We developed a framework for a distributed-memory parallel computer that enables dynamic data management for adaptive mesh refinement and load balancing. We employed simple data structure of the building cube method (BCM) where a computational domain is divided into multi-level cubic domains and each cube has the same number of grid points inside, realising a multi-level block-structured Cartesian mesh. Solution adaptive mesh refinement, which works efficiently with the help of the dynamic load balancing, was implemented by dividing cubes based on mesh refinement criteria. The framework was investigated with the Laplace equation in terms of adaptive mesh refinement, load balancing and the parallel efficiency. It was then applied to the incompressible Navier–Stokes equations to simulate a turbulent flow around a sphere. We considered wall-adaptive cube refinement where a non-dimensional wall distance y^+ near the sphere is used for a criterion of mesh refinement. The result showed the load imbalance due to y^+ adaptive mesh refinement was corrected by the present approach. To utilise the BCM framework more effectively, we also tested a cube-wise algorithm switching where an explicit and implicit time integration schemes are switched depending on the local Courant-Friedrichs-Lewy (CFL) condition in each cube.