HIGH PERFORMANCE COMPUTING IN THE BUILDING CONSTRUCTION SECTOR*

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ABSTRACT

Starting from a commercial package and in the context of the HIPERCOSME project, the Universidad Politécnica de Valencia (UPV) in collaboration with two Spanish construction enterprises developed a parallel software, for the analysis and computation of Reinforced Concrete Building Structures.

The objective of this paper is to show how a software designed by using High Performance Computing and Networking (HPCN) tecniques, has become a code with many advantages with respect to the available packages at the market. The use of this software by the Small and Medium Size Enterprises (SMEs) of the Construction Sector could increase their productivity and volume of business.

The paper describes the technology utilised and the results of the HIPERCOSME project. The characteristics of the Construction-Sector-oriented demonstrator developed, its advantages with respect to commercial packages and the results of assessments to 6 European Construction SMEs interested in the incorporation of this technology, are also presented. Promotion Campaigns in the context of the European HPCN TTN (Technological Transfer Nodes) Network are being prepared, including Workshops in different European countries. Information about these events is also included.

Key words: High Performance Computing, Calculation of Building Structure, HIPERCOSME AND HIPERTTN projects, HPCN-TTN Network, Construction Sector Group.

1. INTRODUCTION

The European construction industry represents one of the industrial sectors most seriously affected by the politic and economic changes that take place in a country. For this reason, and because it is one of the sectors most easily influenced by builder customs, different in each country or even city, the adoption of the new technologies has always been carried out in a very slow way. Moreover, these technologies have normally been acquired when they had already been adopted by other industrial sectors.

However, the construction sector generates each year large volumes of business, designing buildings that suppose sometimes enormous budgets, requiring long periods of time to be constructed. Thus, it is clear the necessity of applying to this sector technologies such as HPCN, that provide a reduction in the construction costs and the design time.

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HIPERTTN-UPV, belonging to the HPCN-TTN Network and to the Construction Sector Group, tries to bring together the right people with the right information to support the growth and success of the European construction industry.

The paper is organised as follows: a brief explanation about the HPCN technology is provided in section 2. The HIPERCOSME project and the HIPERCOSME CS1 demonstrator are described in sections 3 and 4 respectively. Section 5 presents the promotion campaigns developed in the HIPERCOSME project. Advantages of the new demonstrator are shown in the section 6. The section 7 analyses the future developments in the demonstrator. Finally, sections 8 and 9 are focused on the context in which the demonstrator is being disseminated (HIPERTTN project, HPCN-TTN Network and Construction Sector Group).

2. THE HPCN TECHNOLOGY

The HPCN technology, which is now synonymous with parallel computing (several processors working together to solve the same problem) (Kumar, *et al*., 1994), is a well established technology although its use has until recently been restricted to large enterprises and universities. This was because the high cost of HPCN hardware has represented a barrier to its wider use by smaller companies. The advent of low cost multiprocessor machines has now done powerful systems affordable by industry at large. With the introduction of standards and the entry of major manufacturers into the marketplace, parallel processing is now the dominant architecture for low-cost high performance computer systems. HPCN makes possible, by means of the interconnection of PCs or Workstations, to reach a computational power similar to that of the supercomputers, but with lower costs. The techniques developed on large-scale applications can now be used to benefit a wider group of industrial users. In this way, the SMEs, e.g. most of the construction sector, can with reduced investments improve significantly the competitiveness of its businesses.

3. THE HIPERCOSME PROJECT

The HIPERCOSME (*Introducing **HI**gh **PER**formance **C0**mputing in **S**mall and **M**edium Sized **E**nterprises*) project (ESPRIT RTD 20059) was developed by a consortium of partners from different Southern European Regions: Valencian Community, Atika Region, Midi-Pyrenees Region, Basque Country and Porto Region.

The specific objectives of this project were the following:

- To introduce HPCN-based solutions by using demonstrators which were developed using already available software.
- To use these demonstrators as a vehicle to promote the use of HPCN techniques in the solution of the problems which appear in the SME sector.
- To identify new industrial sectors and companies which deal with problems which are suitable to be solved by introducing HPCN technology.

These objectives were approached by means of two actions:

- A Case Studies Action oriented to the development of four HPCN demonstrators, and
- A Promotion Campaigns Action with the main goal of showing the results of the demonstrators to different industrial sectors of the five involved regions.

Each demonstrator was mainly developed by a regional consortium of partners. The Case Study 1, leaded by UPV, was oriented to the Construction and Civil Engineering sector. The associated demonstrator (HIPERCOSME CS1) was entitled "Introducing PVM[1] in the Development of Parallel Software for Construction Engineering".

Additional information about HIPERCOSME could be obtained in the web site: *http://www-copa.dsic.upv.es/hipercosme.html*.

