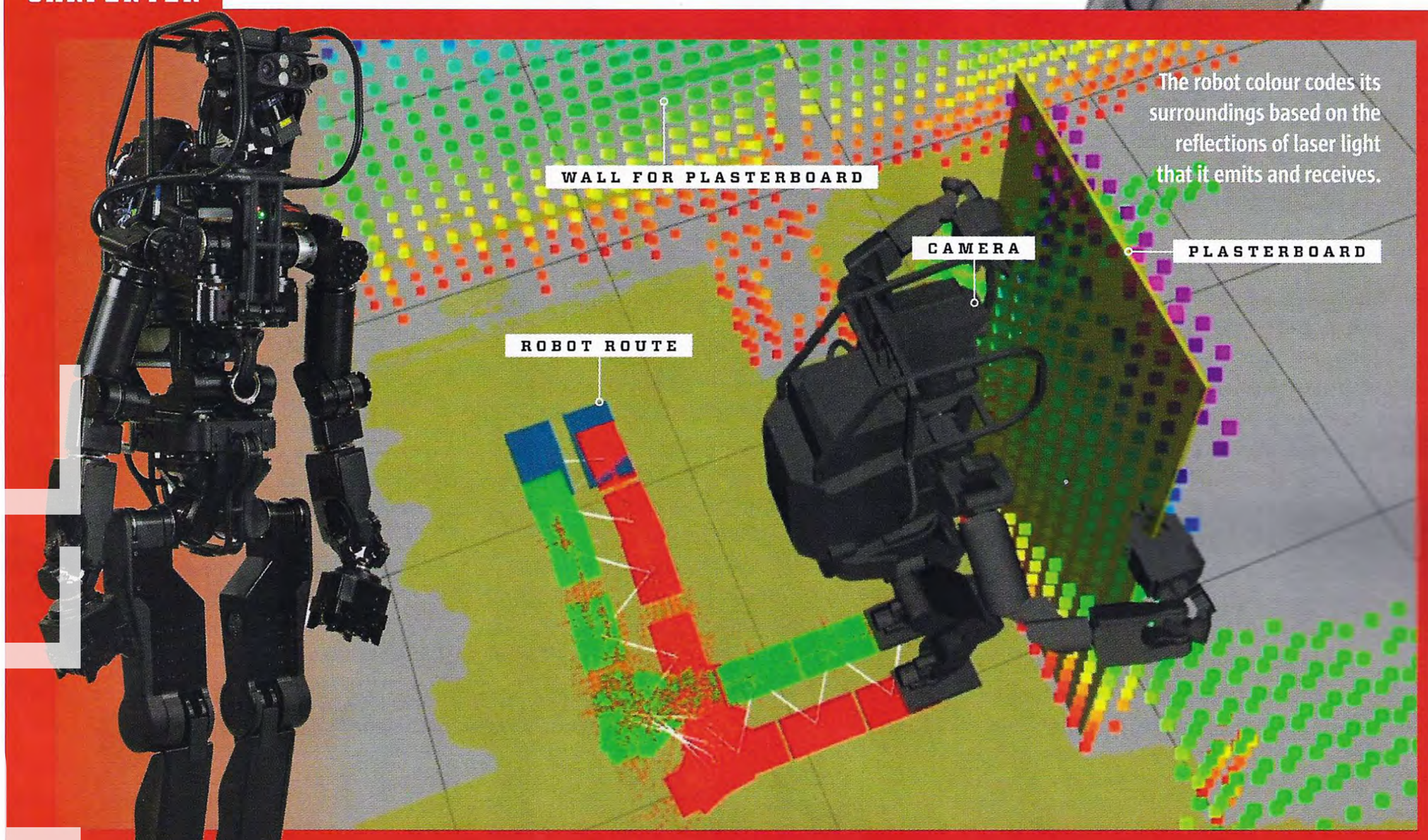
VIRTUAL LIMITS

The excavator's computer navigates according to coordinates indicating the virtual limits within which excavation is to be made. Light sensors and GPS can ensure that the limits are not crossed. The machine can dig a 20 x 20-metre hole with an accuracy of 1-2cm.

BUILT ROBOTICS INC.

If the excavator moves outside virtual limits that have been fed into its computer, it stops to correct its position.

CARPENTER



HRP-5P is 182cm tall and weighs 101kg. A camera in its head can differentiate between power tools.

AIST

Robotic carpenter works according to colour codes

The HRP-5P robot can take a plasterboard sheet, place it up against a wall with one arm and install it with the other. HRP-5P navigates by laser light emitted in all directions, with sensors measuring how quickly the light is reflected back from different angles and objects. A colour-coded 3D map is developed and is then used by the robot to calculate its path for moving around a room safely and efficiently.

robots can use to distinguish between the many different tools and materials used on a construction site.

At the same time as the development of embedded computers, sensors have become more accurate. They are used in conjunction with LiDAR technology, using lasers to allow robots to create a detailed 3D map of their surroundings. Laser light is emitted, and the sensors measure distances and shapes based on reflections and the speed of reflection from the surroundings. LiDAR is already used in driver-less cars, and it will make robots better at navigating the changing environment of a building site.

Drones provide the plan

New technological breakthroughs mean that robots could go further, taking over the entire construction process.

The Komatsu company in Japan has automated the process of measuring, excavation and levelling the site for a house. According to the company, it previously took up to three days for human land surveyors to make an altitude map of an area covering 20,000m², but drones and real-time kinematic positioning (RTK) can draw up an accurate 3D map of the area in about 30 minutes. RTK improves the accuracy of an ordinary GPS signal by comparing GPS coordinates with a signal from an antenna on the construction site. This can correct any small deviations from GPS satellites which are located thousands of kilometres away and so improve GPS accuracy from a few metres down to a few centimetres. A drone equipped with a 20-megapixel camera takes one photo per second, combining them with GPS coordinates so that a computer can subsequently make a 3D map which is transmitted to Komatsu's autonomous machines, including data on where and how much soil is to be removed. Armed with this information a bulldozer and excavator begin to remove soil completely independently.

The HRP-5P carpenter robot can turn through

300

degrees. Humans can rotate only around 80 degrees.

3D printer builds a house in a day

Once the soil has been levelled, there's still the challenge of building walls. For this job, engineers throughout the world are turning to a method normally used for rather smaller things: 3D printing.

These 3D printers for houses use an additive process by which layers are printed on top of other layers to form the walls of the house. An American company, Contour Crafting, has developed a printer

BRICKLAYER

Robotic arm lays 1000 bricks per hour

The Australian robot Hadrian X builds walls at record speed. The robotic arm uses laser light for positioning and lays bricks made of lightweight concrete which are 12 times bigger than ordinary bricks and harden in 45 minutes.

with a print-head that moves in all directions – length, width, and height – via a rail system. Quick-drying concrete flows from the nozzle on the head. In time even exterior treatments and electrical installations could be be printed using the same process. According to Contour Crafting, a house of some 180m² which might take six months to construct conventionally can be printed in 24 hours.

Robot is a quick bricklayer

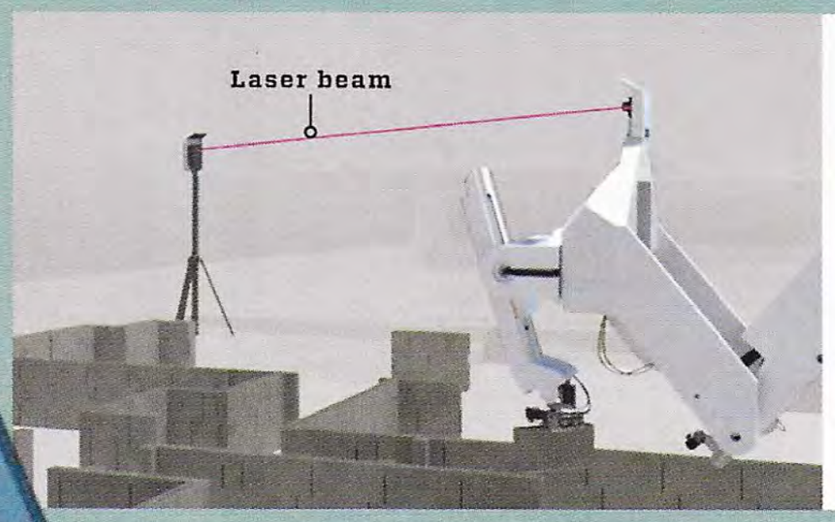
3D printers spray material from nozzles, but there are also robots that imitate a bricklayer's job, placing bricks on top of each other in an accurate pattern.