4. THE HIPERCOSME CS1 DEMONSTRATOR

The UPV, in collaboration with Spanish partners (an SME as technical provider and another SME as end-user), developed a new HPC demonstrator to calculate Reinforced Concrete Building Structures in 2D (HIPERCOSME CS1). Starting from a sequential commercial package widely used by the construction SMEs in Spain, the objective of that project was to develop a portable parallel software package able to cope with large scale problems and more realistic models.

The prototype consisted of two parts: the matrix **generator**, which constructs the stiffness matrices involved in the model of the building structure, and the **solver**, which solves a band, symmetric, positive definite linear system with the mentioned matrix.

A modular organisation of the demonstrator makes possible to use different implementations for each of the two parts, thus providing a very flexible product. Particularly, two main approaches were considered to solve the linear system of equations: one based on direct methods and the other based on iterative methods. The approach used to solve the system of equations also determines the way in which the matrix must be stored, and therefore the type of matrix generator to be used. It was produced a battery of subprograms for the implementation of the two mentioned approaches.

Hardware and software requirements for the prototype are not expensive. The parallel platform can be a cluster of Ethernet linked PCs, running under an easily available operating system such as LINUX (public domain) and the PVM message passing environment (public domain also) (Geist, *et al*., 1994a; Geist, *et al.*, 1994b). This approach was selected attending on the availability of resources. The PC environments are usually available in the SMEs. Moreover, the application is portable and can be run on other computers such as workstations and parallel systems, or other more common operating systems such as WINDOWS.

The modern calculation of building structures must combine a very powerful computing tool, reducing the calculation time, with a graphic hardware able to allow the management of post-process images in real-time. In this way, new functionalities are being developed in collaboration with the Departamento de Mecánica de los Medios Continuos y Teoría de Estructuras (DMMCTE) of the UPV. The performance of the previous software will be increased, allowing to carry out the calculation of the structure with more accurate models (such as 3D models) and visualise the structural details of the building.

[1] Parallel Virtual Machine

Thus, the demonstrator will be composed of modules that calculate efficiently the structure of the building with 2D and 3D approaches, and modules that visualise or show numerically the structural details (deformations and solicitations applied to different parts of the building).

5. PROMOTION CAMPAIGNS IN THE HIPERCOSME PROJECT

Five workshops were organised to promote the results of the HIPERCOSME project in the involved European regions. In these workshops, demonstration actions were carried out with the participation of different SMEs Construction enterprises of each region, previously identified (Hernández, 1997).

The structure of all the workshops was similar. Each one consisted of a plenary session and four parallel sessions. The plenary session was devoted to the HPCN domain at large and the results of the HIPERCOSME project. The four parallel sessions were devoted to technical presentations and demonstrations of each case study, organised in the format of "stand exhibition".

The Workshops were a success. All the demonstrators were promoted in the different regions, obtaining a good dissemination of the results of the four case studies.

Co-operation among the partners led to contacts with new companies and the identification of new industrial sectors interested in the HPCN framework. As a consequence, 17 activities to assess the possibility of introducing HPCN in the SMEs were carried out in the context of the HPCN Preparatory Support and Transfer Activities (PST) of the ESPRIT Programme. Six of these activities were directed to the Construction Sector and were developed with construction companies from Spain, Portugal, France and Greece.

Activity name	SMEs involved	Country
VASSES	AIC, HERVAS	SPAIN
GASSES	P-SYSTEMS	GREECE
EASSES	IDOM	SPAIN
MASSES	SOTEC	FRANCE
PADEM	NEWTON	PORTUGAL

Table 1 Assessments developed after promotion campaigns

6. ADVANTAGES OF USING HPCN TECHNIQUES

6.1 Execution Time and Memory Needs

The performance of the HIPERCOSME CS1 prototype was analysed in the HIPERCOSME project, by means of a test battery composed of 4 real buildings. The performance of the parallel prototype was compared to that of the commercial package, showing that the former was from 20 up to 60 times faster than the latter.

With regard to the assessments developed in the HPCN PST Programme (Vidal, *et al*., 1997a; Vidal, *et al*., 1997b; Vidal, *et al*., 1997c; Vidal, *et al*., 1997d; Vidal, *et al*., 1997e; Vidal, *et al*., 1998), their purpose was the following:

- To study the possibility of applying the demonstrator to the European Construction sector.

- To work with building larger than those of the HIPERCOSME project.
- To demonstrate that the functionality of the demonstrator can be easily increased, working not only with reticular forgings, but also with foundation slab in 2D.
- To demonstrate that a 3D analysis of the building can be carried out.