The SAM100 robot consists of an arm that takes bricks from a belt conveyor, adds mortar, and lays the bricks on the wall. A column on either side of the field of activity emits laser light that functions as the bricklayer's string line when the robot places the bricks. The robotic arm motions are controlled by algorithms that match the arm's speed and angle in proportion to the line. According to Construction Robotics, which is responsible for SAM100, the robot can remove 80% of the physical lifting work for a human bricklayer while making them three to five times more efficient, because they need only install the robot, feed it bricks and mortar, and adjust the joints. SAM100 can lay up to 3000 bricks a day compared with 500 for a human bricklayer.

Map renewed every three seconds

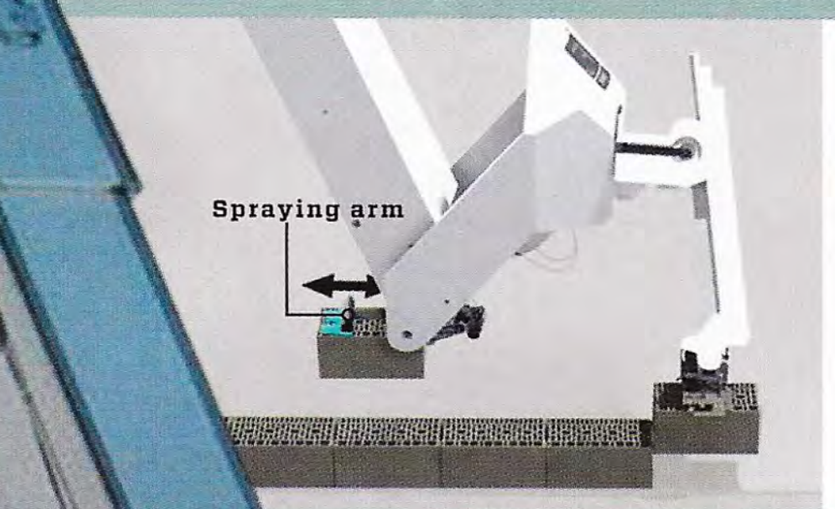
Other robots are ready to carry out carpentry work inside the house. Japanese scientists have programmed the HRP-5P humanoid robot to collect plasterboard sheets and install them using electric power tools.

The robot is equipped with motors and flexible joints allowing its body to rotate in wider angles and to carry more weight than people. The robot moves about the construction site by means of LiDAR technology. ▶



LASER CONTROLS ARM

1 The robotic arm's position is calculated and continuously adjusted by sending laser light from the arm to a permanent station that measures the angle of approach and distance, keeping movements accurate.



ADHESIVE IS ADDED

2 Bricks keep coming via the hollow arm. When a brick arrives, a spraying arm moves back and forth to add adhesive, the brick is rotated and then passed on to the most external of the gripping mechanisms.

BRICKS ARE LAID

3 The arm's most exterior joint is up to 30 metres away, hanging freely and stabilised by motors so it remains vertical regardless of jerks in the rest of the arm due to wind gusts or other issues. The gripping mechanism rotates bricks and lays them.

BRICK TUBE

STABILISERS

GRIPPING JOINT

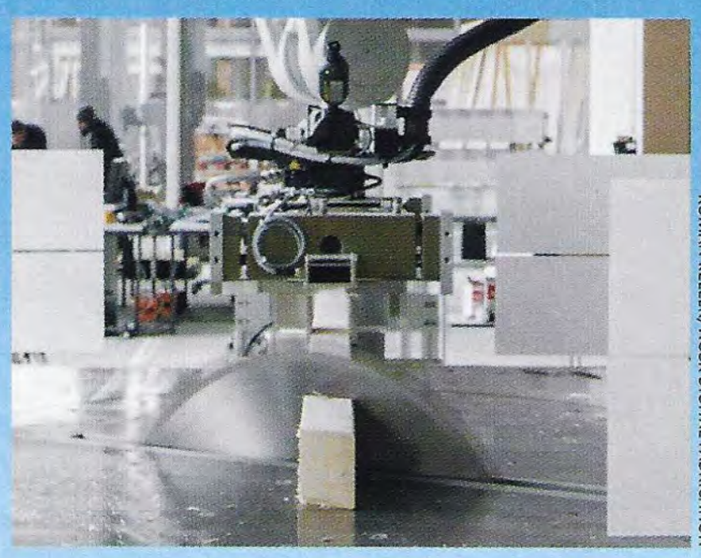
Hadrian X has been tested and was found able to lay the bricks for an entire house in three days.

CLAUS LUNAU & FBR LTD

ROOFER

Robotic arms calculate and assemble the roof structure

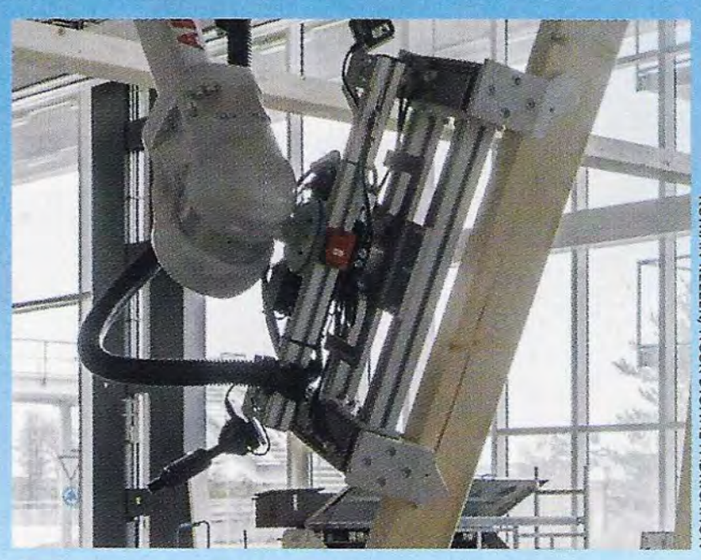
Robotic arms saw up timbers of the right sizes, place them accurately, drill holes in them, and fix the posts into a frame that will carry the roof of a house.



ROMAN KELLER/NCCR DIGITAL FABRICATION

Robotic arm saws up posts

1 A robotic arm uses a circular saw bench. The arm's position is adjusted in 3D based on light sensors that measure distances and angles to the surroundings. Another robotic arm drills holes in the posts.



ROMAN KELLER/NCCR DIGITAL FABRICATION

Algorithm avoids collisions

2 The computer which sends commands to the two robotic arms uses an algorithm to continuously correct the arms' mutual motions as the wooden posts are placed in their proper positions.

GRAMAZIO KOHLER RESEARCH/ETH ZÜRICH

Arms position the timbers

3 The robots place the posts in a geometrical pattern designed to carry a roof without the need for any supporting fittings and plates, saving both time and materials.

Every three seconds the robot emits a shower of laser light which hits objects in the room, updating a detailed 3D map consisting of the points from which the light is reflected. Then when HRP-5P lifts a plasterboard sheet in front of its head, blocking the head's camera and sensors, it can still navigate correctly because it holds the latest 3D model of its surroundings in its memory, and continues to update it.

Before the installation of a plasterboard sheet, the robot must choose the right gear, and for this purpose it uses algorithms with artificial intelligence – neural networks inspired by the human brain – to recognise and differentiate between electric screwdriver, drilling machine and hammer.

Robot-built house has opened

The new generation of computer-controlled workers has already proved that they can take over almost the entire construction process. The DFAB House in Switzerland opened in early 2019. Its load-carrying walls were made by a computer taking metal threads and welding them together into a wall-shaped grid, which was then filled with concrete. The second floor rests on a large concrete plate that was 'printed' by a 3D printer. The roof-carrying woodwork that sits on the concrete plate was sawn, drilled in and assembled by robotic arms.

24

is the number of hours required by the most recent 3D printers to print an entire house.

The next step for the robots may be to take over the task of installing electricity and water pipes, and indeed contractors have already begun to use robots in these fields. Building Information Modelling (BIM) technology allows robots to handle these sensitive installations. BIM provides computer-generated 3D models of houses, from the walls and roof to the location of pipes and cables. These models are constantly amended during the course of the construction so they can be used to fine-tune the motions of the robots.

Mars base to be built by robots

If the future of automated building seems assured, such robots can do more than just solve the problem of housing shortages by more quickly building houses. This could be key to the colonisation of the Solar System, especially in adverse environments such as Mars, where the thin atmosphere subjects astronauts to harmful space radiation. They will need a protective base, but for every kilogram of payload in a space rocket, nine times as much fuel is required. With existing

IN SWITZERLAND, ROBOTS HAVE BUILT AN ENTIRE HOUSE.

The roof is complete

4 When the posts have been positioned, the entire structure can be placed on top of a house. In this photo, the posts carry the roof of the Swiss DFAB House, in which all parts were built by robots.