The execution time (in seconds) and the amount of memory (in Megabytes) of the sequential package and the parallel prototypes in a 2D study, are shown in table 2. Note that for the parallel prototype, the memory used is distributed into the PCs of the cluster. The most appropriate number of processors were used in each case.

The hardware platform used to carry out the assessment experience consists of a cluster of *Pentium*-based PCs interconnected with a *Fast Ethernet* local network. Each of the PCs has 64 Mb of RAM, running at 200 MHz.

The parallel prototype was evaluated with the platform running under the operating system LINUX, and the PVM programming environment. The sequential package was tested with only one of the PCs of the cluster running under MS-DOS.

Assessment	**Commercial Package (1 processor)**		**Direct Parallel Prototype (2-5 processors)**		**Iterative Parallel Prototype (2-5 processors)**		**Number of Processors**
	Time	**Memory**	**Time**	**Memory**	**Time**	**Memory**	
SOTEC	162	23.12	3.60	15.64	5.38	2.80	4
AIC	289	40.87	4.62	26.25	5.10	1.88	5
HERVAS	1438	187.9	17.43	141.49	12.66	7.59	4
P-SYSTEMS	618	70.21	8.93	48.27	14.74	2.30	3
IDOM	65	9.96	1.52	6.54	2.97	0.54	2
NEWTON	115	16.13	2.51	10.17	3.49	0.94	2

Table 2 Execution time and memory needed with the commercial package and the parallel prototypes

As can be checked in table 2, the lowest execution time is obtained by using the direct parallel prototype. However, minor requirements of memory are needed with the iterative parallel one, allowing to calculate buildings of larger dimension.

The speed-up (ratio of the time to calculate the building structure with the commercial package to the time required for the HPC prototypes) and the memory saving using both 2D HPC prototypes are the following.

Assessment	Direct Parallel Prototype		Iterative Parallel Prototype	
	Speed-up	Memory saving	Speed-up	Memory saving
SOTEC	45.00	32.35 %	30.11	87.88 %
AIC	62.55	35.77 %	56.67	95.40 %
HERVAS	82.5	24.70 %	113.58	95.96 %
P-SYSTEMS	29.97	29.82 %	17.25	96.72 %
IDOM	42.77	34.34 %	21.88	94.58 %
NEWTON	45.81	36.95 %	32.95	94.17 %

Table 3 Comparison between the commercial package and the parallel prototypes

As can be seen in table 3, higher speed-ups than the number of processors used has been obtained. This is due to a lot of HPC modifications introduced in the design and implementation of the parallel prototypes (data reusing, organisation by blocks, cache optimisation, improvement in the data storage, etc).

As a conclusion of these experiences with real buildings, it must be pointed out that the amount of time and memory used by the HPC prototype in the 2D analysis of the test cases is highly reduced and the saving in time and memory is very important.

Building structure using 3D model was carried out for the IDOM and NEWTON assessments. It is important to say that HPC demonstrated to be a tool able to solve problems that cannot be addressed until now with the traditional technology, such as the commercial package mentioned.

From a qualitative point of view we can remark that using a more accurate model, like the 3D one, and with the HPC prototypes, the calculation of the building structure can be done faster than the analysis of the same building using less accurate models (2D) provided by the sequential package.

6.2 Technological Benefits

The incorporation of the HPC prototype by the SMEs of the European construction sector can produce an important impact.

The new tool can significantly reduce the amount of time required to analyse building structures in a 2D approach, thus enabling the use of a trial-error procedure, not possible with the current technology. As a consequence of this analysis of the structure in different hypothesis cycles, more accuracy can be achieved in the design stage.

The increase of the calculation speed and the reduction of the needed memory involve the possibility of studying larger structures without the need of using simplified models or substructures. As a consequence, a more realistic 3D analysis can be carried out. Moreover, there are very few packages in the market exclusively aimed at 3D analysis of building structures. On the contrary, most of the tools used for that purpose are general finite element packages, which are difficult to use, and an advanced user, with experience both in the field of finite-element and in construction engineering is required.

6.3 Economic Benefits

The reduction of the execution time in trial-error processes implies a better utilisation of the labour time of the staff, as they have not to wait for a long time to carry out new analysis. This labour time reduction obviously leads to a saving of the enterprise investment. Besides, by using more sophisticated models such as 3D, safer buildings can be constructed with the same design effort.

The possibility of undertaking larger and more complex buildings will allow the construction companies to increase substantially their volume of business.

Last, it is worth noticing that all these economic benefits can be attained with no special new investments in expensive hardware or software systems.

7. FUTURE DEVELOPMENTS

As shown, the new prototype presents many advantages with respect to the commercial packages. Several aspects could be very relevant as key points to improve its competitive position:

- To migrate the code to a more suitable platform for the SMEs, such as WINDOWS.
- To extend its application area to a European dimension, by including capabilities to deal with all the studies that are mandatory in the European Union countries.
- To analyse the building structure from a 3D dynamic point of view. More accurate studies and earthquake proof building would be constructed in this way.

8. THE HIPERTTN PROJECT

The promotion of the HPCN technology, is an issue of interest for all the European industry. The ESPRIT programme of the European commission has established a network of 21 centres across Europe (HPCN-TTN), in which are involved HPCN expertise centres. The purpose is to encourage new users to adopt this technology. The activities of these centres, called Technology Transfer Node (TTNs), include co-ordinating groups of projects which tackle important industrial applications, demonstrations at industrial conferences, dissemination of publicity material, organisation of seminars and workshops, and publication of magazine and journal articles. The focus of all activities is on satisfying requirements, rather than merely promoting technology. Additional information could be obtained *in http://www.hpcn-ttn.org/index1.html.*

UPV is involved in one of these nodes, called HIPERTTN, originated on the base of the successful work carried out in the HIPERCOSME project. HIPERTTN (ESPRIT Project 24003) is composed of the following scientific centres: LABEIN, UPV, CERFACS, NTUA and FEUP. HIPERTTN-UPV is the Valencian Community node. Its objective is to help all sectors of industry, such as construction sector, to exploit the opportunities offered by advanced computing and networking systems, in order to add higher levels of intelligence, reach larger throughputs or ensure shorter response times in their products, processes or services. Further information can be found in *http://www-copa.dsic.upv.es/hiperttn.*

9. CONSTRUCTION SECTOR GROUP

The Construction Sector Group that has been recently created in the HPCN-TTN Network, tries to stimulate the technology transfer and dissemination of the results of the construction HPCN projects in Europe.

Its aims at transferring the HPCN technology to the European construction industry by:

- Identification of the needs of the construction industry.
- Awareness creation of the benefits HPCN can bring (i.e. success stories such as PST actions).
- Stimulation of new HPCN construction actions involving new end-users by bringing the right people together (i.e. end-users plus suppliers and enablers).

The Group comprises representatives from England, Scotland, the Netherlands, Spain, Sweden, Italy, Germany, France, Portugal, Greece and Denmark - The ESCALATE, PDC-TTN, ENTICE, Dutch-TTN, DANHIT, HIPERTTN, NOTSOMAD and CAPRICE TTNs. The co-ordinator of the group is ESCALATE, hosted by the Parallel Applications Centre in Southampton (*ttn@pac.soton.ac.uk*). More information about the group can be accessed in the web site: *http://www.pac.soton.ac.uk/construct.*

During the period 1 April 1998 - 31 March 2000 these TTNs will:

- Consult as many industry sources as possible to produce a set of issues of concern. European Workshops are taking place organised by the members of the group.
- Select a number of these issues.
- For each issue selected, organise a Workshop with key participants to discuss the issue and its potential solution.
- Ensure appropriate follow-up to Workshop with participants to enable new actions towards take-up.

Table 4 shows a list of currently identified HPCN projects which are relevant to the Construction industry and therefore are being considered for demonstrations at Roadshows and for input to the Workshops.

Project	Description	Type	TTN Contact
DVMFLOW	Enabling more aerodynamic bridge design through simulation of wind flow over cable-supported bridges	PST	DANHIT
TOMATO	Improving building capabilities where robots are used through more flexible and improved robot programming	PST	DANHIT
VISAGE	Improving impact analysis of new developments through 3D animated visualisation from CAD drawings	PST	ENTICE
RESOLV	Decreasing cost of building familiarisation for personnel, improving restoration process etc. using VR presentation of building interiors	ACTS	ESCALATE
HIPERCOSME CS1	Improving efficiency of designing reinforced concrete buildings through faster simulation of their structural properties	ESPRIT	HIPERTTN
IDASTAR	Improving heating, cooling and ventilation services through advanced simulation of building properties	PST	PDC-TTN
CAT	Improving evaluation of building re-engineering through immersive visualisation	PST	Dutch-TTN

Table 4 Summary of the projects in the Construction Sector Group

10. CONCLUSIONS

HPCN has demonstrated to be a tool able to provide important economic and technological benefits in the construction industry. HIPERCOSME CS1 has shown in a quantitative and qualitative way these advantages. Cheaper and safer buildings can be constructed with the same constructive effort. Besides, it has been proved that larger dimension building and more realistic models, such as 3D one, not available with the sequential computation approach, could be carried out. Requirements needed to apply this technology are low-cost.

The development of European Promotion Campaigns (Roadshows, Workshops, papers in sectorial congresses or magazines) could help the SMEs of the Construction Sector to incorporate this technology, increasing their profits and volume of business.

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