ROMAN KELLER/NCCR DIGITAL FABRICATION

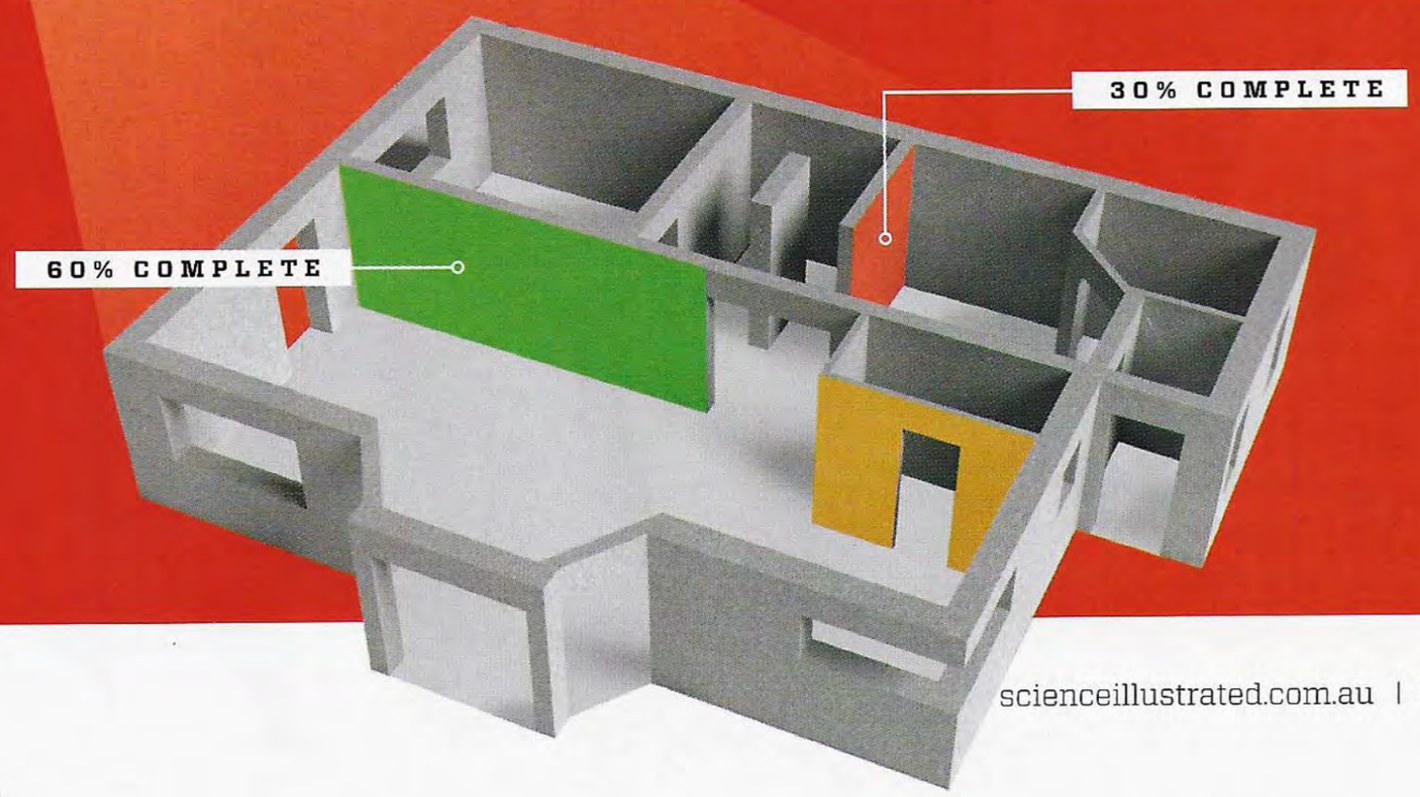
technology it simply isn't possible to send astronauts to Mars with all required machinery and building materials. But it may be possible to send robots which could build a base for astronauts to use later.

NASA is cooperating with AI SpaceFactory in the development of 3D printers which could build a base on Mars. The base is to be printed with a material made of basalt, which exists on Mars, mixed with bioplastic that could be extracted from plants grown on the planet. The resulting material would protect against cosmic radiation and insulate against the extreme temperatures on Mars.

A grand vision of the future might see robots handling construction work on moons, planets and asteroids throughout the Solar System, so that humans can arrive to populate fully constructed bases in which to live, work, and carry out research. SCI

Drones monitor the site

Canadian scientists have developed drones that can fly around a construction site, taking photos and analysing them using image recognition. The drones can recognise different materials and patterns to chart the progress of walls, insulation and more. The images are compared with the 3D building design already encoded and colour-coded for the drones, which can then send new or updated instructions to other robots on the site.



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